Forest Research

Short Rotation Forestry Trials in Scotland

Progress Report

2015

The Research Agency of the Forestry Commission

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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.

Executive Summary

Six Energy Forestry trial sites have now been established across Scotland; four planted in 2010, one in 2011 and one in 2012. In addition, two trials were planted in Orkney in 2013. Further plantings of alternative species have also been added to the mainland sites during 2015 and again in 2016.

The 2010 trials have now had six full growing seasons and it is 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 appear 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. Survival of Italian alder was also poor.

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 four growing seasons.

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 averaging 50 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 to have at

this stage to be comparable, if not better in several cases than 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 opportunity was taken to replace some of the species at Sibster, the most northerly site, with alternatives that may be better able to tolerate the exposed site conditions, based on experience from SRF trials in similar conditions in Orkney.

There has also been an increasing interest in growing more Native aspen in Scotland, a selection of clones were planted out at five of the existing SRF sites in March 2016 (not Sibster).

The trials are continuing 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. The trials are now providing information on which species are most likely to be suitable for SRF in Scotland. As the rotation progresses, this value will continue to be built upon.

This report summarises recent progress made up to March 2016, and gives an overview of the programme for the coming year, 2016/17.

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.

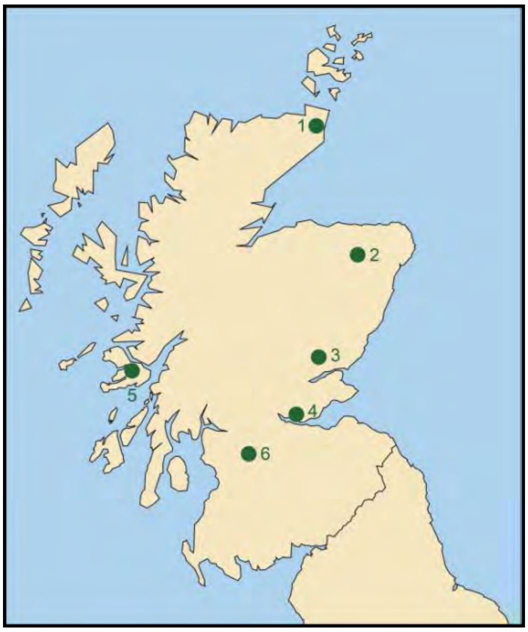
However, there was little current knowledge of SRF in the UK and so in 2007 Forestry Commission Scotland (FCS) and Forest Research (FR) began developing a network of Energy Forestry (EF) exemplar sites. The aim was to address the important information gaps on the growth of short rotation forestry in 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.

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 originally 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 in 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.

Orkney Trials

Two further short rotation forestry trials were established in Orkney by the Agronomy Institute, Orkney College, University of Highlands and Islands, also funded by Forestry Commission Scotland. These are located in Muddisdale (Orkney Mainland) and Newfield (on Shapinsay) and were planted in Spring 2013.

The trials are based on a very similar design to the mainland trials, and contain some of the same species:

Sycamore (SY)	*Acer pseudoplatanus* L.
Italian alder (IAR)	*Alnus cordata* Desf.
Common alder (CAR)	*Alnus glutinosa* (L.) Gaertn.

As well as some additional species suited to Northerly climates:

Downy birch	*Betula pubescens* (Ehrh.)
Beech	*Fagus sylvatica* (L.)
Native aspen	*Populus tremula* (L.)
Goat willow	*Salix caprea* (L.)
Mountain ash	*Sorbus aucuparia* (L.)
Whitebeam	*Sorbus intermedia* (Ehrh.) Pers.

As the most Northerly trial at Sibster was lost due to severe herbicide damage, the results of the Orkney trials may provide important additional information to supplement the mainland network. Summary results are presented here for comparison, and the full results for the end of the third growing season by Dr. Peter Martin, University of Highlands and Islands, is included in Appendix 1.

2016 Native Aspen trials

Native aspen trials have been planted at five of the original SRF sites (not Sibster). These consist of Randomised blocks of clonal material as follows:

C1 Orkney 'Rackwick' origin -CL9 (20-40cm) (used at Sibster and Orkney also)
C2 'Shropshire' -Zone 404 (40-60cm) (used at Sibster also)
C3 Arran origin -EECL024 micro-prop. (20-40cm)
C4 North Galloway origin -EEDG 008 micro-prop. (20-40cm)
C5 South Galloway origin -EEDG 030 micro-prop. (20-40cm)
C6 Standard mixed clones from -Zones 106 and 202 CT LKCM micro-prop. (20-40cm)

Trees were planted at the same 1m x 2m SRF spacing used in the original species trials, each of the four blocks consists of 6 rows of 20 trees, each row contains an individual clone, all plot trees are assessed (80 per clone on each site).

Plant quality testing was carried out on a sub-sample of trees from each clone just before the trees were planted. Root electrolyte leakage (REL) values indicated that all six clones were in good physiological condition with mean scores ranging from 16 to 24%, suggesting all material was fully dormant at planting (below 30%) and well within the acceptable max REL value for cell grown stock (40%).

Update on the past year

Some of the earliest flushing Sitka spruce trees at East Grange were severely damaged by a late frost. This caused complete girdling of some of the smaller diameter trees and subsequent death of all foliage above waist height, any later flushing and/or larger trees were less affected, only losing a few small branches or the newly flushed 2015 shoots, while many sustained no visible damage, (See Fig 2).

Figure 2. Late frost causing serious damage to some early flushing Sitka spruce but no damage to others.

Data from the on-site met station confirmed a period of warm sunny days and cool nights was followed by a rapid drop in temperature to -5.6 on the 27th April, (See Fig 3). Similar damage was also reported at other sites across Southern and Central Scotland.

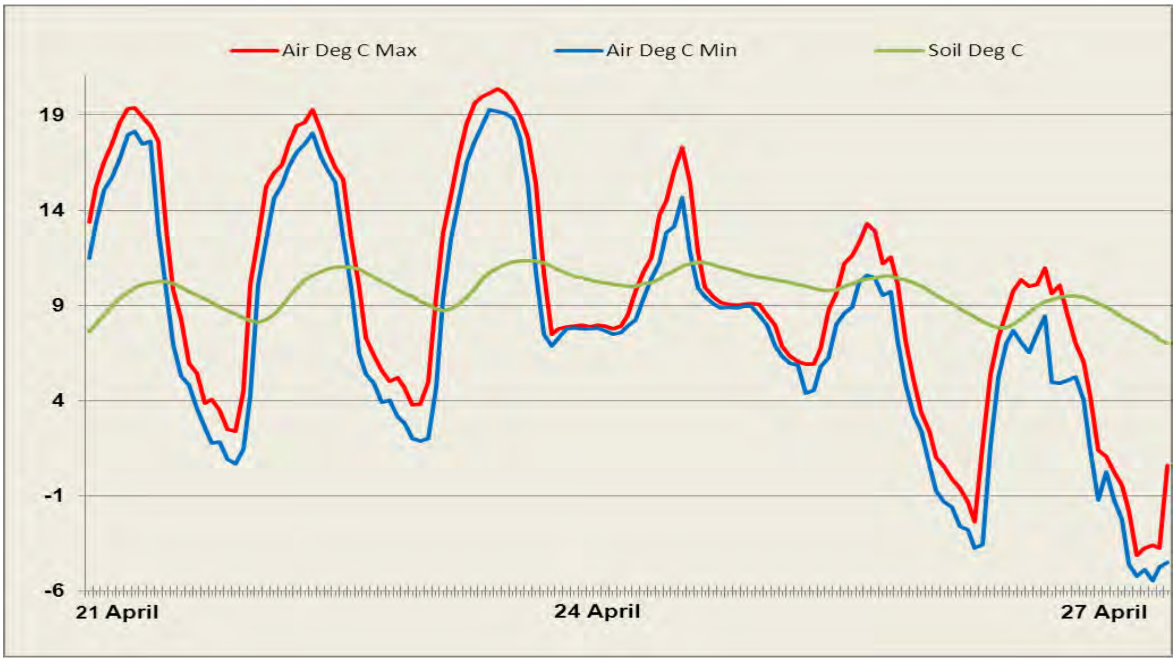


Figure 3. East Grange Met Station air and soil temperatures.

A further outbreak of the common leaf weevil (*Phyllobius pyri*) (See fig 4) was reported on the large scale FCS sycamore site at Alyth in mid-June, but this was not as severe as last year. Advice from FR entomologists indicated there was no effective treatment worth considering; the heavy weed growth and grassy sward on the site would provide ideal breeding conditions allowing the weevils to establish in high numbers.

Figure 4. Common leaf weevil

As in the previous year ash trees at Alyth and East Grange are showing signs of *Hymenoscyphus fraxinea* (new name for *Chalara*) with a large number of trees in some of the plots showing symptoms. Current policy is to leave the trees in place and progress of the disease will be monitored.

Some hybrid aspen at East Grange have developed cankers, this infection was probably present in earlier years, but only now has it become obvious, (See Fig 5). Future assessments will look to follow the progress of this disease.

Figure 5. Canker on Hybrid aspen at East Grange.

The Sibster trial which was badly damaged by herbicide in June 2013 was replanted on a new area of ground next to the original trial. Scottish Woodlands cleared and mowed site in April 2015, new randomised plots were marked out by FR and Scottish Woodland replanted the trial in May 2015. Herbicide (Laser and Toil) was applied late May and a later inspection by FR confirmed trial had been re-established to our satisfaction.

The opportunity was taken, based on previous experience at the site, to replace sweet chestnut with downy birch (*Betula pubescens*) and the hybrid larch and ash with two different native aspen clones (*Populus tremula*).

The original plots of hybrid aspen and red alder, which were not damaged by herbicide due to their larger size have been retained and will to be assessed for comparison with the other 2010 trials. Scottish Woodlands will continue to maintain this site for five years after planting.

Larch on the Mull site were showing signs of needle browning and drop from some form of unidentifiable damage earlier in year, but remaining foliage appears healthy and not thought to be of concern, further checks will be made in 2016.

The Forestry Stewardship Councils decision to withdraw approval on the use of propyzamide weed killer, made it impossible to undertake pre-planting grass control using winter applied granules. As a result, all of the 2016 native aspen trials had to be screef planted. Application of a suitable top up herbicide to control a potentially heavy growth of grass and broadleaf weed competition is now likely. Otherwise the establishment of the new trials went well.

All sites were assessed in spring 2016 and the results are presented below.

Results

Fast-growing broadleaves

East Grange (Kincardineshire)

This site is the most southerly of those planted in 2010 with a low elevation, and the six-year results again show some of the best growth and survival rates (Fig. 6). In addition, as ex-agricultural sites, the soils at most of the trial sites are likely to be richer and better drained than the 'natural' soil of the site. However many of the faster growing species showed a marked drop in increment; this could be down to the relatively poor weather in Eastern Scotland during 2015. Mean height of hybrid aspen is now over 6m but increment only one sixth of last year's strong growth, red alder is nearing 6m but half the level of last year's growth, hybrid larch with mean height around 5 m and down by a third on 2014 (Fig. 6). On the other hand Italian alder has performed well again this year with another increment over 1.3m and now stretching above common alder. Sycamore, sweet chestnut and ash continue to perform very poorly, with silver birch and Sitka spruce slightly better with a mean height of around 3m. Generally the larger species had significantly smaller increments this year compared to 2014. Only Sweet chestnut suffered any real drop in survival in 2015 (-5%).

