Forest Research

Short Rotation Forestry Trials in Scotland

Progress Report

2012 and 2013

The Research Agency of the Forestry Commission

Forest Research is the Research Agency of the Forestry Commission and is the leading UK organisation engaged in forestry and tree related research. The Agency aims to support and enhance forestry and its role in sustainable development by providing innovative, high quality scientific research, technical support and consultancy services.

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Executive Summary

Six Energy Forestry trial sites are now established in Scotland; four planted in 2010, one in 2011 and one in 2012. The 2010 trails have now had four full growing seasons and are beginning to produce valuable growth data. It is now possible to identify some emerging trends in species performance and site suitability from the height and survival assessments to date.

Despite early heavy losses caused by the extremely severe weather conditions in the first two years after planting, survival since beating up is much improved for most species.

Based on performance to date, hybrid aspen appeared to have the most potential for use in SRF systems on these sites as it is tolerant of site conditions and able to grow fast. Hybrid larch also performed very well, but future planting may be limited due to *Phytophthora ramorum*.

Common alder, silver birch and Sitka spruce may also have potential on certain site types, but do not appear to be universally suitable for SRF.

Although red alder had extremely large height increments on most sites, it is not able to tolerate the site conditions and survival was very poor making it unsuitable for SRF on these sites.

In contrast, ash and sycamore (and sweet chestnut at some sites) had high survival rates and appear to be the most tolerant of site conditions, but growth rates were very low. Further monitoring will show whether growth rates of these species improve as the trees become fully established.

Severe winter weather conditions caused very heavy damage to all Eucalyptus species in the 2010 planting, including *E. glaucescens* which was thought to be hardier. The initial sites were replanted in September 2011, and have now had two full growing seasons on site.

In the second planting, which had more favourable weather conditions, *E. gunnii* had the highest survival and largest mean height increment of Eucalyptus across all sites. On the more southerly sites *E. pauciflora* and *E. subcrenulata* had reasonable survival rates. The improved survival of these later plantings to date may be due to the relatively mild winters in recent years, or to the different species planted.

Where Eucalyptus species have survived growth rates are good, often in the region of 40 cm per year, but not as large as the increments achieved by red alder, hybrid larch and hybrid aspen.

For most species, performance at the younger two sites, Aros (a Sitka spruce restock site) and Auchlochan (a higher altitude and relatively exposed site) appears at this stage to be comparable with that at the better quality ex-agricultural sites.

Further monitoring and assessment of the trials will confirm whether these early trends continue, and will allow volume to be calculated indicating which species are the most likely productive SRF candidates.

The trials are starting to make a significant contribution to improving our knowledge of SRF in Scotland. The demonstration value of the sites is increasing, with a greater visual impact to practitioners, researchers and policy makers throughout Scotland. Now that all six sites are planted and data are being collected, we are starting to gather information on which species are the most likely productive SRF candidates. As the rotation progresses, this value will continue to be built upon.

This report summarises recent progress made up to March 2014, and gives an overview of the programme for the coming year, 2014/15.

Background

Wood fuel has an important role in contributing to the Scottish Government's climate change and renewable energy targets, particularly the target for renewable heat. Currently the majority of the wood fuel used in Scotland comes from the conventional forest resource (waste wood is around one third of total wood fuel use) and there may be a role for Short Rotation Forestry (SRF) to produce wood fibre specifically for the wood fuel market with the benefit of obtaining the fibre on a reduced rotation.

However, there was little current knowledge of SRF in the UK and so in 2007 Forestry Commission Scotland (FCS) and Forest Research (FR) began developing a network of Energy Forestry (EF) exemplar sites. The aim was to address the important information gaps on the growth of short rotation forestry in Scotland, as well as being a practical, operational demonstration of its potential. As these trials mature, information from the exemplar sites will highlight the opportunities for these new crops to foresters and farmers as well as providing useful new data on the growth of tree species in their early years.

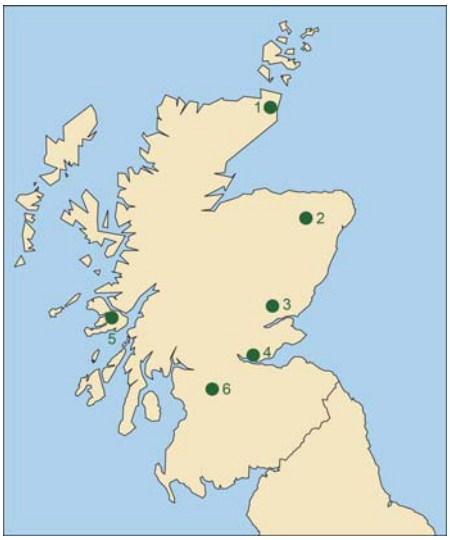
Work was also initiated on the growth of Short Rotation Coppice (SRC) in Scotland but as discussed later, Scotland does not seem to have a climate conducive to growing high yielding SRC.

Establishment of the Trial Sites

Six trial sites have now been established in Scotland. These are all ex-agricultural sites with the exception of Aros which is a restock site, previously a Sitka spruce crop (Table 1; Fig 1).

Table 1. Location and land use history of the six trial sites.

Site	Altitude (m)	Aspect	NGR	History
Sibster	30-40	West	ND147597	Ex-arable
South Balnoon	180-210	North east	NJ645428	Livestock farming
Alyth	210-220	South	NO235493	Ex-agricultural
East Grange	45-60	South	NS993891	Ex-agricultural
Aros	30-90	South	NM541456	Sitka spruce restock
Auchlochan	225-245	West	NS829404	Ex-agricultural



1. Sibster, North Highland FD
2. South Balnoon, Moray & Aberdeenshire FD
3. Alyth (Westfield), Tay FD
4. East Grange, Scottish Lowlands FD
5. Aros (Mull), West Argyll FD
6. Auchlochan, Scottish Lowlands FD

Figure 1. Map showing location of the six experiment sites.

At each of the six sites a fully replicated randomised block experiment was established trialling species likely to have fast early growth of high-density timber suitable for use in SRF. The following 10 species were planted:

Sycamore (SY)	*Acer pseudoplatanus* L.
Italian alder (IAR)	*Alnus cordata* Desf.
Red alder (RAR)	*Alnus rubra* Bong.
Silver birch (SBI)	*Betula pendula* Roth.
Sweet chestnut (SC)	*Castanea sativa* Mill.
Ash (AH)	*Fraxinus excelsior* L.
Hybrid larch (HL)	*Larix x marschlinsii* Coaz
Common alder (CAR)	*Alnus glutinosa* (L.) Gaertn.
Hybrid aspen (ASP)	*Populus tremula* L. *x tremuloides* Michx.
Sitka spruce (VPSS)	*Picea sitchensis* (Bong.) Carr. (from vegetative propagation)

A second experiment at each of the sites planted in 2010 trialled a range of Eucalyptus species with potential for growth in SRF:

E. glaucescens
E. gunnii
E. nitens (NSW)
E. nitens (Vic)

The experiment sites were fenced and ground preparation and weed control were carried out prior to planting. Species plots were 20 m x 20 m, planted at 1 m spacing along the

rows and 2 m spacing between rows, giving 200 trees per plot. Assessments were carried out in the central 12 m x 15 m area containing 96 trees.

After heavy losses during the first two winters, which were extremely severe, the plots were beaten up to 100% stocking with trees of the original species and batch (grown on a nursery until required). Throughout this report the survival figures presented are post beating up, and mean height figures include those of beat up trees.

Results

Short Rotation Coppice trials

The large scale planting (33 ha) of SRC at the East Grange site was due to be harvested in winter 2012/13. The SRC crops did not grow well on the Scottish sites in this study, with yields much lower than expected, probably due to low accumulated temperature compared to sites in England, where similar crops have been more productive. There was little market demand for the material, because it is different from conventional timber, and following difficulties in obtaining harvesting machinery the crop was chipped to waste on site during September 2013. These issues confirm that SRC is a difficult biomass crop to grow and market successfully in Scotland.

Fast growing broadleaves

East Grange (Kincardineshire)

This site, being the most southerly and lowest elevation of the sites planted in 2010, has some of the best growth rates. Survival of most species, other than eucalyptus, has been almost 100% (Fig 2). Growth rate has been very good in some species, with the mean height of hybrid aspen and red alder over 3.0 m. Hybrid larch is also growing very fast and the mean height is now almost 3.0 m (Fig 3). Growth of Italian alder remains good but the increment was less than in 2012.

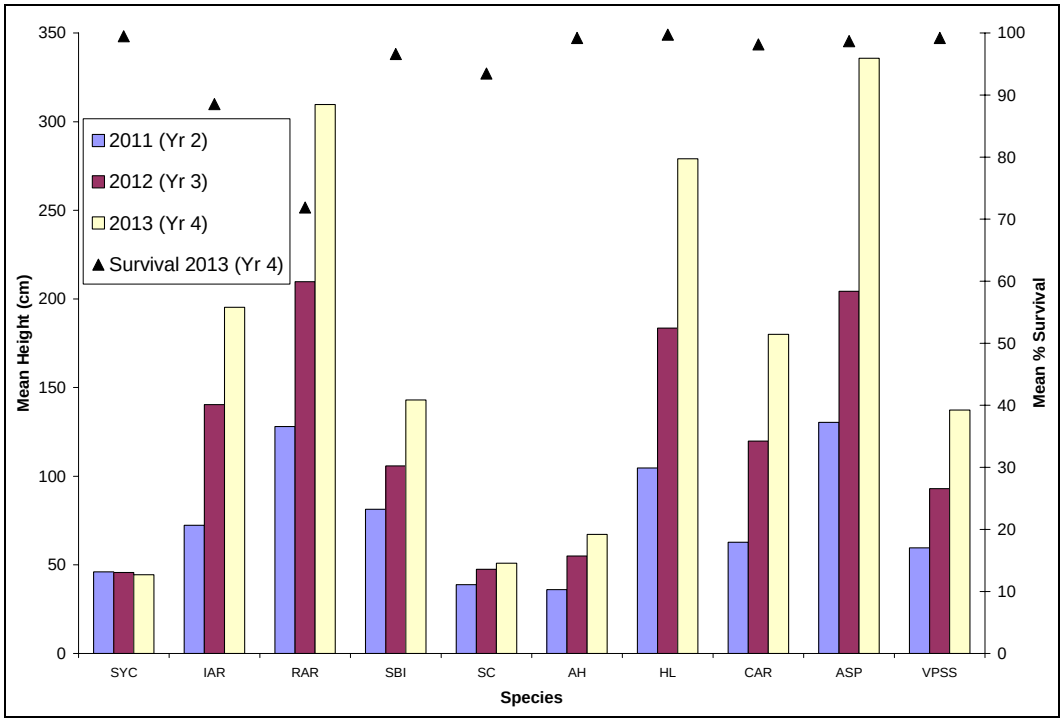


Figure 2. Mean end of year height and survival after four years at East Grange.

Figure 3. Hybrid larch (foreground) and hybrid aspen (background) at East Grange after four growing seasons in March 2014.

The suitability of each species at each of the trial sites was also investigated using Ecological Site Classification (ESC, Version 3). As ex-agricultural sites, the soils at the trial sites are likely to be richer and better drained than the 'natural' soil of the site, therefore only the climatic factors of accumulated temperature, continentality, windiness and moisture deficit were considered. Table 1 summarises species suitability and identifies the limiting climatic factor for each species at each site.

All of the species trialled at East Grange were considered very suitable for the climate at the site according to ESC (Table 2). This is reflected in the high survival figures for all species (Fig 2); the exception is red alder where some deaths were caused by deer damage, see below. Despite their suitability for the site according to ESC, sycamore, sweet chestnut and ash are growing very slowly at East Grange, although survival remains high.

Despite being fenced, there have been some incursions by roe deer and hares that have caused some browsing damage. Of particular significance is the apparent liking for the bark of red alder by the deer, which has resulted in the deaths of several large trees. This is a topic worthy of further consideration given that red alder could be a favoured SRF species. *Chalara fraxinea* has also recently been confirmed within the SRF experimental area and will be closely monitored.

Table 2. Summary of species suitability at each site using Ecological Site Classification (ESC, Version 3).

	East Grange	Alyth	Balnoon	Sibster	Aros	Auchlochan
SYC	VS	S (AT)	M (AT)	S (AT)	VS	S (AT)
IAR	VS	M (AT)	U (AT)	M (AT)	S (DAMS)	S (AT)
RAR	VS	VS	VS	VS	VS	VS
SBI	VS	VS	VS	S (DAMS)	S (DAMS)	S (DAMS)
SC	VS	S (AT)	M (AT)	S (AT)	S (CT)	S (AT)
AH	VS	VS	VS	S (DAMS)	S (DAMS)	S (DAMS)
HL	VS	VS	VS	VS	S (DAMS)	S (DAMS)
CAR	VS	S (DAMS)	S (AT & DAMS)	S (DAMS)	S (DAMS)	S (DAMS)
ASP	VS	VS	VS	VS	VS	VS
SS	VS	VS	VS	VS	VS	VS

Soil moisture regime (SMR) and soil nutrient regime (SNR) have been excluded. U=unsuitable; M=moderately suitable; S=suitable; VS=very suitable. Limiting factors are shown in brackets (AT accumulated temperature; CT continentality; DAMS windiness score; MD moisture deficit).

Alyth (Perth and Kinross)

This site has proven to be one of the best sites for all species, including eucalyptus (see later section). Most species are considered to be suitable or very suitable for the climatic conditions at the site according to ESC (Table 2). Although relatively exposed, the south facing slope and freely draining, brown earth soil provide good conditions for tree growth and survival. Red alder, hybrid larch and hybrid aspen remain the fastest growing species on site (confirming the ESC prediction of very suitable) and are all now over 2.0 m in mean height, but all species are above competing vegetation (Fig 4). Sycamore, sweet chestnut and ash are the slowest growing species; sycamore and sweet chestnut may be limited by accumulated temperature (Table 2). Post beat-up survival is >85% for all species except Italian (limited by accumulated temperature according to ESC) and red alder.

The soil depth on this site is only around 30 cm, making it susceptible to drying out during periods of low rainfall. The water availability monitoring that has been carried out on the site since planting demonstrates that there was a much larger reduction in soil moisture and water availability during the dry summer of 2013 than in the previous two summers (Appendix 1, Figs 3 and 4). Monitoring of water resources on this site will continue and will provide further information as the site matures.

The operational plantings of birch, ash and sycamore are establishing reasonably well with high survival, although growth rates are somewhat uneven. *Chalara* has been found on the ash in the operational area and although there are currently no plans to remove it the situation will be closely monitored. One of the water monitoring arrays is within the ash block and this would become redundant if the ash was to be cleared.

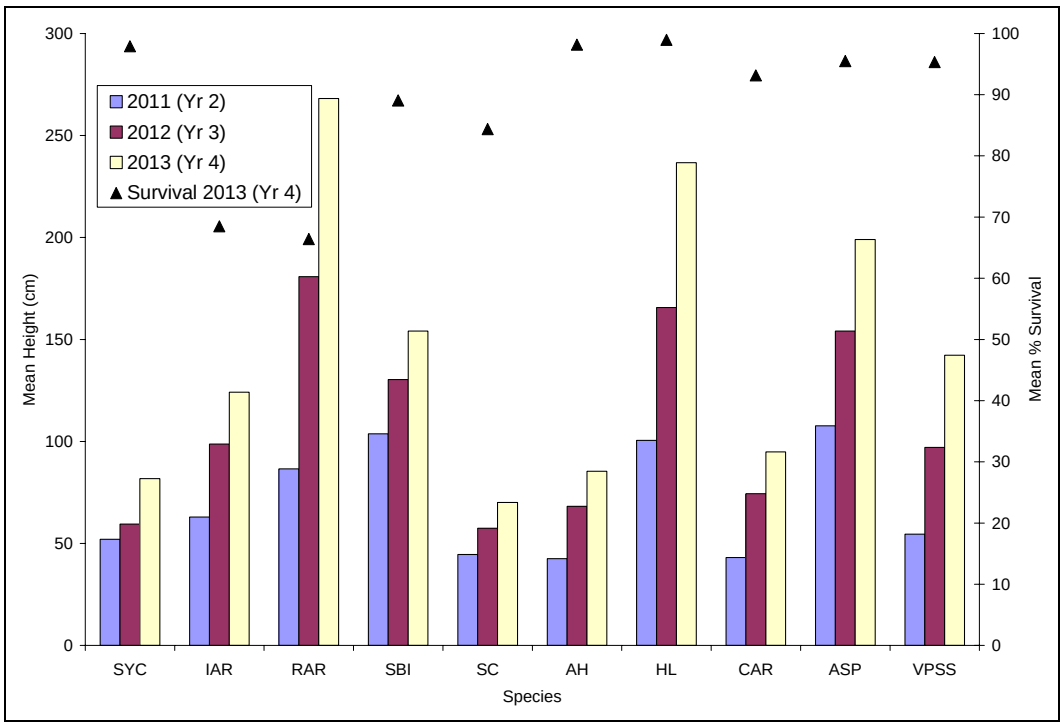


Figure 4. Mean end of year height and survival after four years at Alyth.

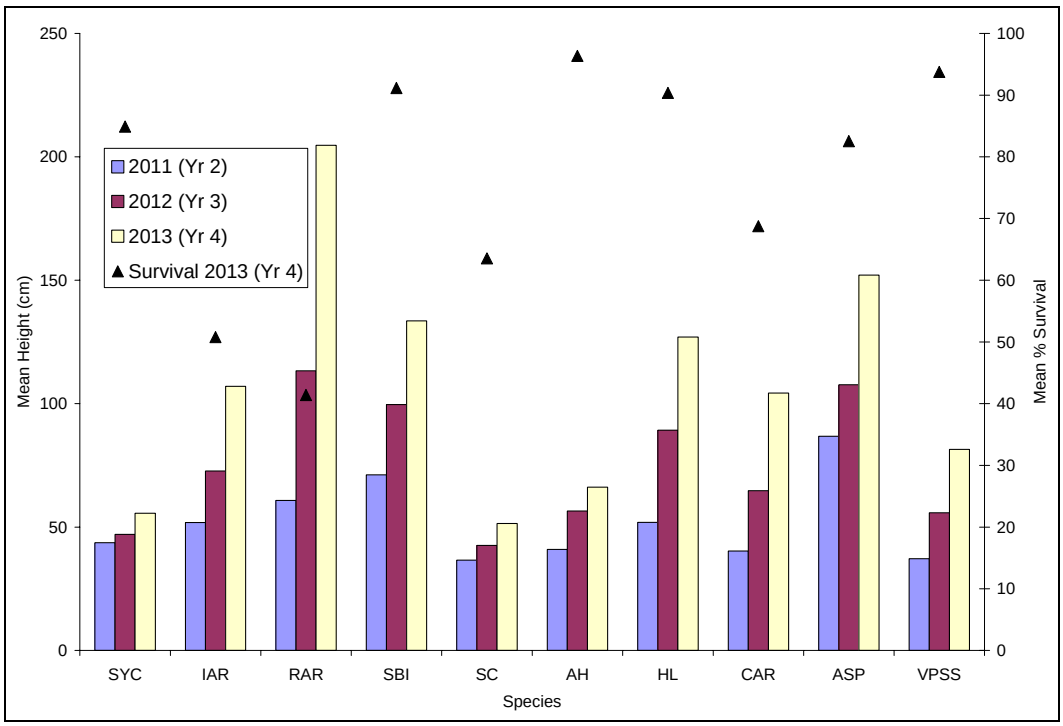


Figure 5. Mean end of year height and survival after four years at South Balnoon.

South Balnoon (Aberdeenshire)

The operational area has recovered well from the initial vole damage and weed competition, with trees now taller than the surrounding vegetation. The conifer plantings (Sitka spruce and larch) above the broadleaves are doing particularly well.

Within the research area the species are beginning to grow with some vigour. Initial weed competition on this site was severe and repeated herbicide treatment was required. Despite this survival has been generally good since beating up, except for the red and Italian alders, presumably due to poor seedling quality and less ability to compete with other vegetation. Survival of Italian alder may also be poor due to low accumulated temperature, which is likely to limit the species on the site (ESC, Table 2).

As in 2011/12, height increment during 12/13 was good for red alder, birch and larch, with mean height of red alder now over 2.0 m (Fig 5). Hybrid aspen did not perform well initially, perhaps due to suffering shoot damage in the late frosts and gales in May 2012, with some individuals suffering significant shoot die-back and subsequently having to re-grow from stem buds. However, the growth rates of hybrid aspen are now increasing, and the increment during 12/13 was the second highest on the site. As was seen in previous years (and also at Alyth) sycamore, sweet chestnut and ash grew slowly during 12/13; sycamore and sweet chestnut are considered only moderately suitable for the site climatic conditions due to low accumulated temperature (Table 2). Although the sycamore in the operational area at Balnoon has started to grow more quickly after a slow start, the species trial sycamore has not yet shown this response. This slow initial growth has also been reported at similar trials in Orkney, planted in 2013 (see Appendix 3).

The three alder species and sweet chestnut have the lowest survival on the site (since beating up) with survival of all other species over 80%.

Sibster (Caithness)

Planted in 2010, this site is the most northerly and the most exposed of all the trials. The site was chosen for its geographical location, and relatively fertile ex-arable land such as this would not normally be planted. However, despite the higher than normal fertility, early growth was slow in all species. Frequent cold winds and gales resulted in shoot die-back and foliage damage in most species. The storm-force winds of May 2012 were particulary damaging and severely affected newly emerging broadleaf foliage and larch needles, resulting in both physical damage and scorching. Many trees had a multi-stemed and 'stag-headed' appearance.