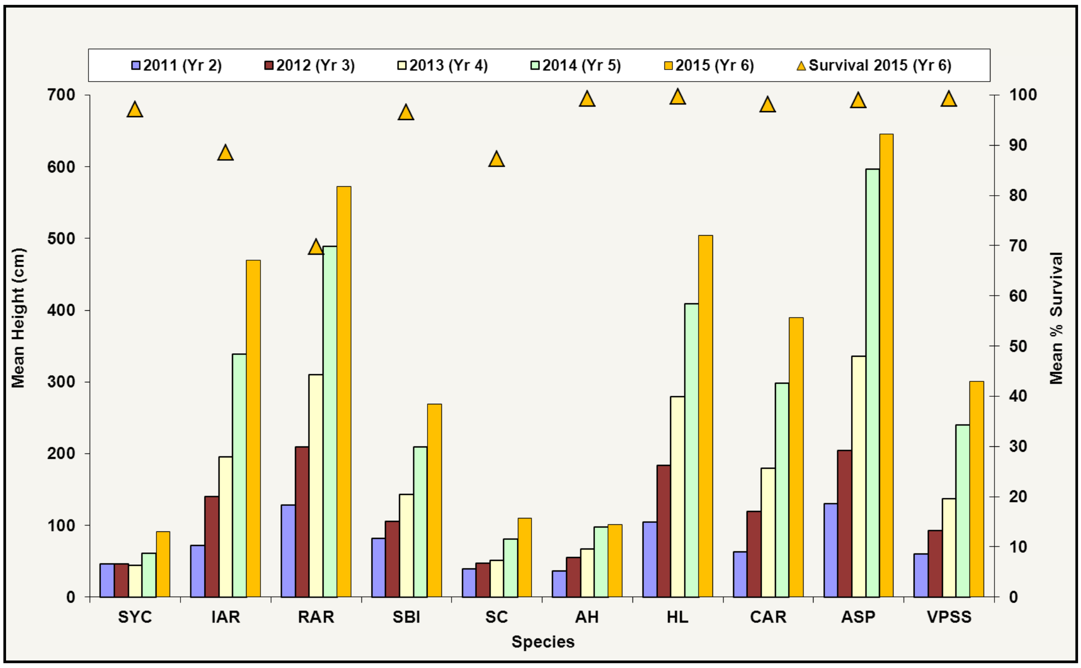


Figure 6. Mean height and survival after six years at East Grange.

Alyth (Perth and Kinross)

This site remains one of the best for all species, including eucalyptus (see later section) despite its relatively high exposure. The south facing slope and freely-draining brown earth soil provide good conditions for growth and survival. Although the tallest species are smaller than those at East Grange, the others are broadly similar and survival is also generally high.

Hybrid larch at 4.5m remains the tallest species on the site, with an increment of almost 1m (Fig. 7). Although red alder and hybrid aspen are still among the tallest species at Alyth, poor annual growth again this year coincides with further common leaf weevil damage, which has been particularly severe on these species. Sitka spruce has overtaken hybrid aspen this year standing over 3.2m, having performed well for the last two years (Fig. 7).

Growth rates of sycamore continue to improve after a slow start, but ash has slowed again with many trees infected with *H fraxineus*. Sweet chestnut continues to struggle this year, while Italian alder, common alder and silver birch maintain slow but steady growth. Survival has remained level for all species over the last three years.

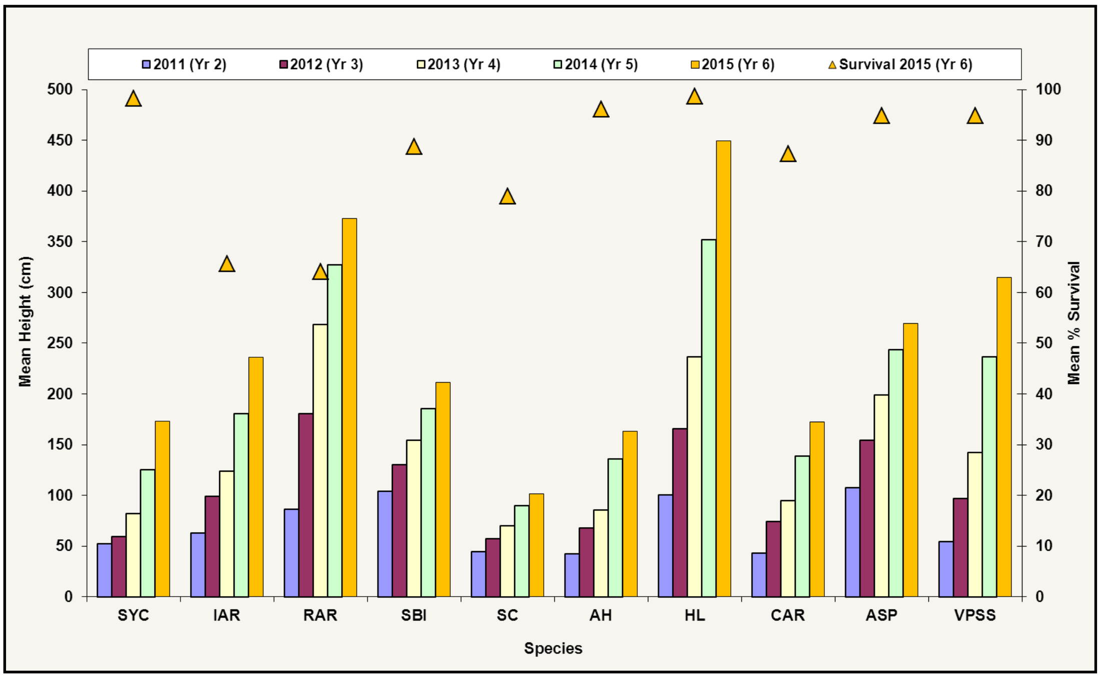


Figure 7. Mean height and survival after six years at Alyth.

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 adjacent operational site since planting (see Appendix 1 for full report) demonstrates that soil moisture under grass decreases more than under ash or sycamore during dry periods, such as the summer of 2013. This is likely to be caused by the well developed deeper root system of the grass and high transpiration requirement compared to that of the young trees.

Monitoring of water resources on this site will continue and will provide further information as the site matures.

South Balnoon (Aberdeenshire)

Despite the severe weed competition on this site initially, survival has remained reasonable since beating up except for the alder species and sweet chestnut, probably 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.

Red alder, hybrid larch and silver birch are performing well with good growth increments for the last two years (Fig. 8). Hybrid aspen demonstrated improved growth last year but this has halved and has been overtaken by hybrid larch. Sycamore, sweet chestnut and ash continue to grow slowly but sycamore and ash increments were much better in 2015 and Sitka also maintained its steady improvement (Fig. 8).

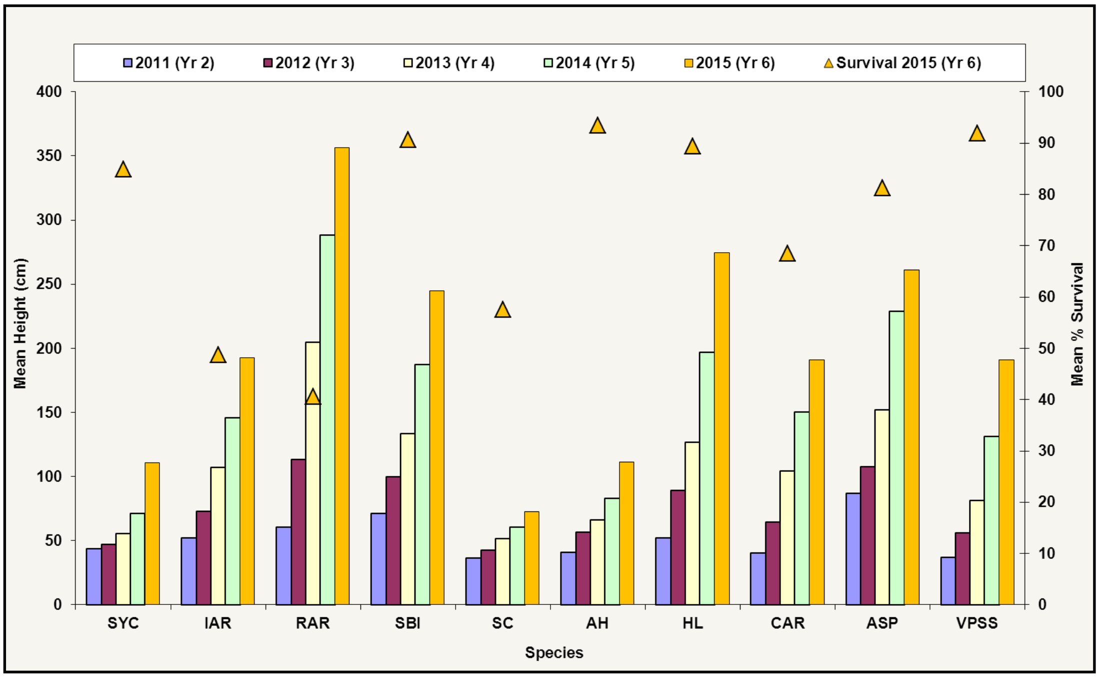


Figure 8. Mean end of year height and survival after six years at South Balnoon.

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). Only red and Italian alders had lower survival, 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.

Eight species were replanted on the site in May 2015 and their initial and first year height, together with first year survival rates are shown in Figure 9 below. All except for the Orkney origin native aspen have put on growth of approx. 10%. As the other native aspen clone appears to be growing fine, it could be down to poor quality stock, although this particular aspen clone also struggled at both Orkney trials in 2015.

Italian alder has experienced a slight drop in survival to 86%, but all the other species have good rates in the mid to high 90s.

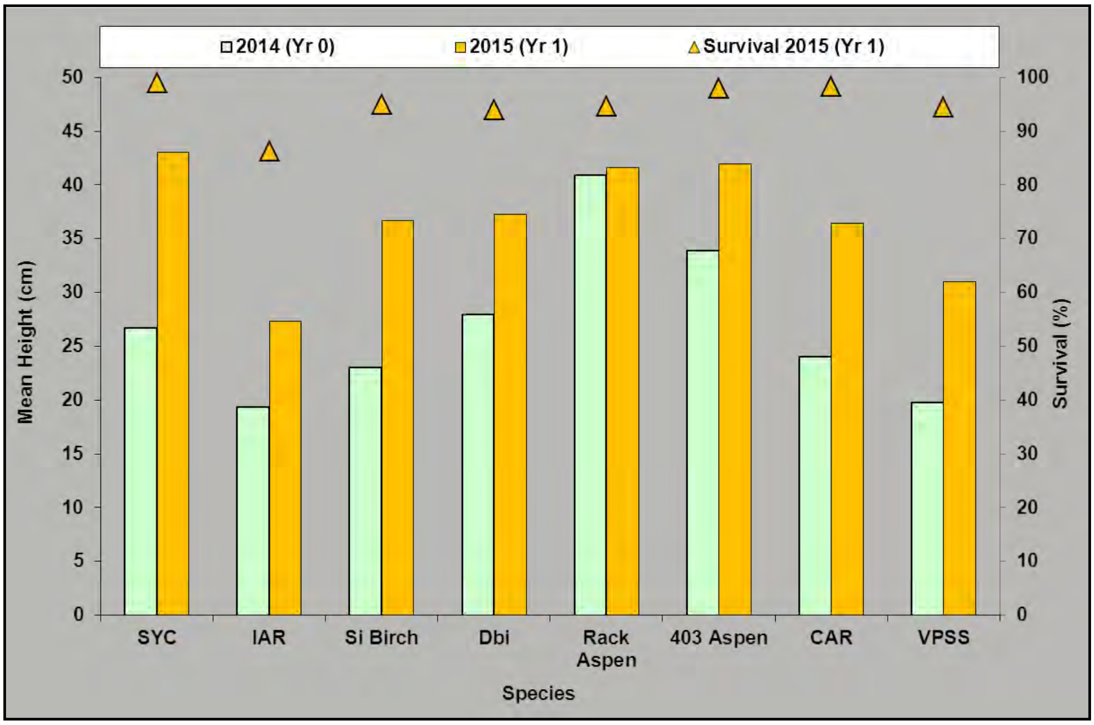


Figure 9. Mean Height and survival after one year at Sibster (replacement planting)

Figure 10 below shows the year six height and survival for remaining red alder and hybrid aspen assessed in 2015. Survival of red alder at Sibster is down to 9% with a negative height increment recorded this year. Survival of hybrid aspen was also down 8% to 61%, growth was almost static during 2015 with a mean height increment of less than 2cm.

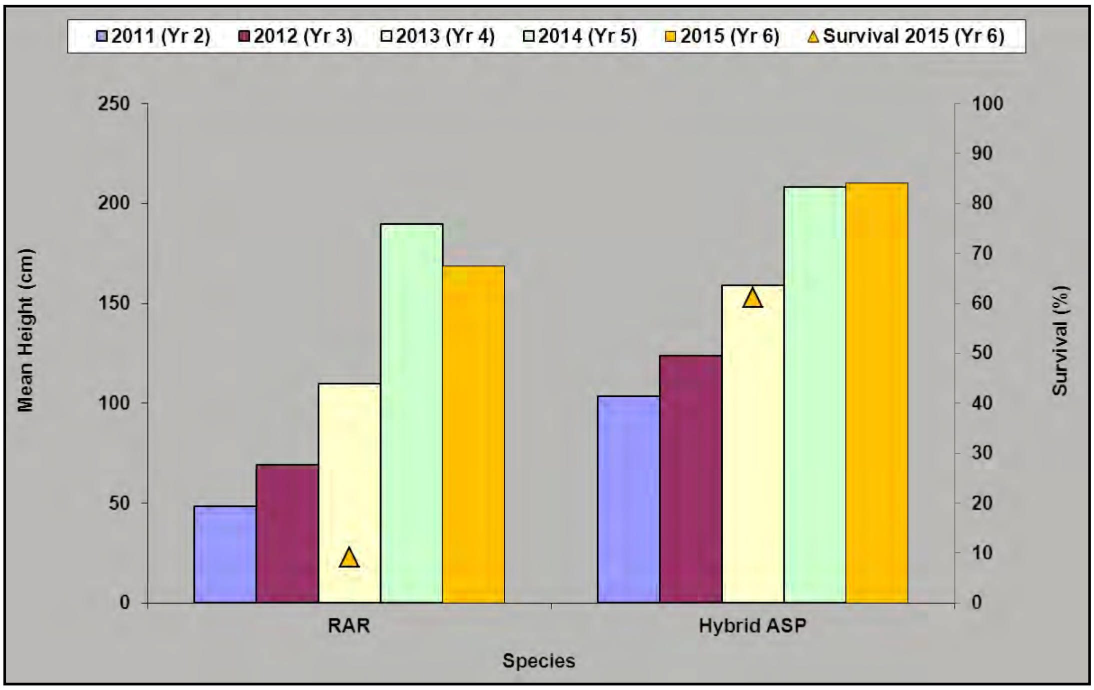


Figure 10. Mean height and survival after six years at Sibster (red alder and hybrid aspen only).

The early results from Sibster suggest that SRF is unlikely to be very successful on such sites without additional wind breaks.

Aros (Mull, Argyll)

This site was planted one year after the initial planting at East Grange, Alyth, South Balnoon and Sibster in spring 2011. It is a relatively sheltered 6.0 ha restock site with a south-facing slope, between 30-90 m elevation and an upland brown earth soil. The site has recovered well from early Hylobius problems and survival of most species is reasonably high.

The same general species growth responses can be seen as at the initial four sites. Red alder and hybrid aspen performed well in 2014, but increments were significantly lower in 2015, both reached a mean height of around 3.5 m (Fig. 11). Hybrid larch, common alder and Italian alder grew well over both of the last two years and mean heights are now at or just below 2m. Ash, sycamore, silver birch and sweet chestnut continue their relatively steady slow growth, but Sitka spruce has made improved growth during 2015. (Fig. 12).

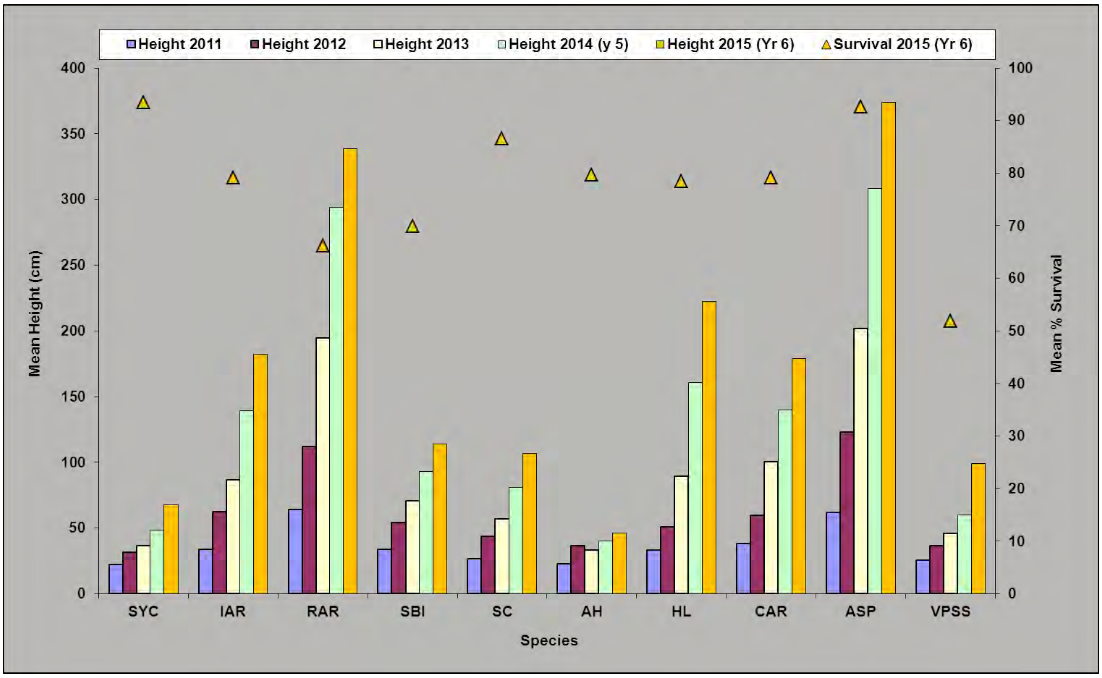


Figure 11. Mean height and survival after five years at Aros.

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. 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.

Survival of most species remains high at the end of 2015, with the exception of Italian alder where less than half survive (Fig. 12). As with 2014 the majority of species produced similar levels of good growth over the 2015 season. However, hybrid aspen did not do as well with a 50% reduction. Red alder is now the tallest tree at 3.5m (Fig. 12) having put on over 1m in 2014 and 2015. Hybrid larch and common alder have identical growth patterns with both extending over 90cm to 2.6m in 2015 and not far behind the hybrid aspen at 2.8m (Fig 12).

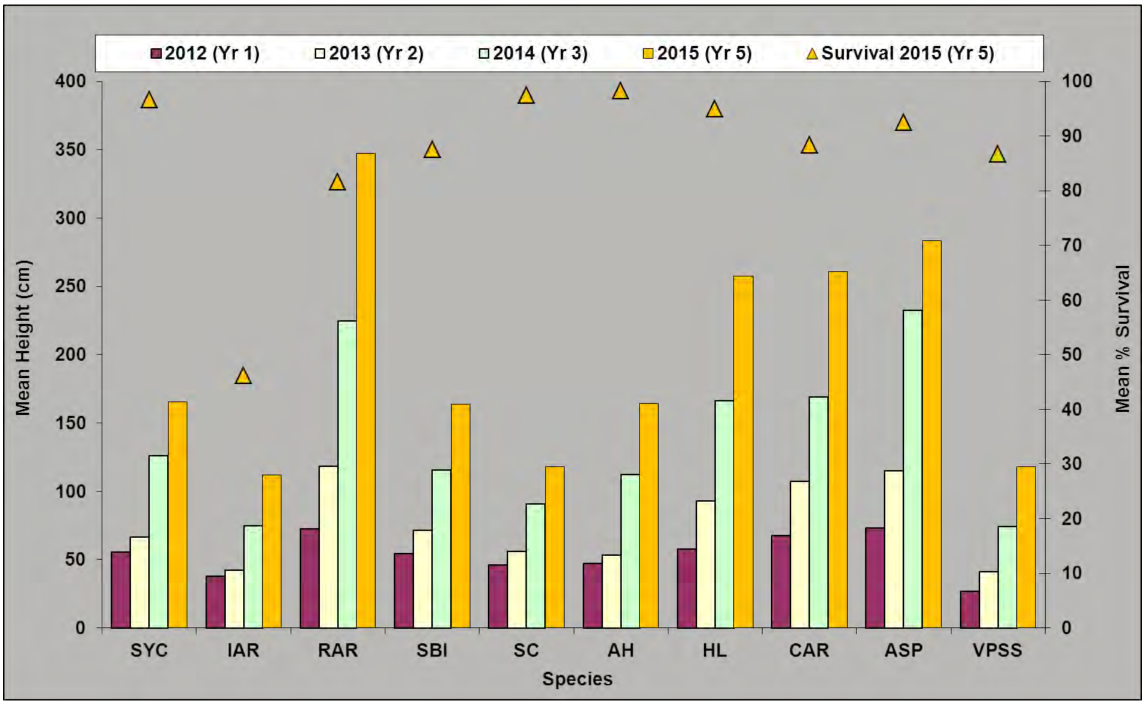


Figure 12. Mean height and survival after four years at Auchlochan.

Orkney sites

In addition to the trials described above, Forestry Commission Scotland continues to fund two SRF trials in Orkney, established in 2013 and managed by the Agronomy Institute, Orkney College, University of Highlands and Islands (UHI). These trials are on ex-agricultural land, located at Muddisdale (Orkney Mainland, HY 435 110) and Newfield (Shapinsay, Balfour Mains Farm, HY 516 181). The windy, exposed conditions of these northerly sites make them a good comparison for the Sibster site, which was lost due to herbicide damage.

Rabbit/hare damage was a serious problem at the Muddisdale site during the first growing season and trees were protected with guards shortly after planting. At the Newfield site dry weather conditions in the spring and early summer following planting resulted in some defoliation and scorching in trees that were not protected by guards.

Survival of all species was very high over the first two years and remains so at Muddisdsale. However, at Shapinsay rates are significantly down with Sycamore (31%) and Beech (44%) being the worst performing, while whitebeam and mountain ash are also below 70% at this site. Goat willow (not planted in the mainland SRF trials) was the tallest species with the largest height increments of 60-80 cm at both Orkney sites.

Several species at both sites had comparatively low or negative height growth over 2015 compared to the previous year (Fig 13 & 14). Shipinsay was particularly affected with severe die-back of goat willow and considerably reduced growth in most of the other species. Whitebeam and common alder at Muddisdale put on the best increment in 2015 while the poor aspen growth at this site dropped it to fourth place behind the alders and willow.

It will be interesting to see how the same species grown as part of the 2015 Sibster restocking compare with the Orkney trials in future.