Regardless of damage and slow growth, survival to Spring 2013 was good overall, with most species >70% (after beating up) reflecting the ESC prediction that most species are suitable or very suitable for the climatic conditions on the site (Table 2). Only red and Italian alders had lower survival (Italian alder is considered only moderately suitable for the site by ESC), although the survivors were among the best performing trees on the site. The quality of initial seedling stock of these species was not as good as some other species, being small and relatively thin. This combined with the exposure will have contributed to low initial survival.

Unfortunately, in June 2013, the Sibster plots were mistakenly treated with glyphosate herbicide. This resulted in major damage to most species except the red alder and hybrid aspen, which were sufficiently tall to avoid most of the spray. Responsibility for this error has been admitted by the contractor, who has agreed to replant and re-establish the plots in 2015/16. The red alder and hybrid aspen plots will be kept, as the planting stock is difficult to replace, and the opportunity will be taken to substitute native aspen and downy birch for the sweet chestnut and ash. Native aspen has been found to perform well in recently established SRF trials in Orkney (Appendix 3).

Figure 6 below shows end of growing season height and survival for each species at Sibster, with only the remaining red alder and hybrid aspen assessed in 2013. The 2011/12 increment (prior to the herbicide damage) was relatively even across the species at around 10 – 20 cm, confirming the slow rate of growth due to the high exposure. For the remaining red alder and hybrid aspen, the 2012/13 increment increased to around 40 cm. The early results suggest that SRF is unlikely to be successful on such sites without additional wind breaks.

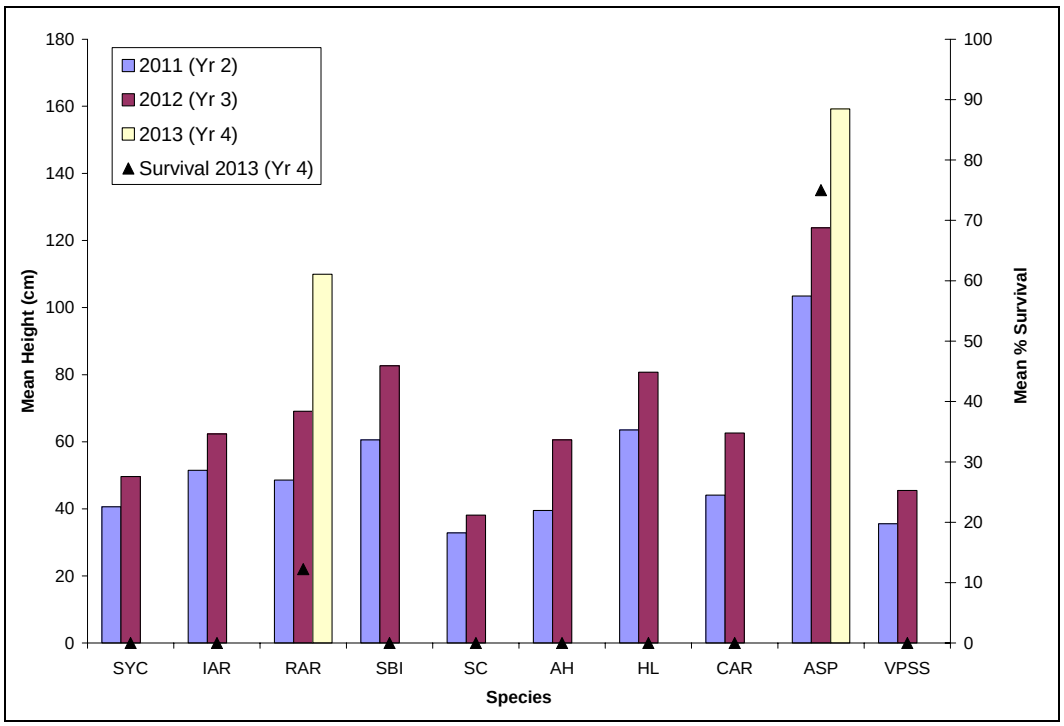


Figure 6. Mean end of year height and survival after four years at Sibster.

Aros (Mull, Argyll)

This site was mounded and planted one year later than the previous four sites in Spring 2011. It is a relatively sheltered, 6.0 ha restock with a south facing slope, between 30 – 90 m elevation and an upland brown earth soil.

After some initial *Hylobius* problems, the site has established well with a reasonable level of survival across all species. Although a year younger than the four initial sites, the same general trends can be seen (Fig 7). Red alder and hybrid aspen have grown extremely well, with mean heights of around 2.0 m. Italian and common alder are also growing well, and larch has grown particularly quickly during 2013 after a slightly slower start. Sitka spruce has continued to grow surprisingly poorly given that this was a quality Sitka site previously, and survival is only 36%. All species are considered to be suitable or very suitable for the site by ESC (Table 2) with the limiting factor being windiness.

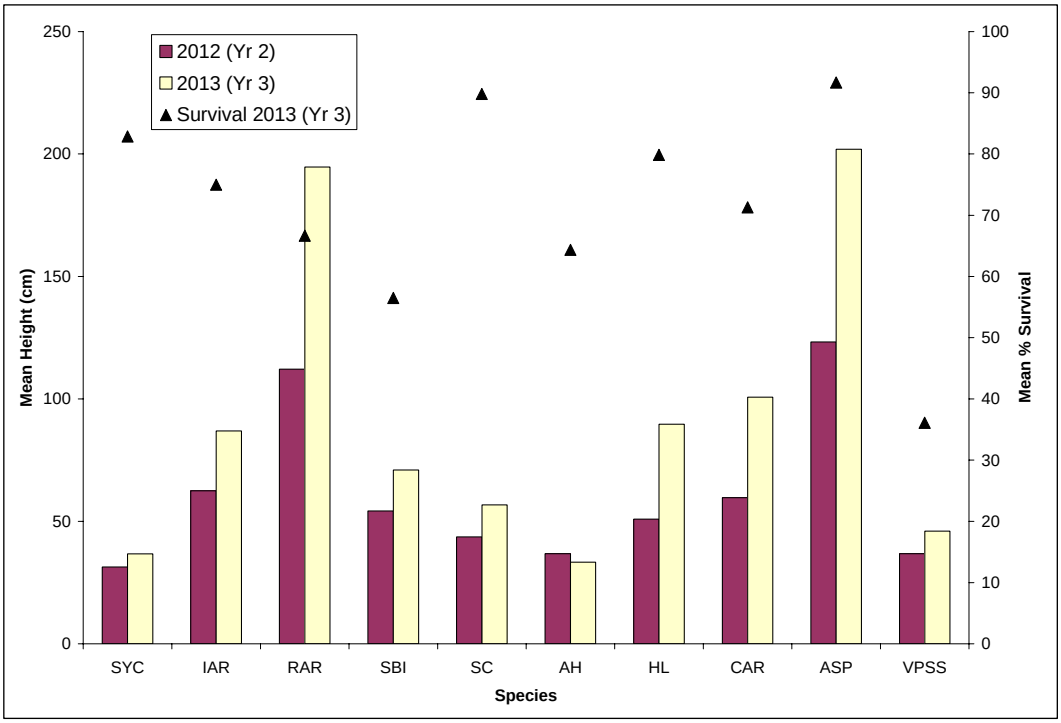


Figure 7. Mean end of year height and survival after three years at Aros.

Auchlochan (South Lanarkshire)

This site, near Lesmahagow in South Lanarkshire, was planted in the spring of 2012, two years after the initial four sites, and one year after Aros (Fig 8). Delays in site acquisition and determining the location of mains water pipes forced changes in the ground preparation and the ultimate layout of the site. Way-leaves for the pipes and also overhead cables reduced the usable area of the site by about a third. As a result, fewer trees could be planted here than at the other EF trial sites, although it still remains a substantial trial.

Survival of all species during the first year was very good (>90%) compared to the sites planted in 2010, probably because winter weather conditions after planting were much less severe than for the first four sites. Minor beating-up was carried out in April 2013.

Figure 8. (a) Sycamore in June 2012 shortly after planting and (b) Common alder in May 2013 at Auchlochan.

Survival during the second year remained high on the site, with the exception of Italian alder (12%) and red alder (50%) and height growth was also good (Fig 9). As at the other sites, red alder and hybrid aspen had the largest increments during 12/13, with mean heights of around 1.2 m at the end of the second growing season. Hybrid larch

and common alder have also grown well, although in contrast to the results at East Grange and Balnoon Italian alder has not grown well. Sitka spruce, which was small planting stock, had a larger annual increment than sycamore, Italian alder, sweet chestnut or ash, but this has not yet compensated for the small planting size. All species are considered to be suitable or very suitable for the climatic conditions on site according to ESC (Table 2).

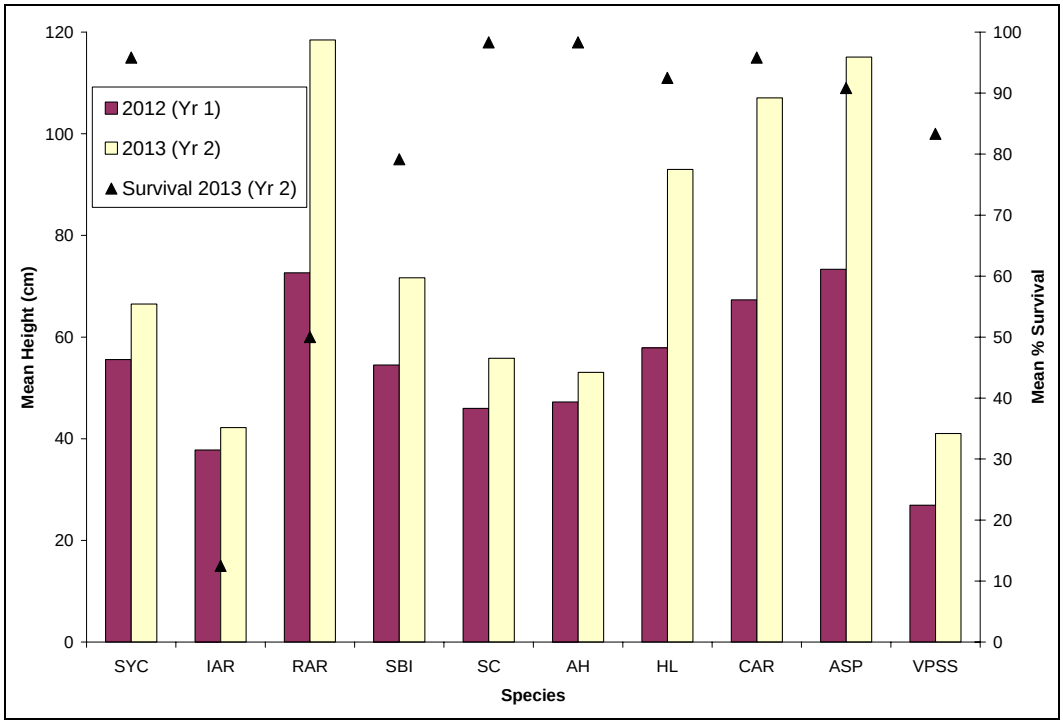


Figure 9. Mean end of year height and survival after two years at Auchlochan.

Eucalyptus species

First planting

The Eucalyptus plots on all the four sites planted in 2010 (East Grange, Alyth, Balnoon and Sibster) appeared virtually wiped out by the severe weather conditions in winter 2010. However, a few individuals of *E. nitens* and *E. gunnii* did remain alive near ground level and had re-sprouted by July 2011. The 2011/12 winter was relatively benign and most of these sprouts survived and grew on, although those at Sibster did not, presumably due to the greater exposure causing desiccation. The best survival of the original planting was at Alyth. The *E. glaucescens* did not survive or resprout on any of

the four sites, which was surprising given that the species is reputedly less tender than *E. nitens*, however, the initial *E. glaucescens* seedlings were significantly less robust.

Second planting

Some of the eucalyptus plots were replanted in September 2011 using *E. nitens* (New South Wales), *E. pauciflora*, *E. subcrenulata* and *E. gunnii*, which were surplus plants from 2010.

After two growing seasons on site, none of the second planting of Eucalyptus trees at Sibster has survived. At Balnoon the few individuals remaining have grown quite well, with mean heights of 1.0 – 1.5 m (Fig 10). However survival of all species is now almost zero indicating that growth of Eucalyptus species is unlikely to be successful on such Northerly exposed sites.

Survival of the second planting at Alyth and East Grange is a little better, with *E. gunni* and *E. pauciflora* (particularly at Alyth) achieving good survival rates (Figs 11 and 12). *E. nitens* had the lowest survival at each site, although the surviving trees were also the tallest, with the largest height increment in 12/13. Survival of *E. subcrenulata* at Alyth was 40%, but the growth rate was low.

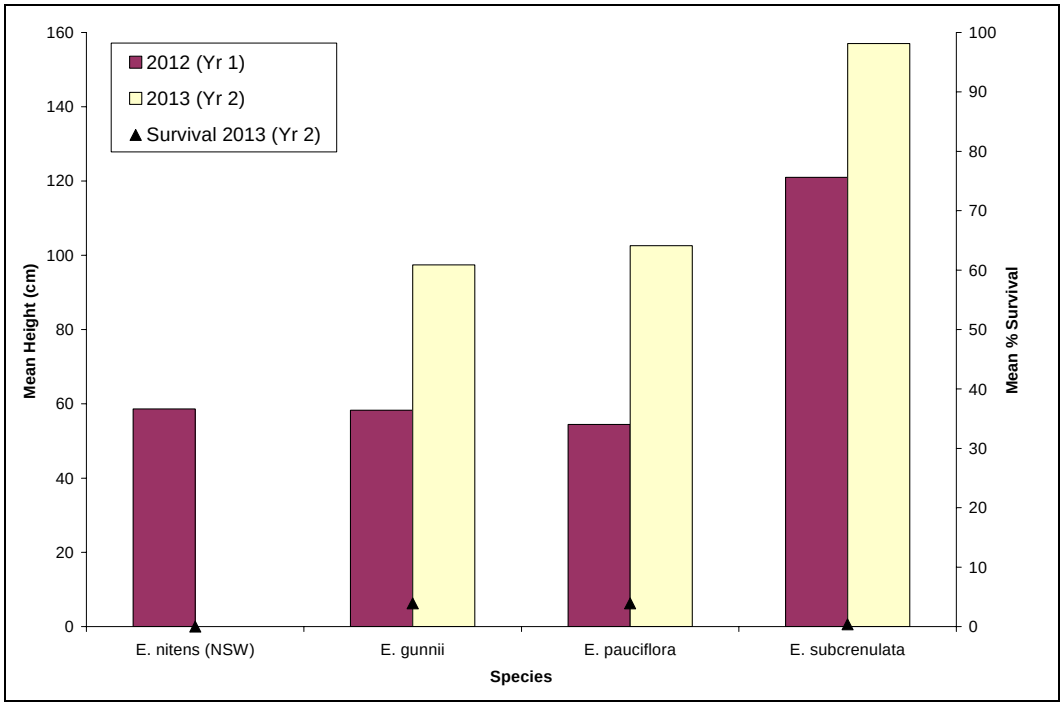


Figure 10. Mean end of year height and survival of Eucalyptus species after two years at Balnoon.

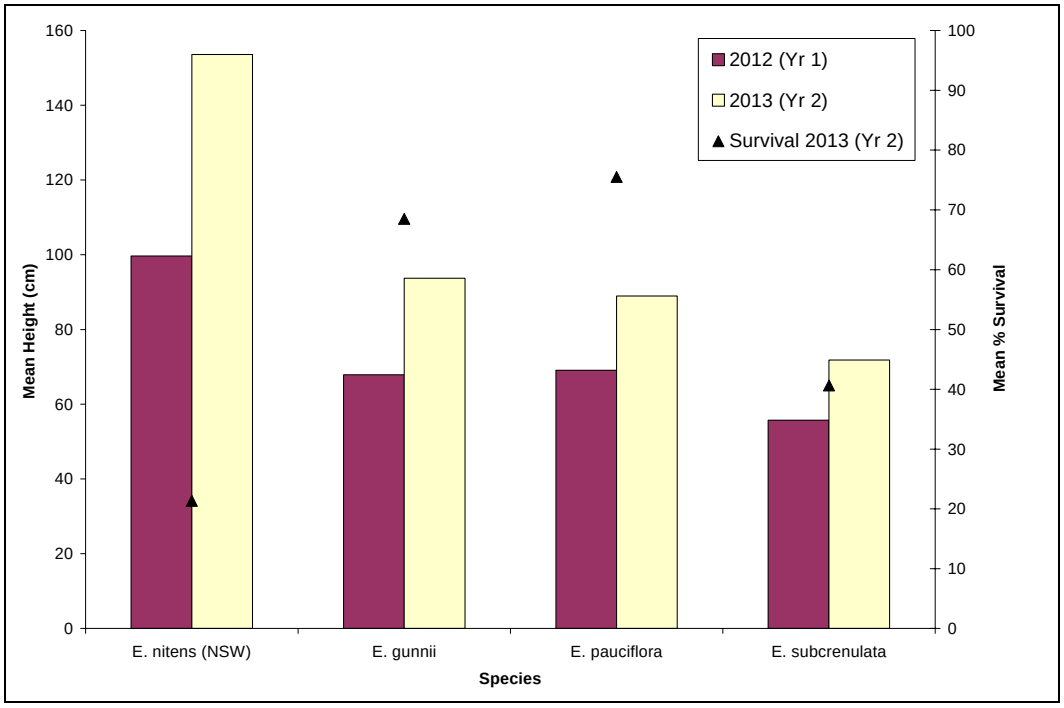


Figure 11. Mean end of year height and survival of Eucalyptus species after two years at Alyth.

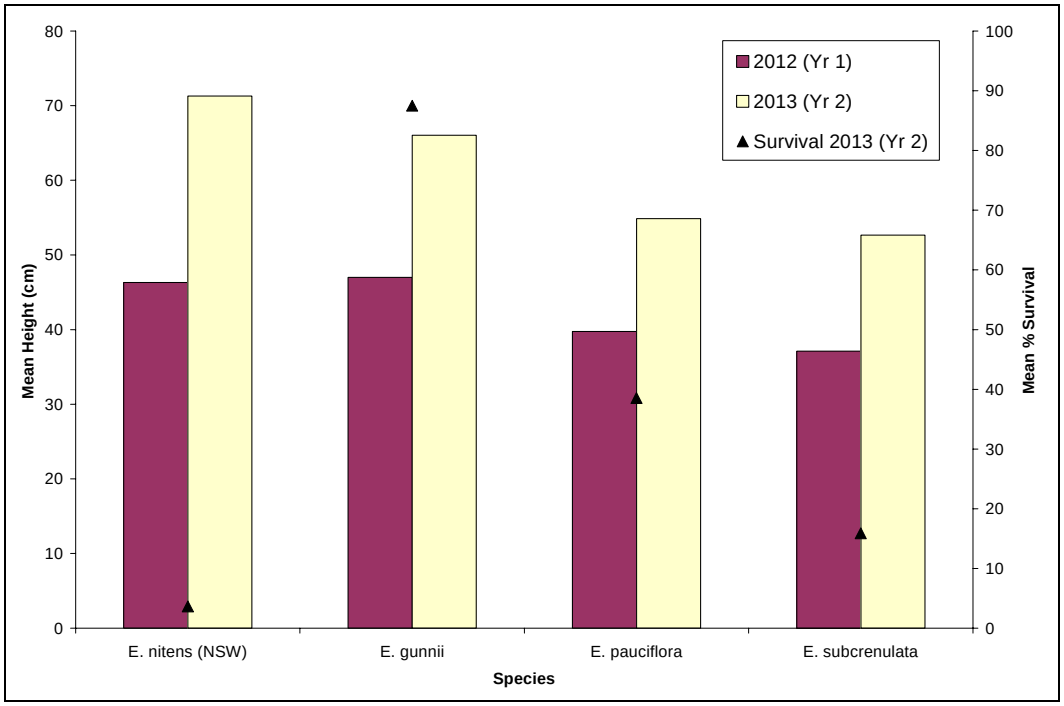


Figure 12. Mean end of year height and survival of Eucalyptus species after two years at East Grange.

Planting of other Eucalyptus species at Aros and Auchlochan

In addition to the Eucalyptus plots planted at the initial four sites, plots of *E. debeuzevillei*, *E. gunnii*, *E. nitens* (Victoria) and *E. subcrenulata* were planted at Aros in Spring 2011. These have now had three growing seasons (Fig 13). Survival rates for *E. debeuzevillei* are highest at 50%, with survival *for E. nitens* and *E. subcrenulata* very low. As at Alyth, the few survival *E. nitens* individuals have the best growth rates. *E. debeuzevillei*, not trialled at the other sites, has the second best growth rate, achieving an average of 55 cm after three years.

Plots of six Eucalyptus species (*E. pauciflora*, *E. nitens*, *E. glaucescens*, *E. subcrenulata*, *E. brookeriana* and *E. gunnii*) were also planted at Auchlochan in spring 2012. Although survival at the end of the first growing season was high (>80% for all species), almost all trees are now dead except for *E. gunnii* (30% survival) and *E. subcrenulata* (65%). The surviving individuals of these species are growing well with large height increments during the 12/13 growing season (Fig 14).