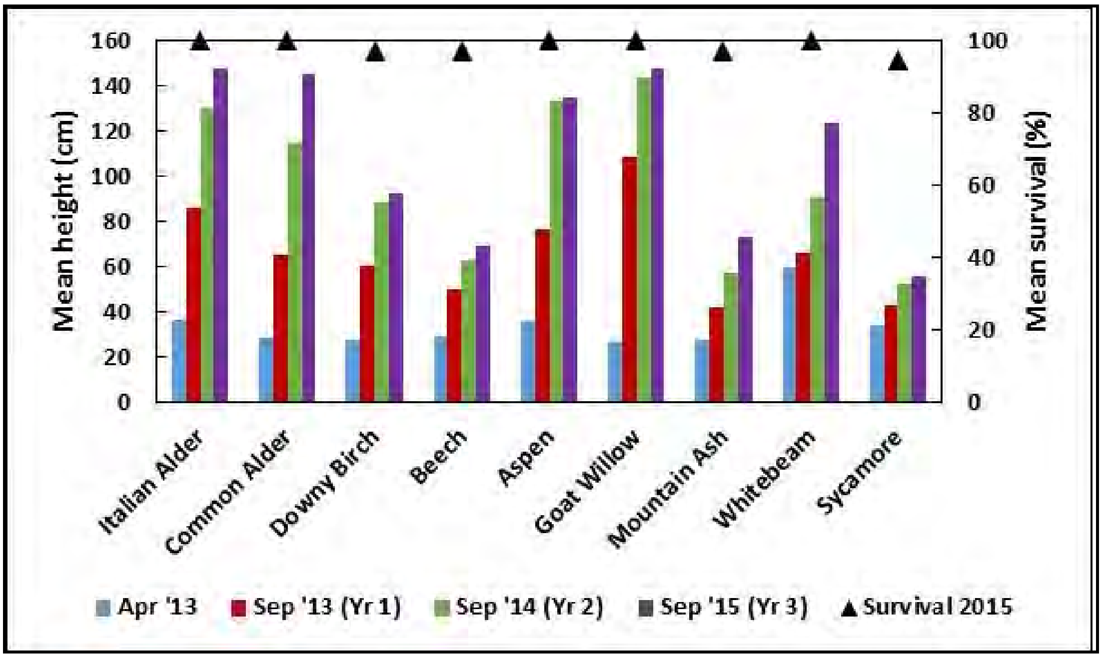


Figure 13. Mean end of year height and survival after three years at Muddisdale

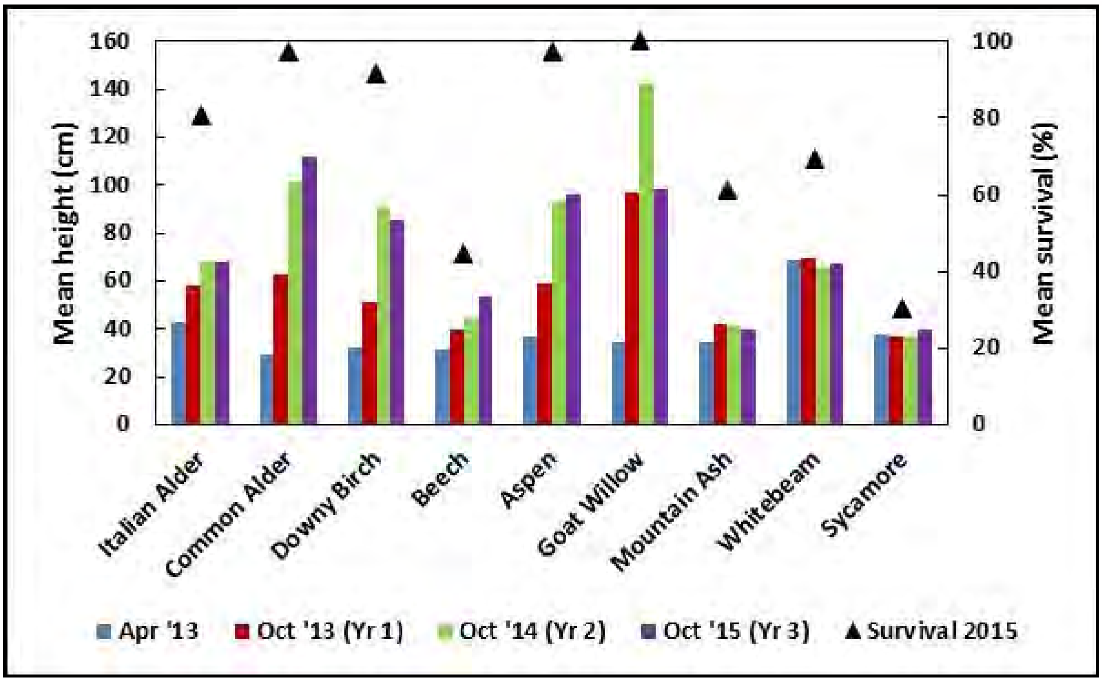


Figure 14. Mean end of year height and survival after three years at Newfield

The full 2015 UHI report appears as Appendix 1.

Eucalyptus species

Surviving plots from first series of sites

Of the original four sites (replanted in Sept 2011) only East Grange and Alyth have eucalyptus plots that are worth assessing; survival at Sibster and South Balnoon is virtually zero. The eucalyptus species continue to grow faster at Alyth than at East Grange.

At both East Grange (Fig. 15) and Alyth (Fig. 16) the few remaining individuals of *E. nitens* have the best eucalyptus growth rates on the site, with mean height of over 2.2m and 3.8m respectively after 4 growing seasons. However, a year four survival rate below 10% make them unsuitable species for the sites.

At both sites *E. gunnii* has the highest survival rates of any eucalyptus species (>60%) with survival of *E. pauciflora* and *E. subcrenulata* being considerably lower (<30%).

Annual increment of *E. gunnii* has shown a similar increase at both sites of around 95cm. All other species also put on a considerable increase in growth compared to previous years at over 1m at Alyth and between 70 and 90cm at East Grange.

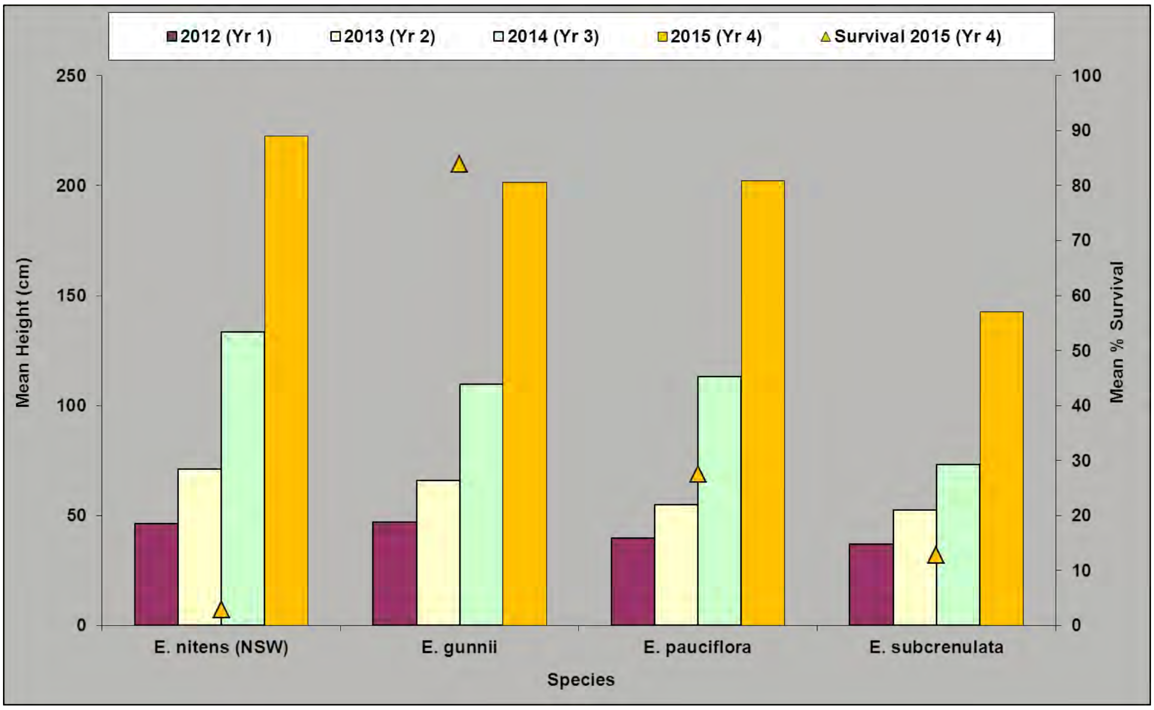


Figure 15. Mean height and survival of Eucalyptus species after four years at East Grange

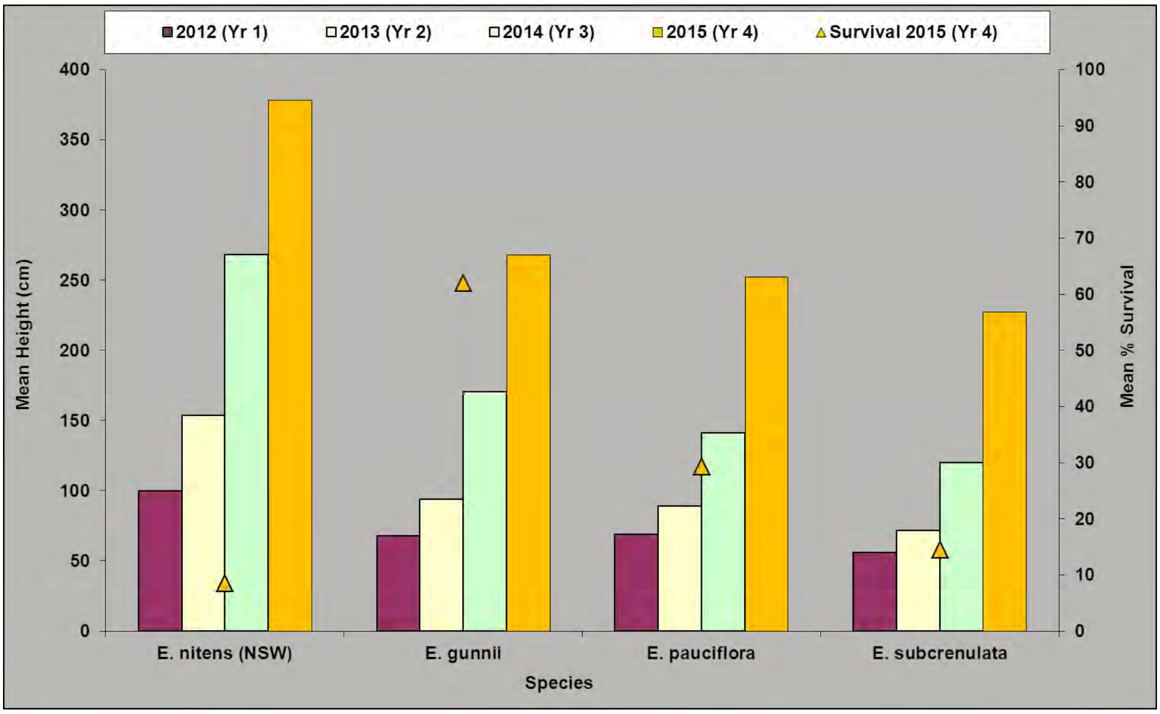


Figure 16. Mean height and survival of Eucalyptus species after four years at Alyth

Early conclusions from the sites

Comparison of current height across sites

A comparison of mean height at the end of six growing season across the four sites that were planted in 2010 and also looking at the younger 2011 Mull and 2012 Auchlochan trials (Fig. 17), show there is a general growth gradient from North to South (and West) for some species. This is particularly strong for Italian alder, red alder, hybrid larch and hybrid aspen. As was the case in2014, for all species except silver birch and common alder growth was better at Alyth than at Balnoon, as would be expected for the latitude and southerly aspect at Alyth. Sycamore, ash and now also Sitka spruce have grown better at Alyth than at East Grange, despite being further north, perhaps due to the south facing slope and freely-draining soil.

Geographical growth patterns are even more pronounced when the performance of the two younger sites are included. Despite having one or two less seasons of growth, the hybrid aspen at Mull and Auchlochan are already taller than all sites except Alyth, for red alder and common alder they have caught or surpassed the trees at Balnoon and East Grange. Ash and sweet chestnut at Mull is already the best performing of all sites and the sycamore here has caught up with the best performing site East Grange, (Fig. 17).

Despite this general latitudinal trend across the Scottish mainland sites, two of the three species grown at both Sibster and the Orkney sites had much better two-year height growth at the Orkney sites. This highlights the importance of the weather conditions during the early establishment years, which were particularly severe in winter 2010 and 2011.