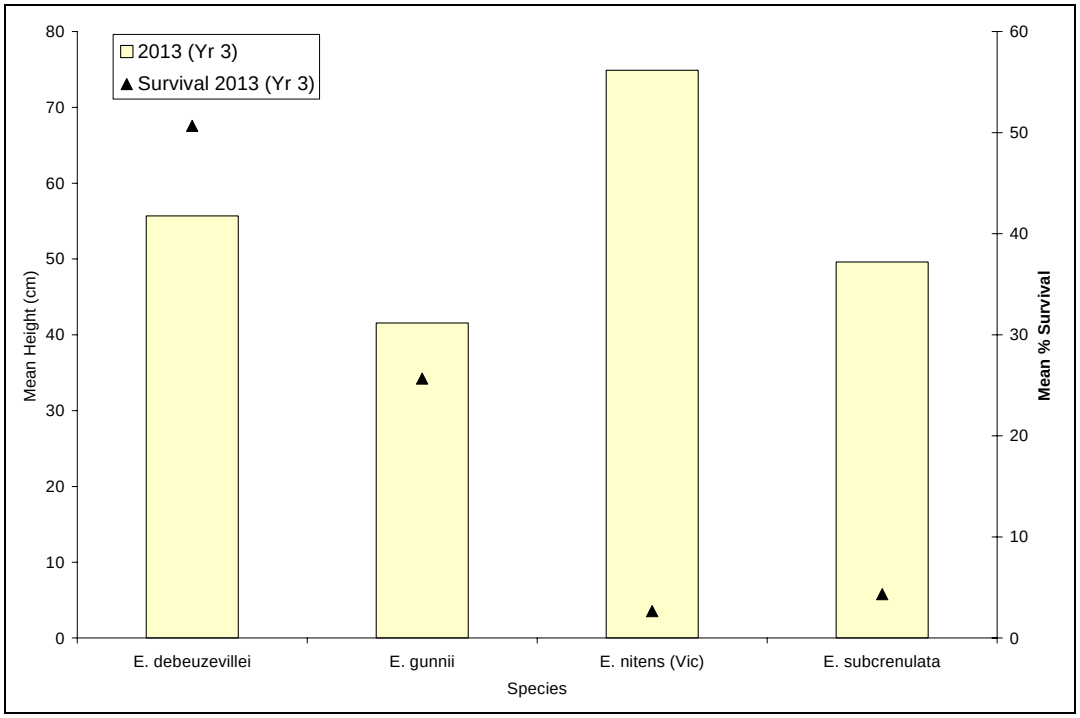


Figure 13. Mean end of year height and survival of Eucalyptus species after three years at Aros.

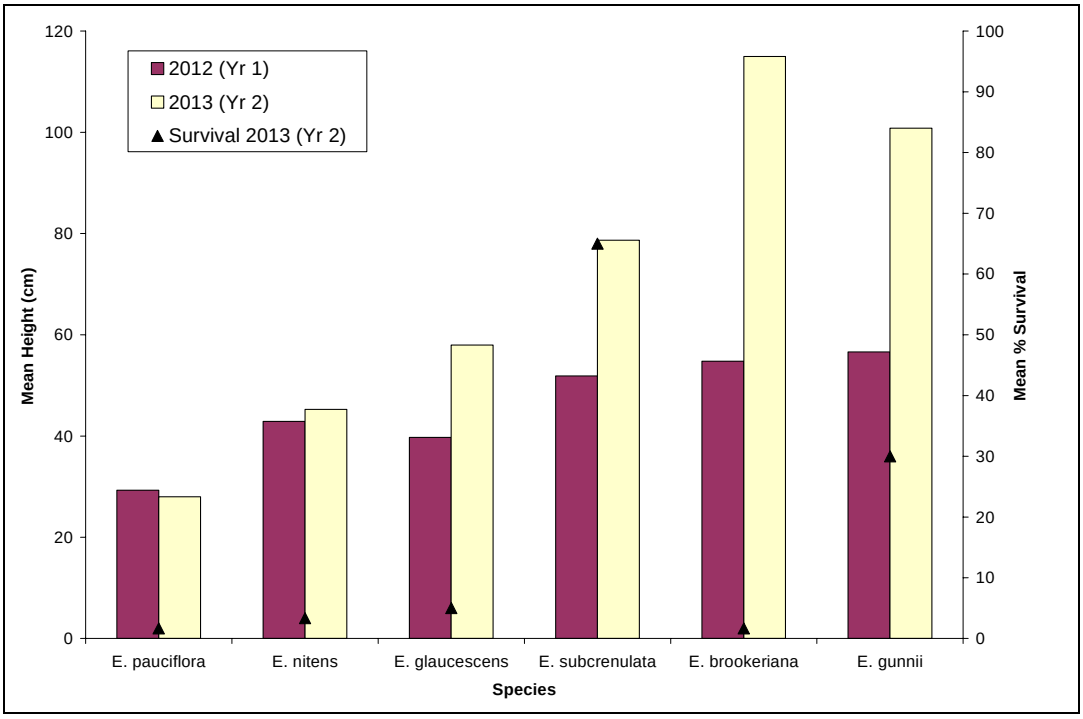


Figure 14. Mean end of year height and survival of Eucalyptus species after two years at Auchlochan.

Early conclusions from the six sites

Comparison of 4-year height across sites

Comparing the 2013 height (end of fourth growing season) across the four sites planted in 2010 (Fig 15) shows that as would be expected there is a growth gradient from north to south for most species. This is particularly clear for the Italian and red alders, hybrid aspen and hybrid larch. Common alder appears to have grown more slowly than might be expected at Alyth.

For sycamore, birch, sweet chestnut, ash and Sitka spruce growth was better at Alyth than Balnoon, as would be expected for the latitude and the southerly sloping aspect at Alyth. However, at East Grange growth of these species was much lower than would be expected for the latitude. Spring frost damage has been noted each year at East Grange, particularly on ash, and although it is the most southerly site, the high level of exposure appears to have affected growth of these species. This is probably also the reason for the better eucalyptus survival at Alyth than at other sites.

Species performance at the younger two sites, Aros (a Sitka spruce restock site) and Auchlochan (a higher altitude and relatively exposed site) was comparable with that at the better quality ex-agricultural sites.

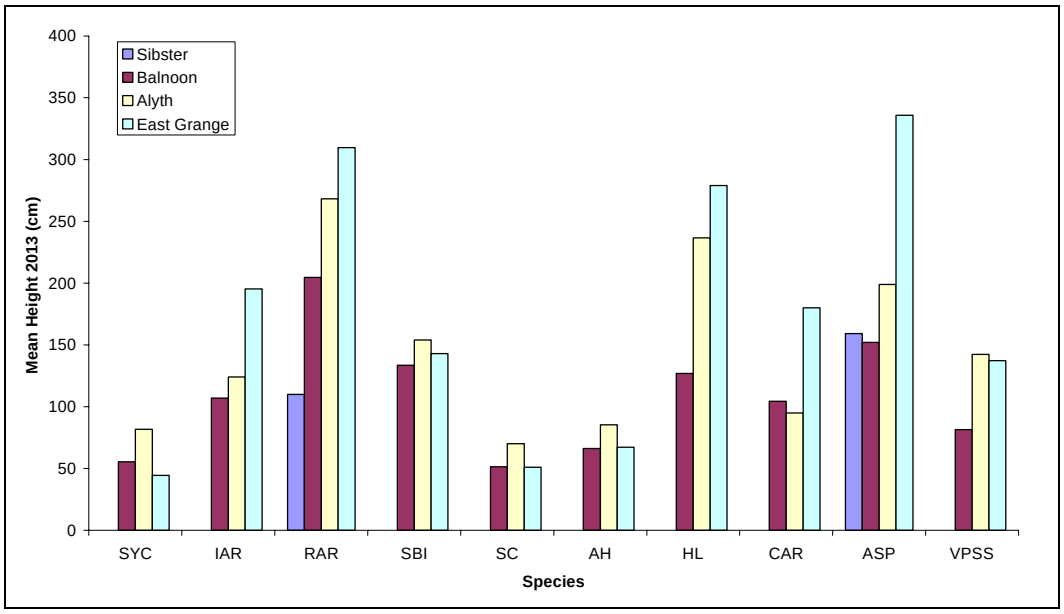


Figure 15. Comparison of mean height at the end of 2013 across the four sites planted in 2010.

Ranking of species across sites

To summarise performance across all sites, the 10 species were ranked at each of the 6 sites according to their 12/13 height increment. The species with the largest height increment at each site scored 1, and the species with the smallest height increment at each site scored 10. The same process was repeated for survival, with the species having the highest survival scoring 1, and the lowest survival scoring 10. At Sibster data for 11/12 were used due to the glyphosate damage in summer 2013.

Total survival and height increment scores across all sites for each species are shown in Table 3, with the mean and the range across the sites for each species also shown. The best and worst performing species are highlighted in green and red respectively. The ranking of each species at each site is shown in Appendix 2.

Table 3 shows that red alder had the best height increment overall (it was ranked in the top three species at all sites, Appendix 2) and is considered to be very suitable for the climatic conditions on all sites by ESC. However, the survival of red alder was the worst overall, suggesting that the potential of this species is difficult to achieve and the species is not suitable for SRF systems on these sites.

Table 3. Ranking of species across all sites according to survival and height increment in 12/13

	Survival		Height Increment 12/13	
Species	Total rank	Mean % survival	Total rank	Mean Height Increment (cm)
AH	18	91.8	46	10.4
SY	20	92.2	52	9.1
HL	21	91.0	23	49.2
ASP	23	92.5	15	60.3
SS	33	82.3	38	24.7
CAR	35	83.6	26	57.3
SC	35	82.8	53	8.9
SBI	38	83.8	31	25.1
IAR	51	58.4	37	25.7
RAR	56	53.6	9	71.3

Hybrid aspen was the second best performer overall based on height increment (in the top four species at all sites, Appendix 2) and was also fourth best overall in terms of survival (with lower survival at Balnoon and Auchlochan). Hybrid larch also performed well at most sites, scoring third best overall for both height increment and survival, although survival was reduced in the highly exposed conditions at Sibster. With high survival and growth rates, both hybrid aspen and hybrid larch appear to be suitable

species for use in SRF systems on the sites used in this study at the current time, although ongoing monitoring will be needed to confirm this. In the longer-term larch may become unsuitable on some or all of these sites due to the development of *Phytophthora ramorum*.

The height increment of common alder was good at Balnoon, Aros and Auchlochan, although the survival on these sites was lower than for hybrid larch and hybrid aspen. This species may be appropriate for SRF on some sites, perhaps where conditions are more sheltered; the limiting factor on most sites is windiness according to ESC (Table 2).

Silver birch had the best height increment at Sibster (Fig 5) but did not grow fast elsewhere. Survival of silver birch was better at the more northerly sites, Sibster and Balnoon, than at other sites, suggesting that it may have potential where exposure limits other species.

Sycamore, ash and sweet chestnut grew consistently poorly across all sites, except for ash, which had the second largest height increment at Sibster. However, survival of ash and sycamore was very good across all sites (and sweet chestnut survived well at Aros and Auchlochan). Ongoing monitoring will determine whether longer term growth rates of these species increases after establishment.

Height increment of Sitka spruce was quite poor overall, and survival was variable, despite being very suitable for the sites according to ESC. The planting stock was noted as small and there is some evidence that increments are now starting to increase, particularly at Alyth and East Grange, and this species may have some potential where good survival can be achieved.

Overall, some of the species identified that have high growth rates (red alder and common alder) are unable to tolerate the site conditions and have very low survival rates; these would be high risk choices for SRF. In contrast, those which appear to be the most tolerant of site conditions and have the highest survival rates (ash and sycamore) are currently growing very slowly, although this may improve once the trees are fully established.

The species that currently appear to have the most potential for use in SRF systems on these sites are those that are relatively tolerant of site conditions and are also able to grow fast. Based on performance to date, hybrid aspen and hybrid larch (depending upon the development of *Phytophthora ramorum*) appear to be the most suitable species. Common alder, silver birch and Sitka spruce may also have potential on certain site types, but do not appear to be universally suitable for SRF.

Eucalyptus species

In general the Eucalyptus species have not survived well. Severe winter weather conditions caused very severe damage to all species in the first planting, including *E. glaucescens* which was thought to be hardier. In the second planting, which had more favourable weather conditions, *E. gunnii* had the highest survival and largest mean height increment across all sites (Table 4). On the more southerly sites *E. pauciflora* and *E. subcrenulata* had reasonable survival rates. The improved survival of these later plantings to date may be due to the relatively mild winters in recent years, or to the different species planted.

Where Eucalyptus species have survived, height increments are good, often in the region of 40 cm per year at the most suitable sites, but not as large as the increments achieved by red alder, hybrid larch and hybrid aspen.

Table 4. Performance of Eucalyptus species across all sites according to survival and height increment in 12/13

	Survival	Height Increment 12/13
Species	Mean % Survival	Mean Increment (cm)
GUN	41.2	25.6
SUB	30.5	23.6
PAU	29.9	20.5
NIN	7.1	20.3

Sibster excluded due to 0% survival of all species.

Work Due in 2014/15

Additional plots of downy birch and common aspen may be added to the trials. There is currently interest in these native species as alternatives to larch and as a means to diversify the forest estate. Hybrid aspen has performed very well across the sites but is not currently widely available for planting. Although it would not perform as well as hybrid aspen in terms of height growth, Forest Research trials have identified some clones of native aspen which can perform well, and may grow in less favourable conditions.

These species will certainly be included in the replanting of the Sibster trial in Spring 2015, taking the opportunity to replace ash and sweet chestnut with native aspen and downy birch.

Annual survival and growth assessments will be carried out at all sites at the end of the growing season and species and site performance will be analysed and summarised in an end of year report.

Meteorological and hydrological monitoring will be continued throughout 14/15.

The most recent site, Auchlochan, will continue to be monitored to ensure effective establishment, and all sites will be inspected twice during the year and any maintenance required will be carried out.

Management of Balnoon, Alyth and East Grange is to be handed back to Forest Enterprise Scotland forest district staff; site meetings with local staff will be required to ensure that the trials are managed appropriately.

Appendix 1: Report on Studies to Assess the Hydrological Impacts of Energy Forestry

Dr. Nadeem Shah, Forest Research

Objectives

To quantify the impacts of short rotation forestry (SRF) on water resources and assess the effects on water quality.

Background

Concern has been raised that the establishment of energy forest crops could have an adverse impact on water resources due to the potential high water use of SRF, which could lead to reduced water supplies and ecological flows. Another issue is the effect on water quality; energy crops are expected to benefit water quality compared to the previous agricultural land use due to reduced soil disturbance and chemical and pathogenic inputs. However, there is a need to assess the impacts of the final harvesting phase and to confirm that the pollution risks associated with harvesting can be minimised by best practice measures.

The impacts of SRF on water resources

The field experiment on water resource impacts is being carried out at Alyth, Tayside (Figure 1). The two experimental plots were planted with Ash (*Fraxinus excelsior L.)* and Sycamore (*Acer pseudoplatanus*) in April 2010; the grass control was left unplanted.

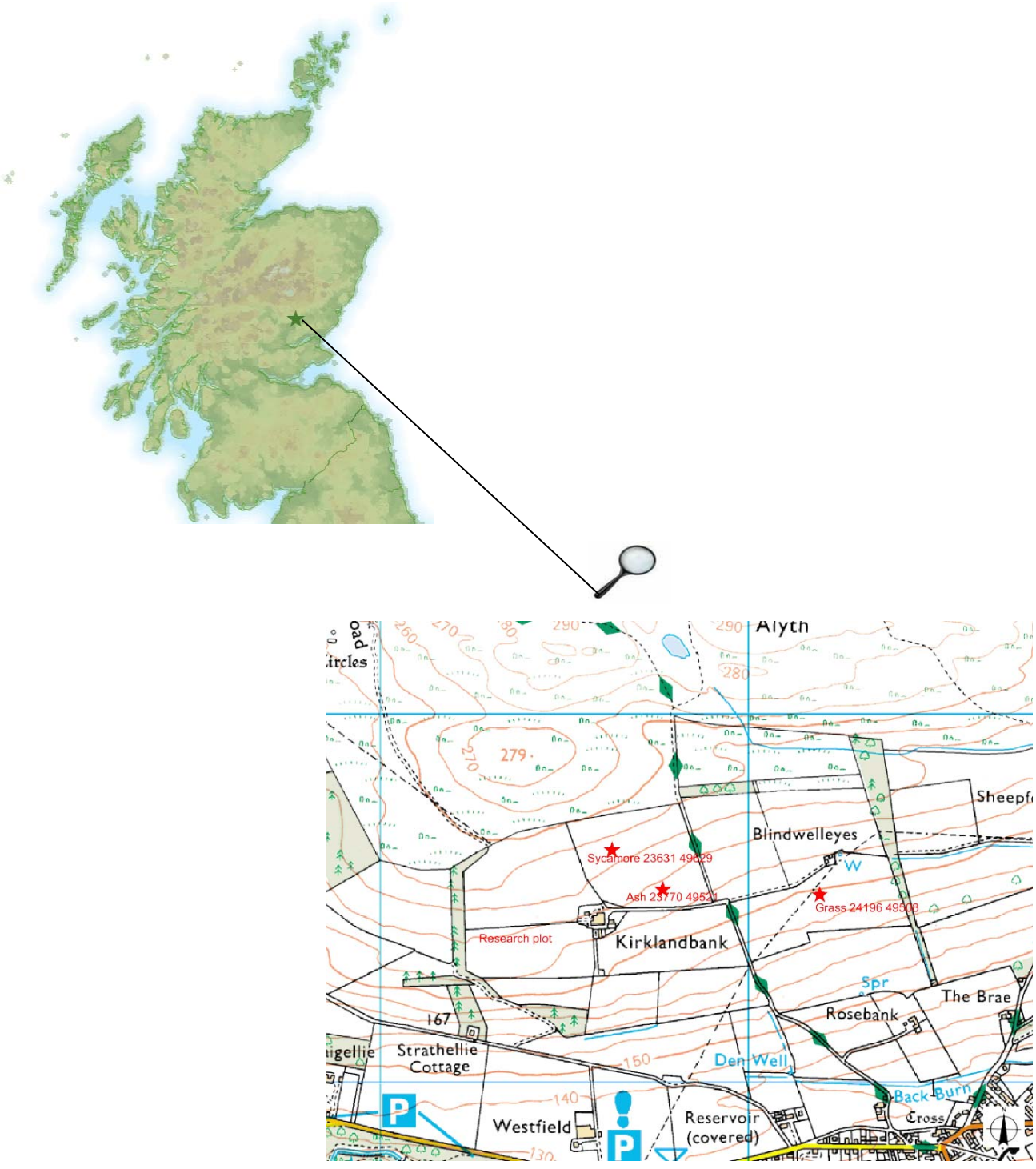


Figure 1. Alyth water use experiment – location of monitoring equipment within experimental plots planted with Sycamore and Ash, and grass control unaffected by SRF planting. © Crown copyright. All rights reserved. Forestry Commission. 100025498. 2010.

Monitoring equipment was installed at all three plots in July 2010, consisting of soil moisture probes to measure volumetric soil moisture content and tensiometers to measure soil water potential. A network of rainguages was put in at the two planted plots and an automatic weather station was installed at the grass control plot. With the exception of the weather station all monitoring equipment was connected to logger boxes which were programmed to collect data every 10 minutes. The measurements will allow estimates to be made of water use via transpiration and interception processes.

Following installation electronic problems were identified with the logger box setup and this together with the heavy snowfall over winter 2010 led to a delay in baseline data collection from some of the probes; most of the problems have been resolved and data has been collecting from all sites since early 2011.

Figure 2. Soil moisture probes installed at various depths in soil profile to measure soil moisture content (left) and tensiometers to measure soil water potential.

Fortnightly visits are made to the site to download data and maintain equipment; we considered reducing the frequency of sampling but have kept the current sampling regime due to large amount of data generated and the sensitive nature of the equipment, which requires regular checks and maintenance. The intention is to continue measurements throughout a complete SRF rotation.

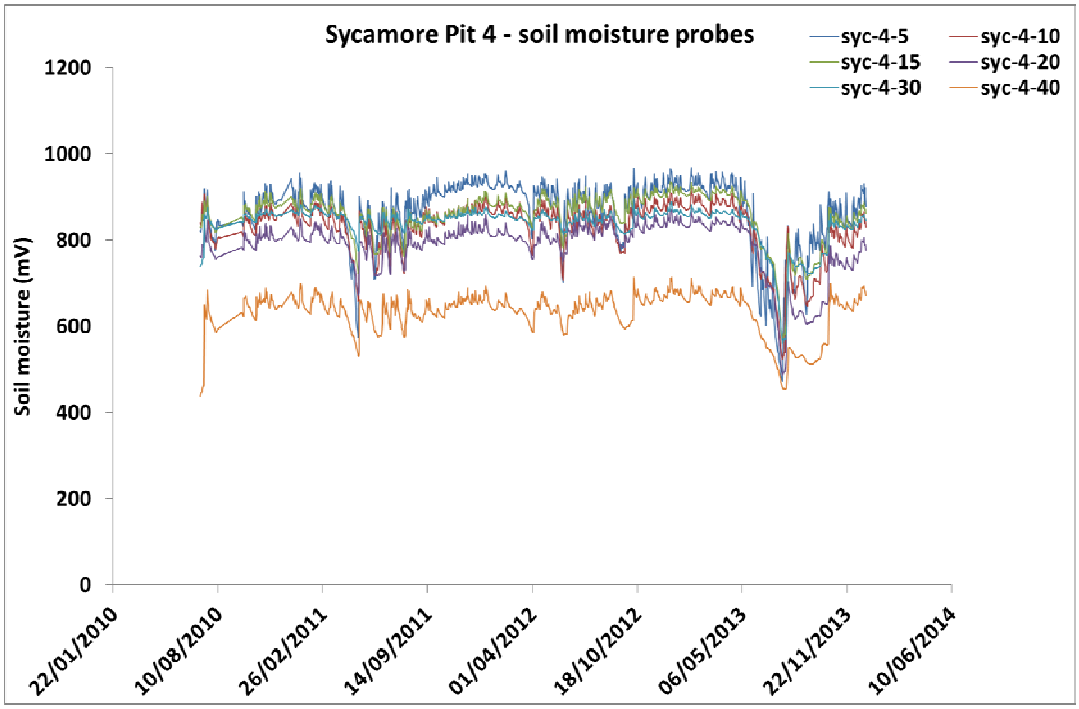


Figure 3. Soil moisture content measured by soil moisture probes at the Sycamore SRF site.