To summarise performance to date across all sites the ranked height at the end of 2015 and the mean percentage survival of each species is presented in Table 2. The best performing species at each site received a score of 1, and the poorest a score of 10. The overall score across all six sites is shown in Table 2, with the four best and worst performing species highlighted in green and red respectively.

Although red alder has replaced hybrid aspen as having the best height performance across all sites, it ranked last for survival (54%). Common alder displayed a similar pattern of reasonable height growth but very poor overall survival.

Hybrid aspen was second for height and fourth for survival, closely followed by Hybrid larch which had both good height and survival across all sites. Both of these species appear able to tolerate a range of site conditions and to grow fast, having potential for use in SRF systems on these sites.

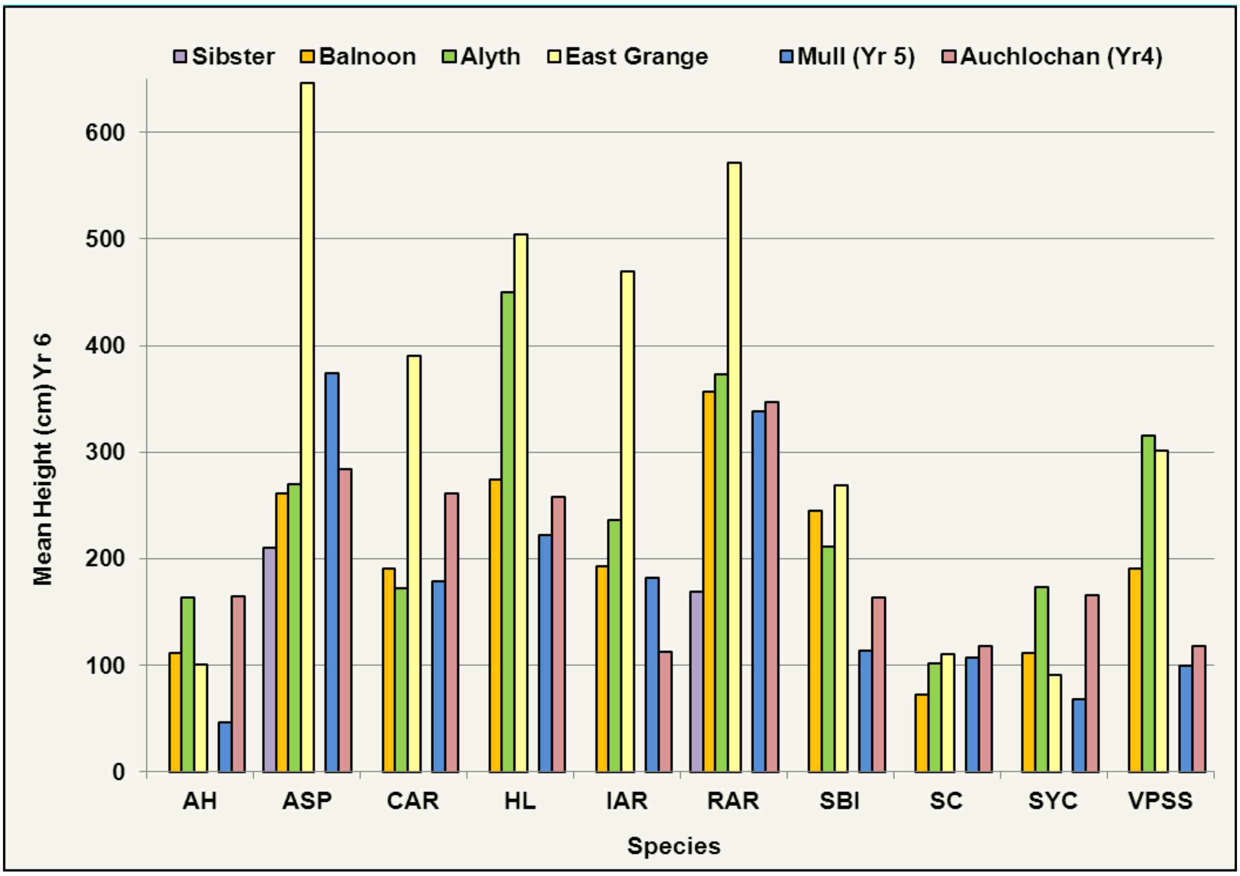


Figure 17. Comparison of mean height after 6 years (Mull Yr5 & Auchlochan Yr4 data).

Despite good height growth rates, red alder had poor survival across all sites, suggesting that the potential of the species is difficult to achieve and that it may not be suitable for SRF systems on these sites. The poor survival of Italian alder also suggests that it is not able to tolerate the conditions on these site types and is not suitable for SRF systems. Common alder also had good height growth on most sites, and although survival was a little better than that of red alder and Italian alder, it was lower than for some other species, particularly at Balnoon. Common alder may be more appropriate for use in SRF systems on sites where conditions are relatively sheltered.

The height growth and survival of silver birch was moderate across all sites, but the species performed better at Balnoon than at most other sites, suggesting it may have potential where other species are limited by exposure, but is not universally suitable for use in SRF systems.

Early growth and survival of Sitka spruce has not been that good in previous years, but it has improved during 2015 achieving equal second overall height increment score with hybrid larch and common alder.

Sycamore, sweet chestnut and ash grew consistently slowly across all of the original sites compared to other species, but growth is considerably better at Auchlochan. 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.

Species	Mean height ranked across sites	Mean % survival ranked across sites
Red alder	1	10
Hybrid Aspen	2	4
Hybrid larch	3	3
Common alder	4	8
Italian alder	5	9
Silver birch	6	6
Sitka spruce	7	5
Sycamore	8	2
Ash	9	1
Sweet chestnut	10	7

Table 2. Ranking of species across 5 sites by height and survival at the end of 2015.

For a species to be a suitable choice for use in SRF systems in Scotland it must be able to tolerate the site conditions and achieve good growth rates. The results to date show that some of the species found to have high growth rates (red alder, Italian alder and on some sites 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, some of the species which appear to be the most tolerant of site conditions and have the highest survival rates (ash and sycamore) are currently growing very slowly on the older sites, although this may improve once the trees are fully established. It will be interesting to see if the newer Aros and Auchlochan sites, maintain their faster initial growth rates in future.

The species that currently appear to have the most potential for use in SRF systems on these sites based on performance to date are hybrid aspen and hybrid larch (depending upon the development of *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.

Eucalyptus species

Eucalyptus species have not survived well at any of the trial sites and do not appear to be appropriate choices for use in SRF systems in Scotland. Severe winter weather conditions in the first two years 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* appeared to have reasonable survival rates and good height growth; however heavy beating-up was still required during the early establishment phase. 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 now good achieving 80-100cm in 2015 but this only equates to an average of 50cm per annum at the most suitable sites, this is still not as large as the average increments achieved by red alder, hybrid larch and hybrid aspen.

Future plans for the sites and work due in 16/17

Annual assessments of the original species trials will continue to the end of year 6, this means only Aros and Auchlochan are due assessment in the coming year 2016/17. Any weed control requirements on the slower growing species should be assessed at the same time as maintenance of new native aspen trials takes place.

A year two height assessment will also be required on the replanted Sibster plots. Establishment operations and maintenance will be provided by Scottish Woodlands until the end of the fifth year.

A general pest and disease inspection should take place to assess if any further weevil damage has occurred or hybrid aspen canker has significantly spread to other trees.

For the new native aspen trials, application of herbicide to control weed competition will be required at all sites, as will end of year height measurements, projected assessment times for these are included in brackets within Table 3. These should be combined with any other work on same sites whenever possible. A small hidden air temperature logger will be installed at Auchlochan over the summer as there is currently no met station recording at this location to record any adverse conditions that may cause damage.

Longer-term assessments at all sites are recommended at years 10, 15 and perhaps 20 for each site according to the schedule in Table 3. These later assessments would include measurement of diameter at breast height and calculation of volume.

Calendar year	16/ 17	17/ 18	18/ 19	19/ 20	20/ 21	21/ 22	24/ 25	25/ 26	26/ 27	29/ 30	34/ 35
East Grange	(1)	(2)	(3)	10 (4)	(5)	(6)	15			(10)	(15)
Alyth	(1)	(2)	(3)	10 (4)	(5)	(6)	15			(10)	(15)
South Balnoon	(1)	(2)	(3)	10 (4)	(5)	(6)	15			(10)	(15)
Aros	6 (1)	(2)	(3)	(4)	10 (5)	(6)		15		(10)	(15)
Auchlochan	5 (1)	6 (2)	(3)	(4)	(5)	10 (6)			15	(10)	(15)
Sibster	2	3	4	5	6		10			15	

Values are age in years. (n) indicates Native aspen trials also scheduled.

Table 3. Recommended assessment schedule all SRF experiments.

Appendix 2:

Report on Studies to Assess the Hydrological Impacts of Energy Forestry

Nadeem Shah

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 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.

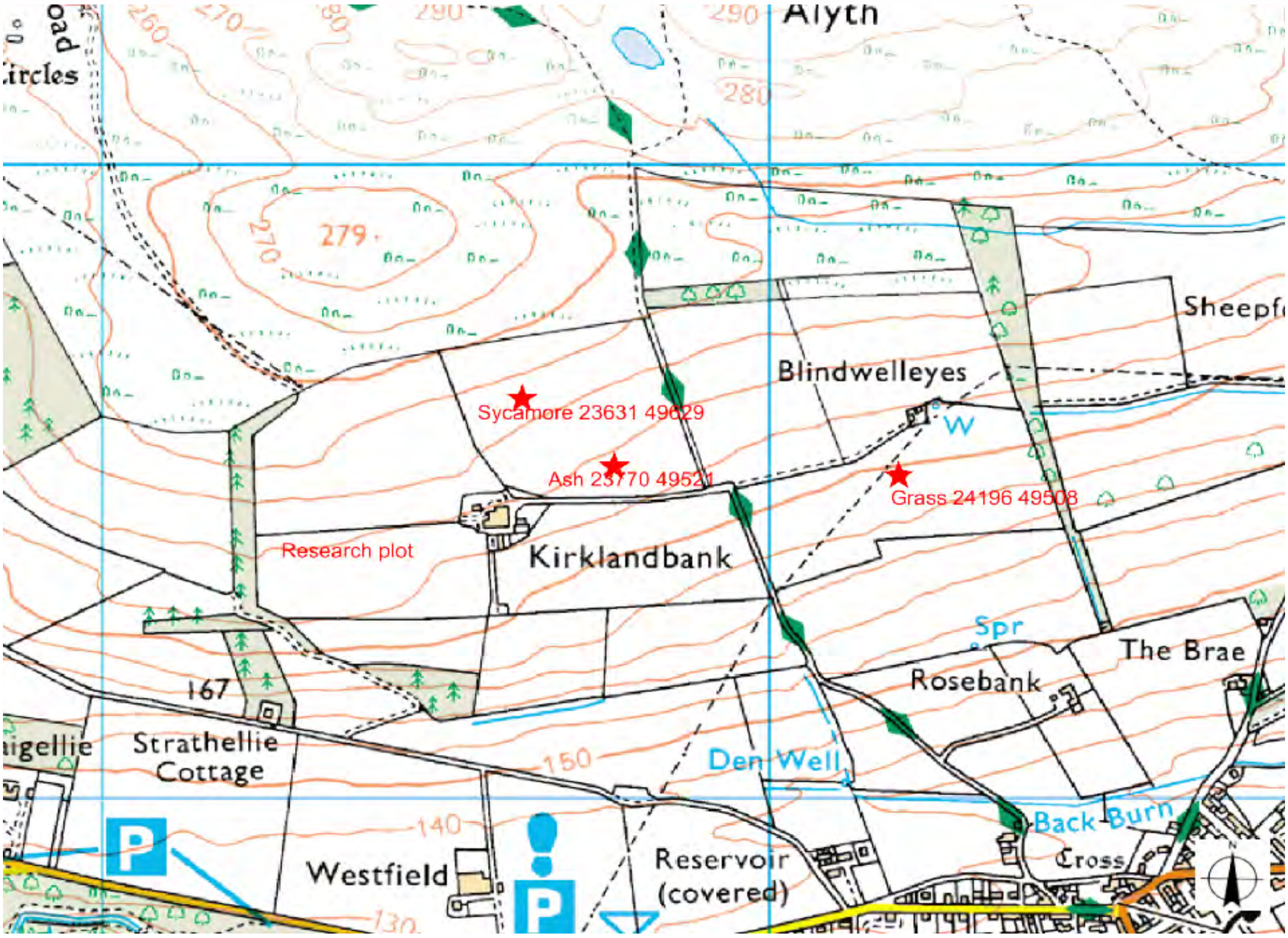


Figure 1 Alyth water use experiment – location of monitoring equipment within experimental plots planted with Sycamore and Ash, and grass control unaffected by SRF planting.

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 data loggers that 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 the three 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.

Results and Discussion

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 on soil water. 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.

Figure 3 shows the change in soil moisture content at the three sites from 2010 until 2015; fluctuations are generally seasonal - the effects of the dry summer of 2013 can clearly be seen.

Soil moisture content is similar at all sites at 5 cm and 10cm depth but is considerably lower at the grass site at 15 cm, 20 cm and 30 cm depths; this can be seen in the annual mean plots (Figure 4) and the depth plots shown in Figure 5. The lower soil moisture content under the grass could be due to the presence of a more developed and deeper rooting system, which allows the grass to use more water or it could simply be due to higher background soil moisture content at the 15 cm, 20 cm, and 30 cm depths within the soil at the grass site. At 40 cm depth the moisture content is similar at all of the sites indicating that the grass roots are not using any more water than the sycamore or ash at this depth; it could be that the roots of the trees and the grass do not extend down to 40 cm as of yet.

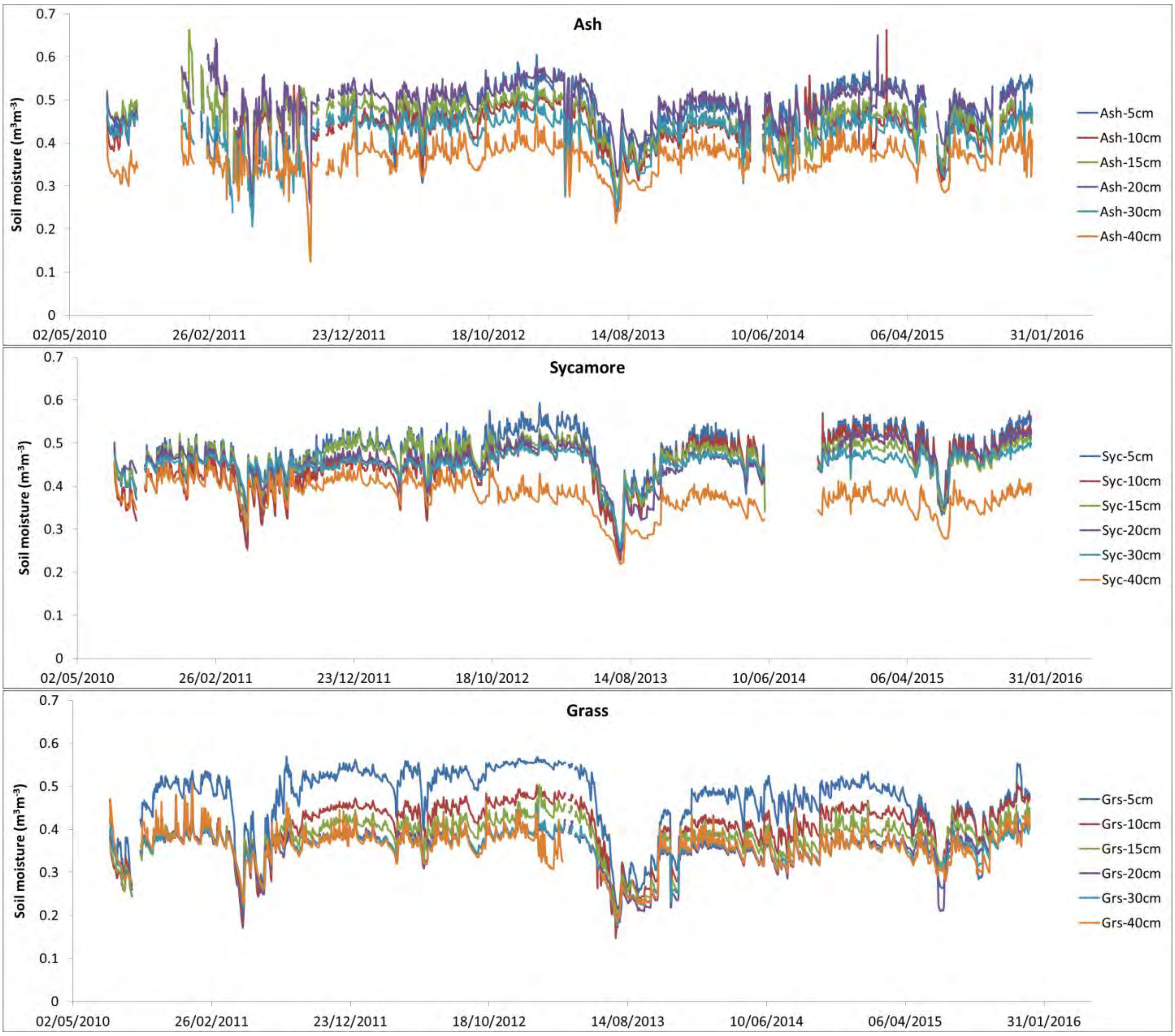


Figure 3 Soil moisture content measured by subsurface soil moisture probes at the Ash and Sycamore SRF sites and at the grass control. Gaps in data are mainly due to electronics malfunctions.