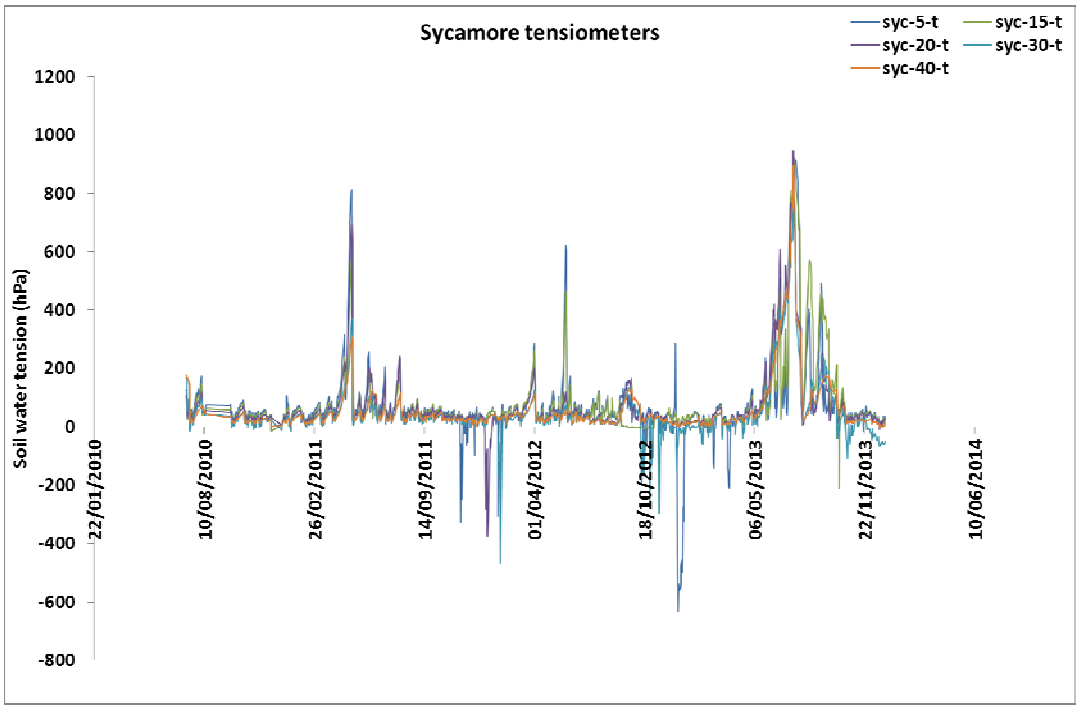


Figure 4. Volumetric soil moisture content measured by tensiometers at the Sycamore SRF site.

Example plots of the raw data are shown in Figures 3 and 4; from the soil moisture and tensiometer data we can calculate the total amount of water in the soil and the availability of water for vegetation growth, which then allows us to assess the effects of the growing trees. The water potential measurements at different depths can also be used to calculate the gradient in pressure with depth in order to determine whether water is stationary or moving up or down the soil profile. In Figures 3 and 4 we can see that soil moisture and soil water tension follow seasonal patterns – the effects of the dry summer of 2013 can clearly be seen in both graphs.

One of the main challenges is keeping the probes (at least 30 at each site) operational; apart from the effects of weather extremes we've had voles chewing through tubing and wires. Any major effects should be seen when the trees are further through their growing cycle; at this stage little impact of the trees on the water resource would be expected.

The effects of SRF on water quality

The water quality experiment is located at Sibster Farm, Caithness; two water sampling points were selected, one in a stream draining the experimental area (dominated by the proposed SRF trial) on Sibster Farm and the other in the Achingills Burn, a stream unaffected by the SRF planting and therefore suitable as a control (Figure 5). Sampling began in September 2009 to provide baseline data prior to planting with SRF species; initially water samples were taken fortnightly for water quality analysis at our laboratory in Alice Holt and same day microbiological analysis at Scottish Water's laboratory in Inverness – sampling frequency was reduced to monthly in November 2013 and we intend to continue at this sampling rate until the SRF crop reaches harvesting age.

Early results from the microbiological data showed relatively high numbers of Coliforms, Escherichia coli and Enterococci at the Sibster Farm site, most likely due to the presence of livestock (Figure 6). Microbial numbers fell when the livestock were removed in October 2009 but increased again when livestock were returned to the site in April 2010. Livestock were again removed in October 2010, and again the microbial numbers were reduced; the results show a direct relationship between microbial contamination of the stream and the presence of livestock.

In general, nitrate concentrations are low but were found to be higher at Sibster Farm compared to the control site when sampling began, perhaps reflecting the previous practice of cereal farming. Nitrate concentration at Sibster Farm fell following livestock removal (Figure 7). Little effect of the trees on water quality would be expected at the current growth stage but may develop as the trees grow.

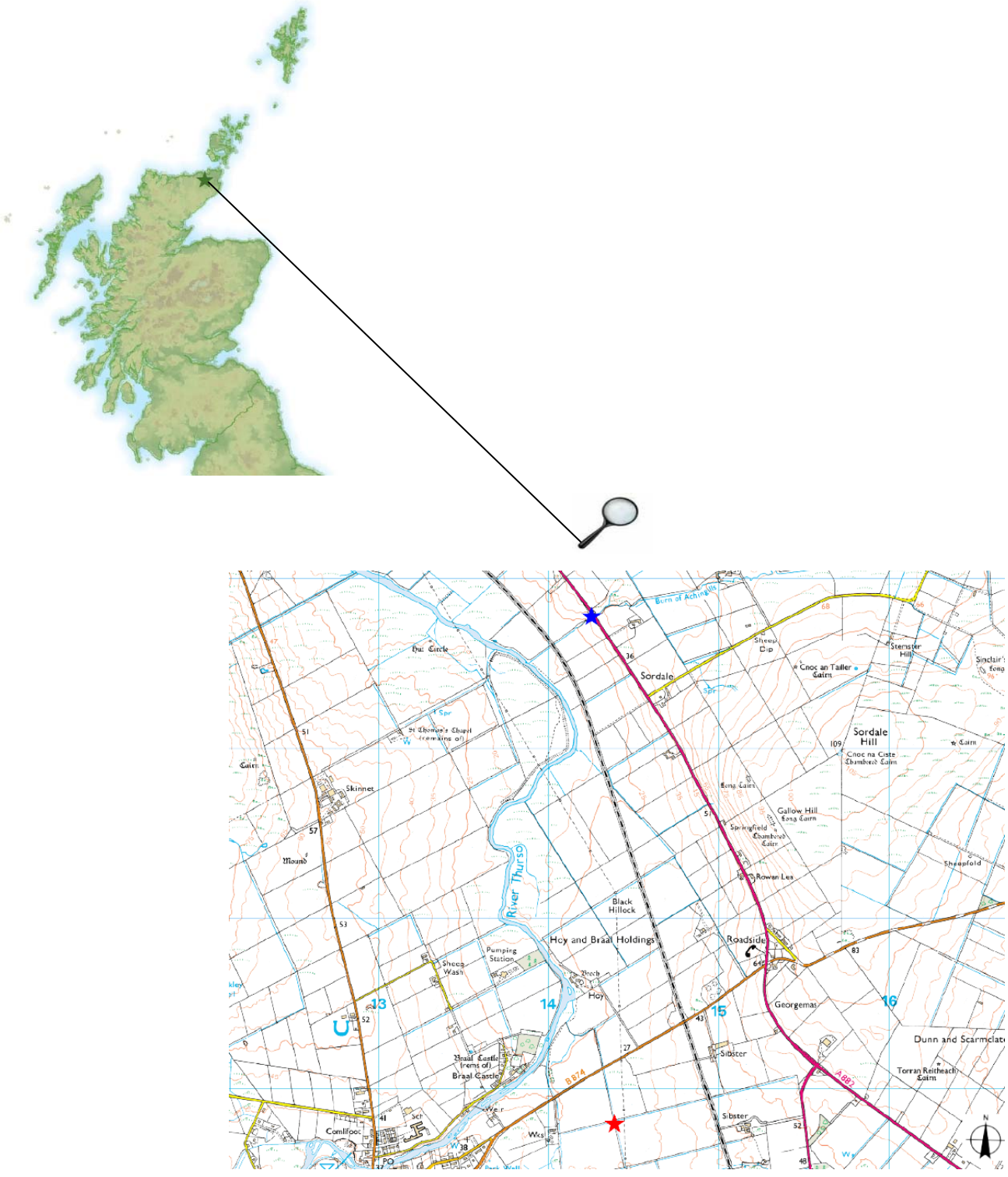


Figure 5. Sibster water quality experiment – Location of water sampling points and water level recorders in operational area on Sibster Farm (ND143 597) and control catchment unaffected by SRF planting (ND142 627). © Crown copyright. All rights reserved. Forestry Commission. 100025498. 2010.

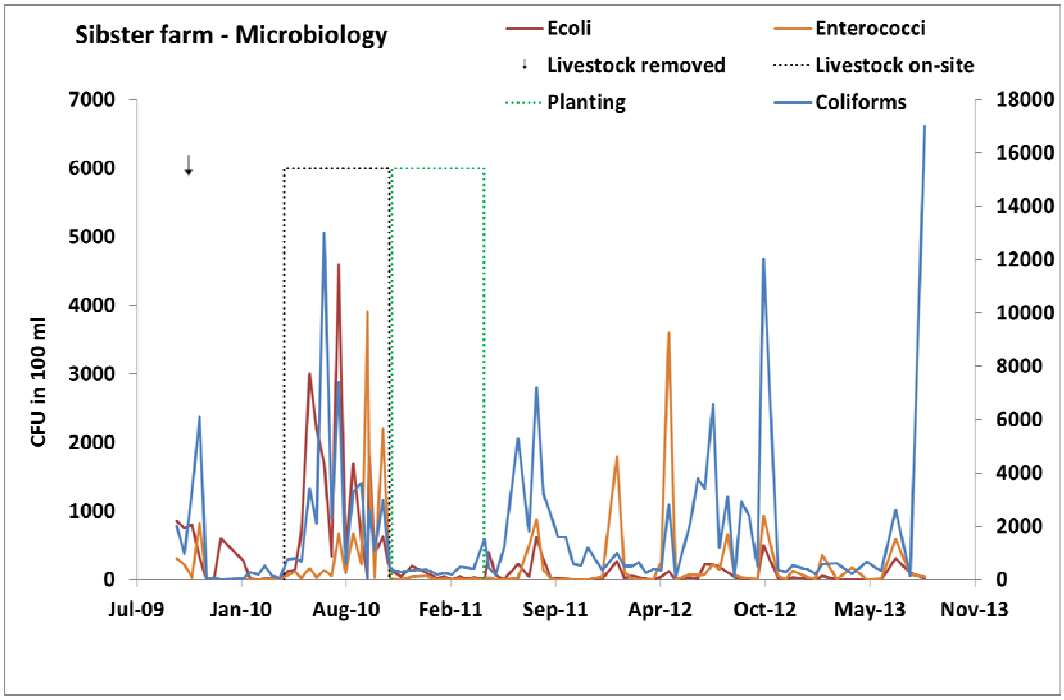


Figure 6. Microbial concentrations in colony forming units per 100ml at the Sibster Farm SRF site.