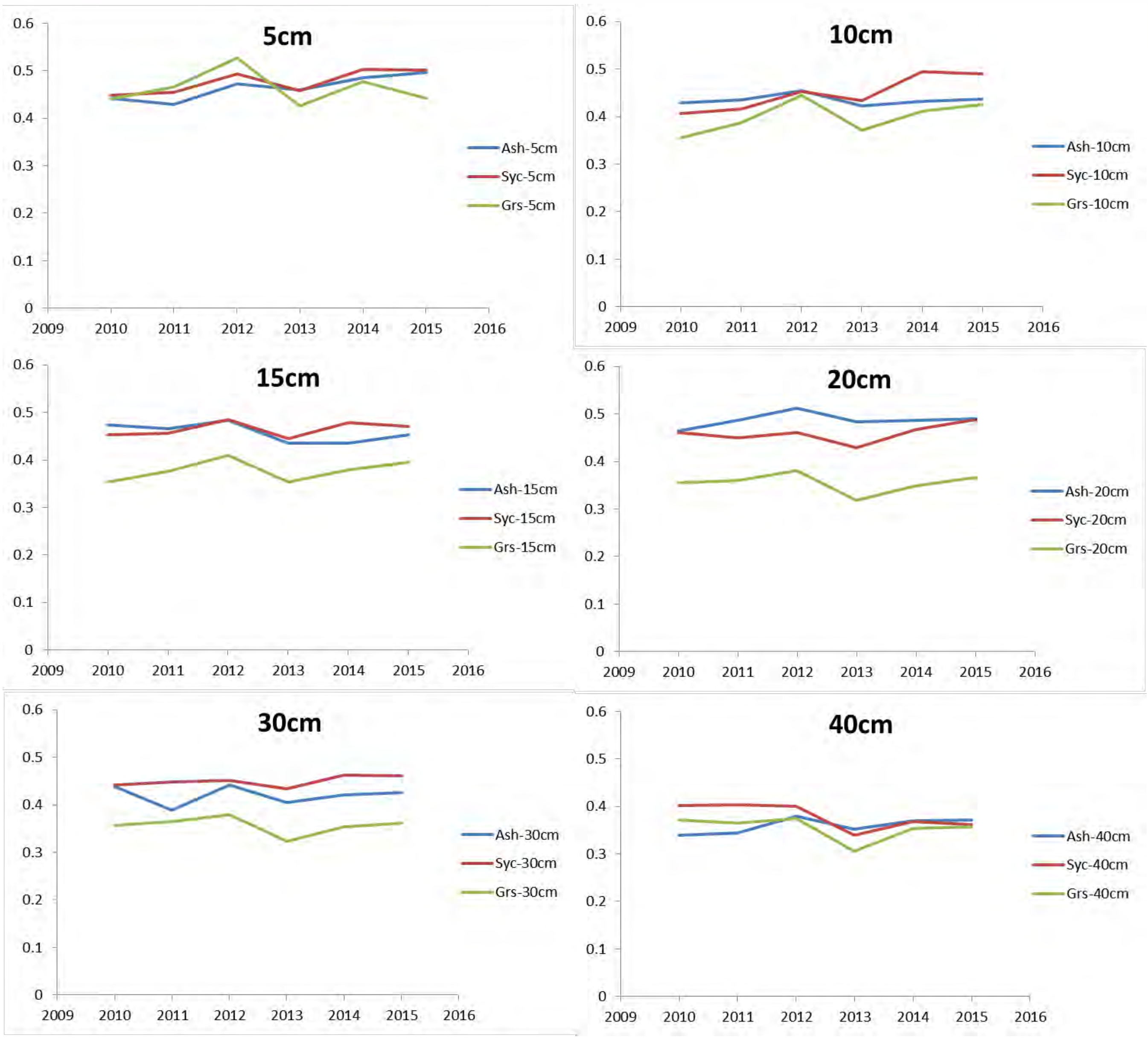
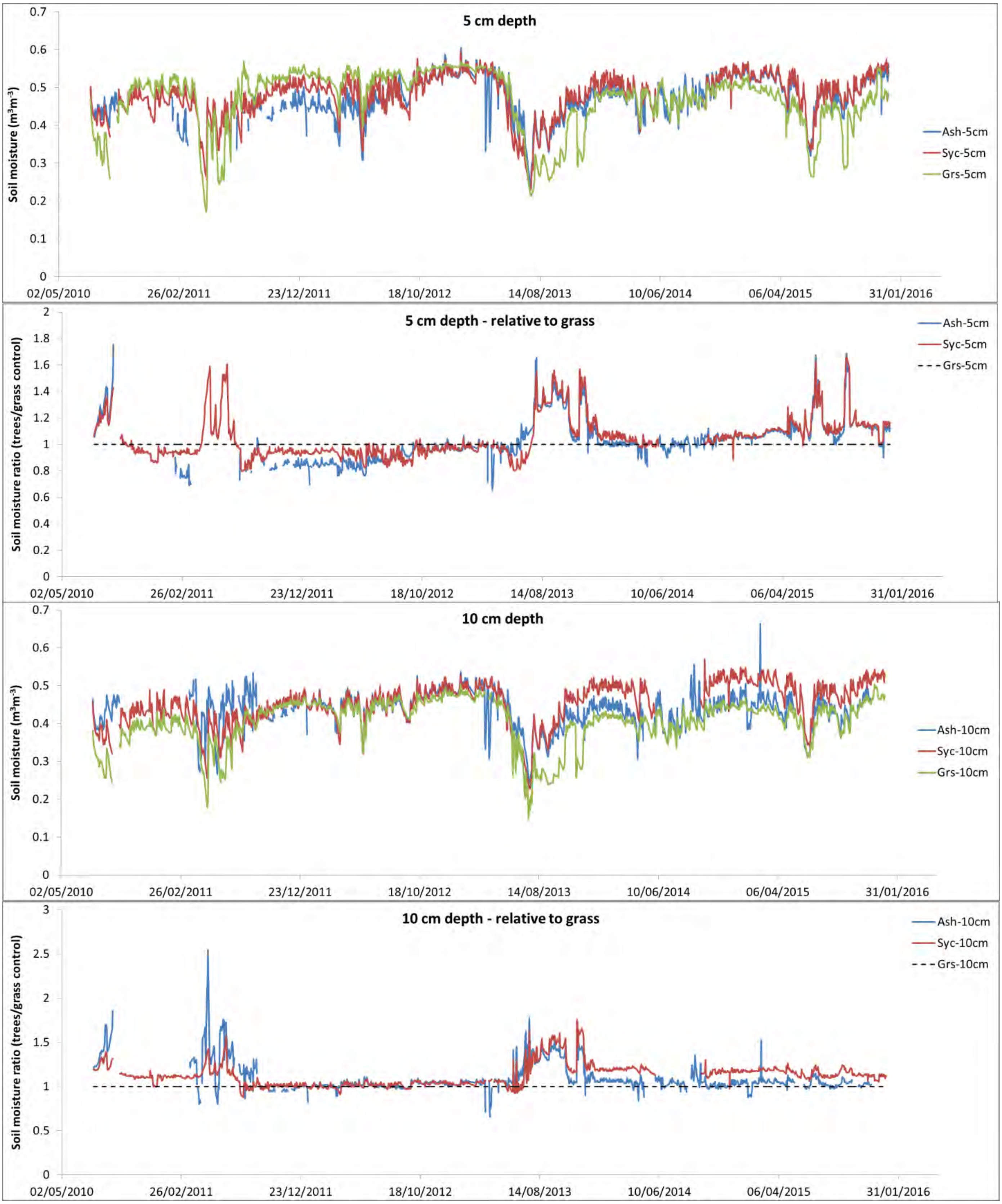
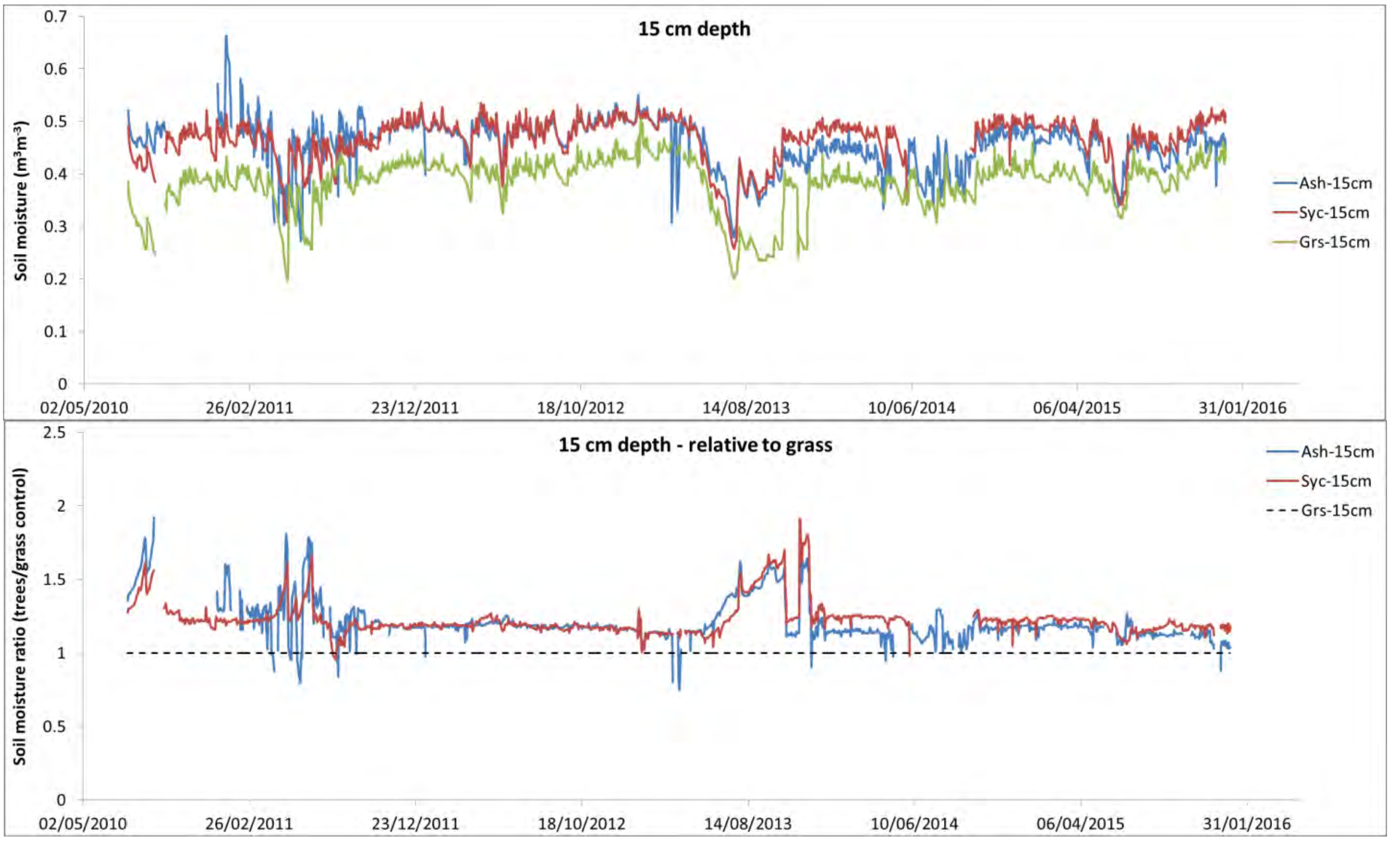
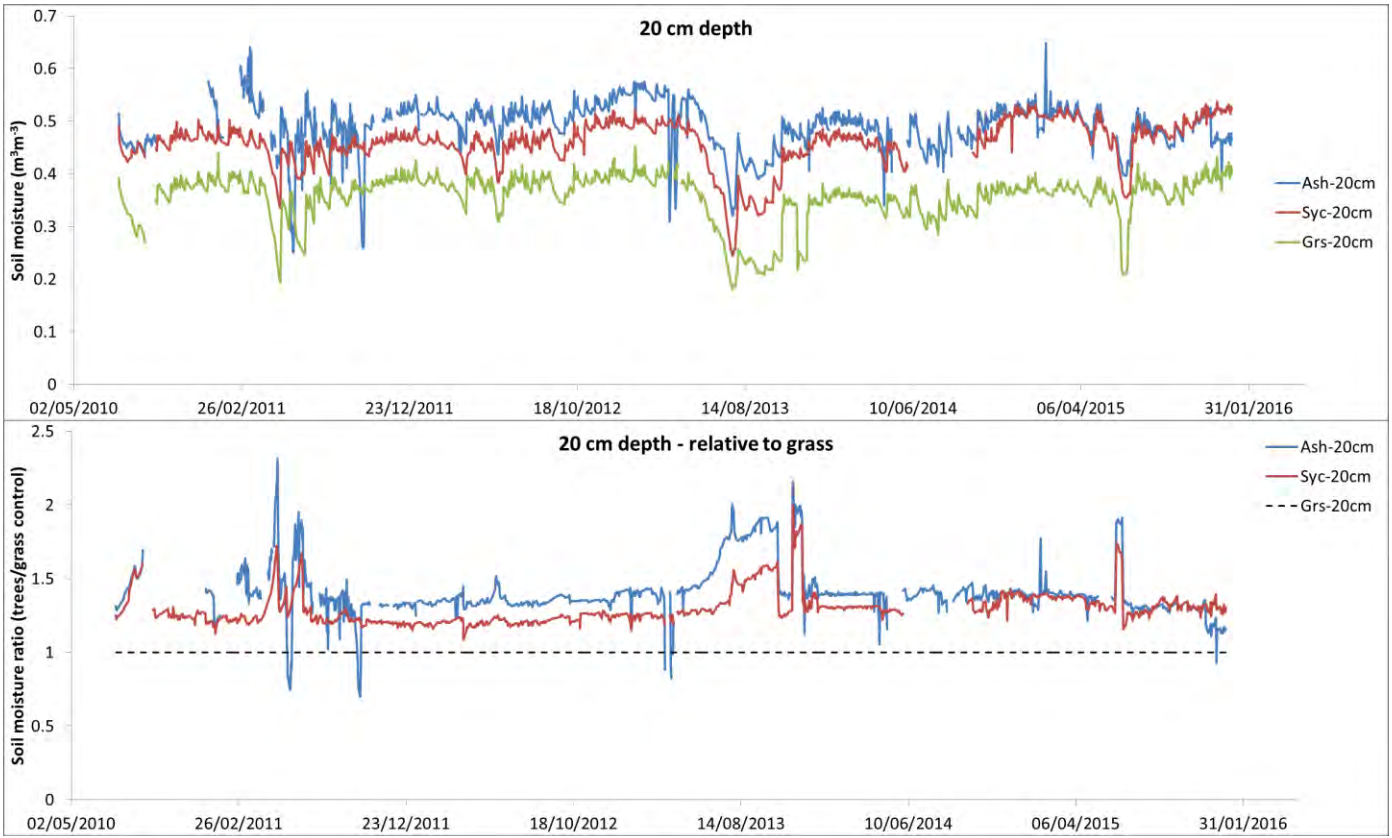


Figure 4 Annual means of soil moisture content at the various depths measured by subsurface soil moisture probes at the Ash and Sycamore SRF sites and at the grass control.


5 cm depth
Soil moisture (m³m⁻³)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
02/05/2010
26/02/2011
23/12/2011
18/10/2012
14/08/2013
10/06/2014
06/04/2015
31/01/2016
Ash-5cm
Syc-5cm
Grs-5cm
5 cm depth - relative to grass
Soil moisture ratio (trees/grass control)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
02/05/2010
26/02/2011
23/12/2011
18/10/2012
14/08/2013
10/06/2014
06/04/2015
31/01/2016
Ash-5cm
Syc-5cm
Grs-5cm
10 cm depth
Soil moisture (m³m⁻³)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
02/05/2010
26/02/2011
23/12/2011
18/10/2012
14/08/2013
10/06/2014
06/04/2015
31/01/2016
Ash-10cm
Syc-10cm
Grs-10cm
10 cm depth - relative to grass
Soil moisture ratio (trees/grass control)
3
2.5
2
1.5
1
0.5
0
02/05/2010
26/02/2011
23/12/2011
18/10/2012
14/08/2013
10/06/2014
06/04/2015
31/01/2016
Ash-10cm
Syc-10cm
Grs-10cm


15 cm depth
Soil moisture (m³m⁻³)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
02/05/2010
26/02/2011
23/12/2011
18/10/2012
14/08/2013
10/06/2014
06/04/2015
31/01/2016
Ash-15cm
Syc-15cm
Grs-15cm
15 cm depth - relative to grass
Soil moisture ratio (trees/grass control)
2.5
2
1.5
1
0.5
0
Ash-15cm
Syc-15cm
Grs-15cm


20 cm depth
Soil moisture (m³m⁻³)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
02/05/2010
26/02/2011
23/12/2011
18/10/2012
14/08/2013
10/06/2014
06/04/2015
31/01/2016
Ash-20cm
Syc-20cm
Grs-20cm
20 cm depth - relative to grass
Soil moisture ratio (trees/grass control)
2.5
2
1.5
1
0.5
0
Ash-20cm
Syc-20cm
Grs-20cm