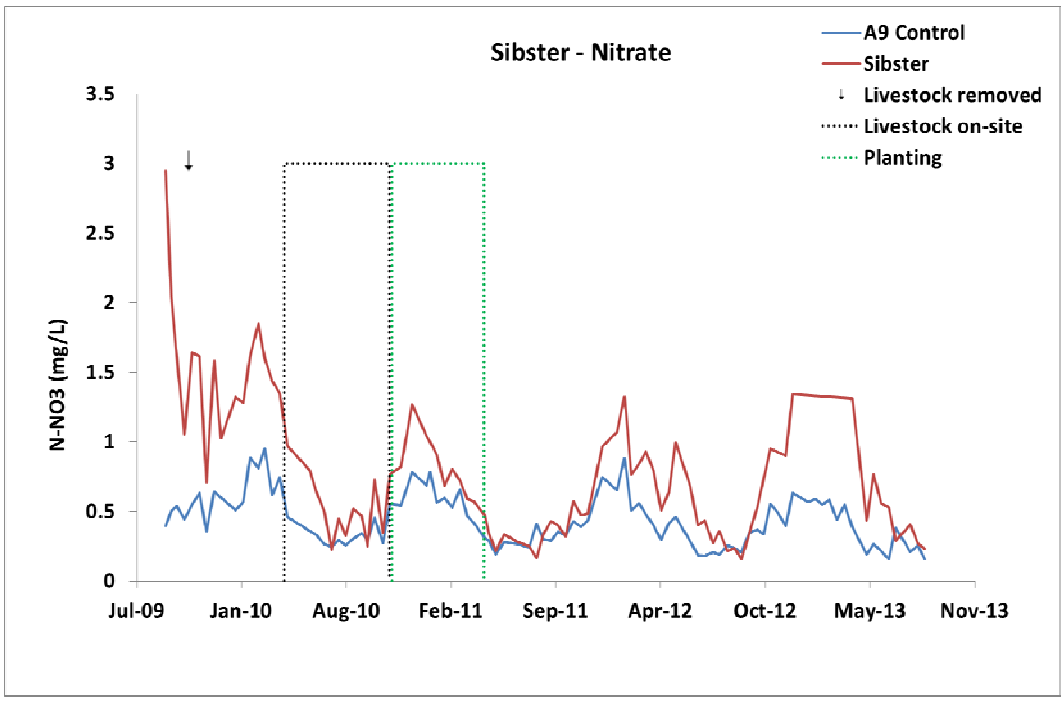


Figure 7. Nitrate concentrations at the Sibster Farm SRF site and the A9 control site.

Automatic water level recorders were installed in March 2010, which gives us the option to estimate the volume of runoff and convert chemical concentrations (mg/l) to fluxes (kg/ha). Operations carried out by the farmer adjacent and immediately downstream to the experimental site has led to a change in the flow regime at the Sibster Farm site, which in turn has caused erosion of the river bank where our recorder is located. Site characteristics are such that there are few alternative locations for the recorder; therefore it will remain where it is unless data quality is affected.

Appendix 2: Ranking of species performance at each site.

Performance of the 10 species was ranked at each of the 6 sites. The species with the largest height increment at each site scored 1, and the species with the smallest height increment at each site scored 10. The same process was repeated for survival (highest survival=1; lowest survival=10). At Sibster data for 11/12 were used due to the glyphosate damage in summer 2013.

Total survival and height increment scores across all sites for each species are presented in the main report. The ranking of each species at each site is shown in the tables below. Species are listed in each table according to their overall score. The three best performing species at each site are highlighted in green, and the worst in red.

Table 1: Ranking of species at each site according to mean height increment in 12/13.

Species	East Grange	Alyth	Balnoon	Sibster	Aros	Auchlochan	Total
RAR	2	1	1	3	1	1	9
ASP	1	4	2	4	2	2	15
HL	3	2	4	6	4	4	23
CAR	4	8	3	5	3	3	26
SBI	7	6	6	1	6	5	31
IAR	5	5	5	7	5	10	37
SS	6	3	7	8	8	6	38
AH	8	9	8	2	10	9	46
SY	10	7	10	9	9	7	52
SC	9	10	9	10	7	8	53

Table 2: Ranking of species at each site according to mean percentage survival at the end of 2013.

Species	East Grange	Alyth	Balnoon	Sibster	Aros	Auchlochan	Total
AH	3	2	1	2	8	2	18
SY	2	3	5	3	3	4	20
HL	1	1	4	6	4	5	21
ASP	5	4	6	1	1	6	23
SS	4	5	2	5	10	7	33
CAR	6	6	7	7	6	3	35
SC	8	8	8	8	2	1	35
SBI	7	7	3	4	9	8	38
IAR	9	9	9	9	5	10	51
RAR	10	10	10	10	7	9	56

Appendix 3: Summary of other SRF Trials

There are a number of other, complimentary, SRF trials underway in various parts of the UK, which indicate the ongoing interest in SRF. The following summarises the work in chronological order.

1. Department for Energy and Climate Change (DECC)

This series of trials is based upon the FCS model and commenced in England during 2010, funded by the Dept. for Energy and Climate Change (DECC). The research element of the trials exactly replicates the Scottish trials, but the operational plantings were pure eucalyptus. Site locations range from Totnes in Devon to Roan Farm, just outside Canonbie on the Scottish border, which is a useful surrogate Borders site for FCS.

As with the FCS trials, progress with species other than eucalypts has been good, with high survival rates and robust initial establishment. As might be expected, the more southerly sites are showing slightly faster growth rates. Funding for the DECC trials has been problematic and has reduced the ability to maintain and assess the plots, although sufficient funding to carry out annual height assessments has been found and these are currently ongoing. These sites will continue to be monitored and comparisons drawn with the results of the Scottish trials.

2. University of the Highlands and Islands (UHI)

In spring 2013, three small SRF trials were planted by UHI at various locations on Orkney. These trails have been supported by FC Highland and Islands and have received regular advice from FCS Business Development since the commencement of the planning process in 2011.

The trials are planted on ex-arable agricultural land with a range of broadleaf species chosen for their likely survival and potential growth rates in the challenging Orkney environment.

Though not on the scale of the FCS trials, the Orkney series is likely to provide a useful indication of the northerly limits for SRF.

The Executive Summary of the December 2013 report is included here:

REPORT TO FORESTRY COMMISSION SCOTLAND ON PHASE TWO OF A PROJECT TO ESTABLISH SHORT ROTATION FORESTRY TRIALS IN ORKNEY

Executive Summary

By
Peter Martin
Agronomy Institute
Orkney College (University of the Highlands and Islands)
December 2013

- A second phase of a project to establish research trials/demonstrations of short rotation forestry species in Orkney was implemented for Forestry Commission Scotland by the Agronomy Institute at Orkney College UHI from April to December 2013.
- Two trial sites, one at Muddisdale (Orkney mainland) and one at Newfield (on Shapinsay), were marked out and planted in April 2013. The trials used the same 9 tree species (sycamore, *Acer pseudoplatanus*; Italian alder, *Alnus cordata*; common alder, *Alnus glutinosa*; downy birch, *Betula pubescens*; beech, *Fagus sylvatica*; aspen, *Populus tremula*; goat willow, *Salix caprea*; mountain ash, *Sorbus aucuparia*; whitebeam, *Sorbus intermedia*) and a similar trial design at each site.
- Tree species were planted in plots of 25 trees (5 x 5) with one plot of each species represented in 6 replicates. Four replicates were planted with a 1.5 x 1.5 m spacing and no mulch; one replicate used the same spacing but had all the trees mulched with black polythene squares (0.6 x 0.6 m); one replicate was planted with a 1.0 x 1.0 m spacing with no mulch. All trees were protected by transparent polythene spiral guards.
- At Newfield, the more exposed trial site, a windbreak of 3 rows of willow and one of common alder was also planted around the trial in April. An additional windbreak was not necessary at Muddisdale because of existing shelter provided by willow on its northern border and an area of woodland on its southern side.
- Hares and rabbits became a serious problem at Muddisdale soon after planting and it was necessary to add a rabbit-proof fence around the trial in June.
- Survival and height measurements were taken on the innermost 9 trees of each plot at both sites in September-October 2013. Survival at both sites was very good and, amongst 324 trees in the four replicates planted at 1.5 x 1.5 m without mulch, mortality was only 0.3% at Muddisdale and 1.9% at Newfield. Over the growing season, the increase in tree height was greatest for goat willow (60-80 cm) at both sites followed by common alder, aspen and, at Muddisdale, Italian alder. Whitebeam and sycamore increased very little in height over the season while mountain ash, beech and downy birch were intermediate in their increase in height. Tree species had a similar pattern of survival and increases in height in the 1 x 1 m and polythene mulch replicates.
- A small trial using the guard trees in each plot was set up to compare the survival and growth of 5 trees of each species which had no spiral guard with that of the same number with i) spiral guards and ii) rigid plastic net guards. Mortality at both sites was high in the absence of any tree guard (42% at Muddisdale and 22% at Newfield). The height increment over the season was also much less in all species without tree guards. So far, the rigid plastic guards have not resulted in any marked improvement in survival or growth compared with the much cheaper spiral guards.
- An open event for the public was held at the Muddisdale trial site in December 2013 and an interview about the trial was featured on Radio Orkney in October 2013.

3. Natural Resources Wales (NRW)

NRW, in collaboration with FR, are in the process of planting a major SRF trial. There will be three trial sites; two restock and one new planting, each of approximately 3 ha. Individual trials will contain 400 trees each of 16 species, which include:

Broadleaves:

Sycamore	Italian alder	Aspen
Red alder	Silver birch	Common alder
Sweet chestnut	Balsam poplar (clone)	Small-leaved lime

Eucalypts: *Eucalyptus glaucescens* *Eucalyptus gunnii*

Conifers:

Grand fir	Japanese cedar	Sitka spruce (VP)
Coast redwood	Western red cedar	

The species mix reflects the Welsh approach to SRF. They see it not only as a biomass crop, but also as a tool to add species and age class diversity to existing woodlands, including native woodlands. Balancing these objectives will be interesting, and it may well be that, in some situations, economic biomass production will not be the primary objective.