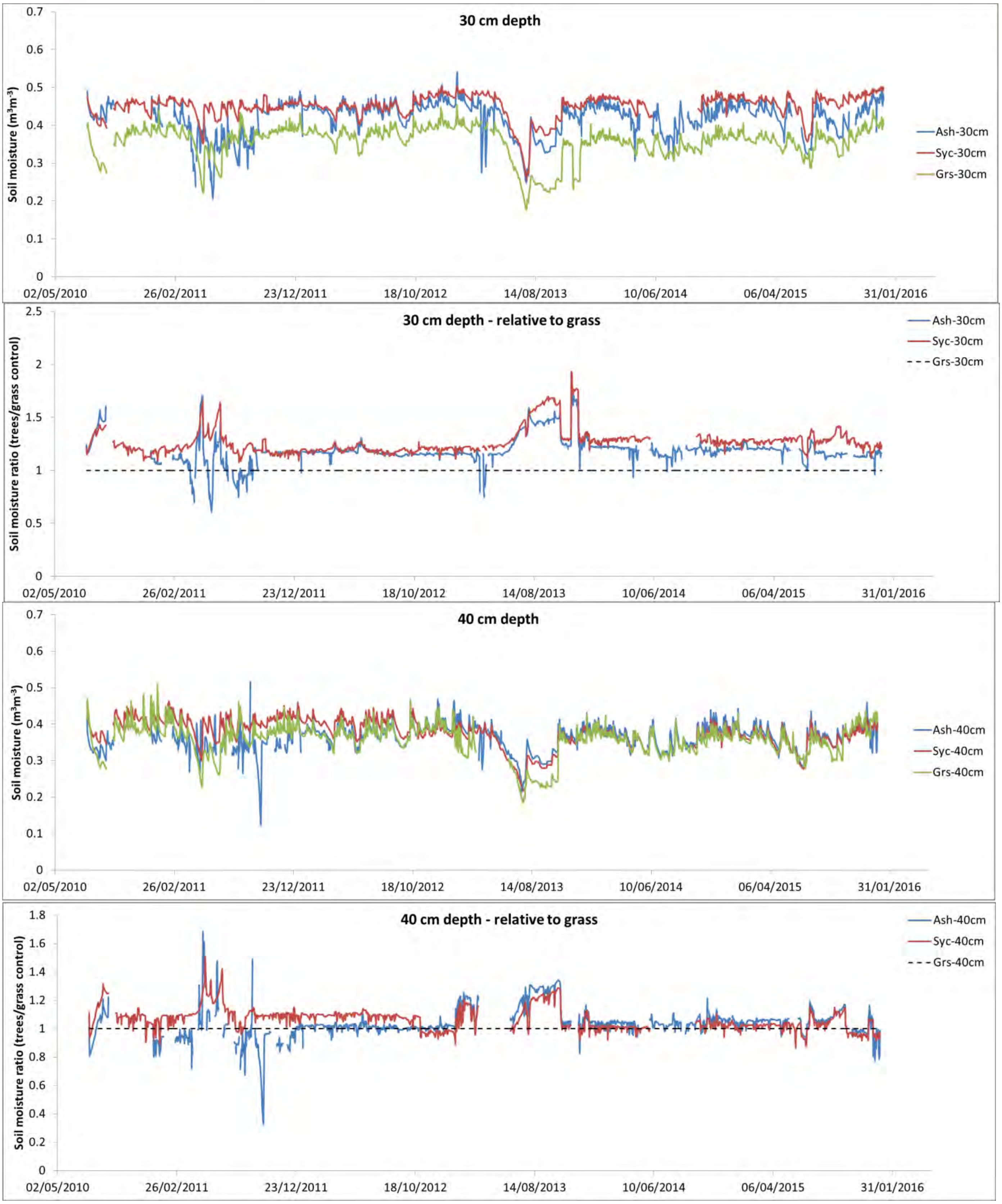


Figure 5 Soil moisture content by depth and relative to the grass control.

The year 2013 was particularly dry with rainfall at only 787 mm compared to over 1000 mm in each of the other years of the experimental record (Figure 6). This gives rise to an interesting trend in summer 2013 where soil moisture decreases more under the grass than under the sycamore or ash (Figure 5).This is most likely because the grass grows fairly long in the summer months and has a higher transpiration requirement than that of the young trees; moreover, the rooting system is likely to be more developed under the grass than the trees and so it is able to access water from deeper and hard to reach places. A similar trend can be seen following dry periods in June and September 2015 but only at 5 cm depth. It will be interesting to see how the soil moisture regime changes as the trees and their roots grow, although in in relation to this we need to be careful to control competing vegetation, otherwise it will be difficult to isolate the effects of tree growth on soil moisture. Moreover, competing vegetation appears to be stunting tree growth and promoting weevil infestations (see main report); therefore, vegetation management is recommended at the ash and sycamore sites.

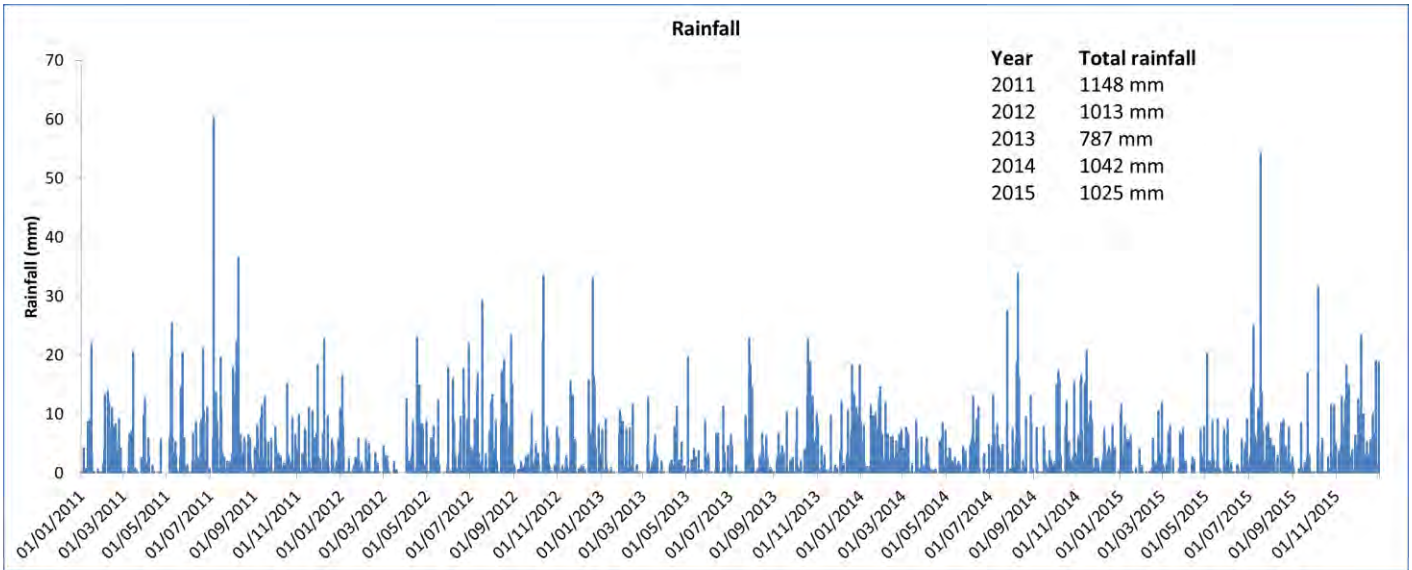


Figure 6 Daily rainfall as measured by raingauges in the sycamore plot.

The tensiometer equipment has suffered from a number of setbacks including subterranean damage by burrowing animals (possibly moles) and electronic malfunctions. In late 2015 some of the tensiometers were found ripped out of the ground and cracked, most likely due to an attack by an animal, perhaps a hare or deer, although the latter is unlikely given the fencing around the trees. An example of the data generated can be seen in Figure 7, which is a plot of the volumetric soil moisture at the sycamore site; dry periods are clearly indicated by increases in soil water tension.

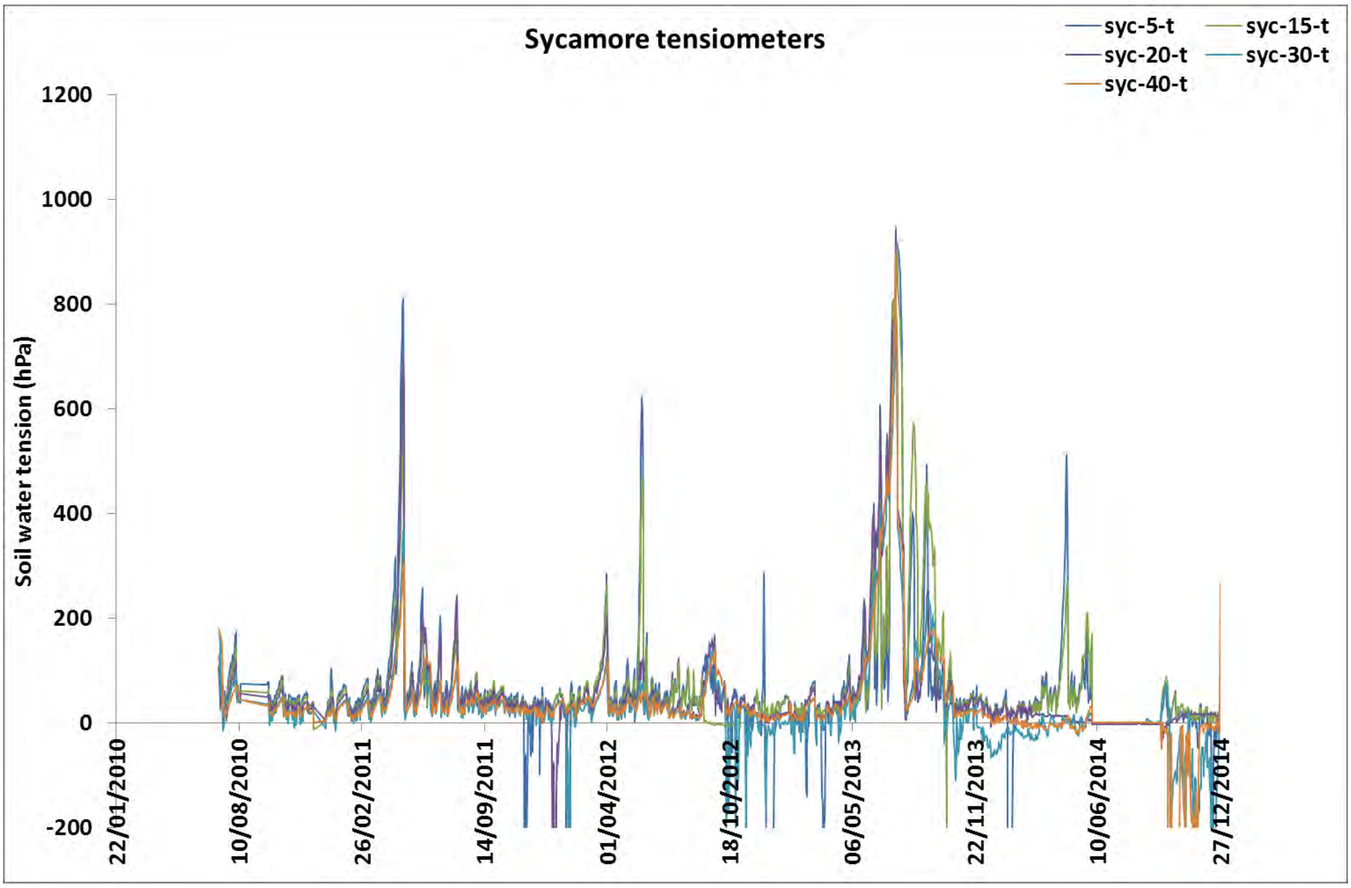


Figure 7 Volumetric soil moisture content measured by tensiometers at the Sycamore SRF site

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 8). 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 9). 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 10).

We took the decision to cease the microbiological analysis in December 2014 mainly because there is little chance that livestock will be put back on to the site. Moreover, the farmer in the adjacent field now pastures livestock on a field adjacent to the Sibster Farm sampling point and this is likely to cause interference with our data. The analysis can be reintroduced if needed.

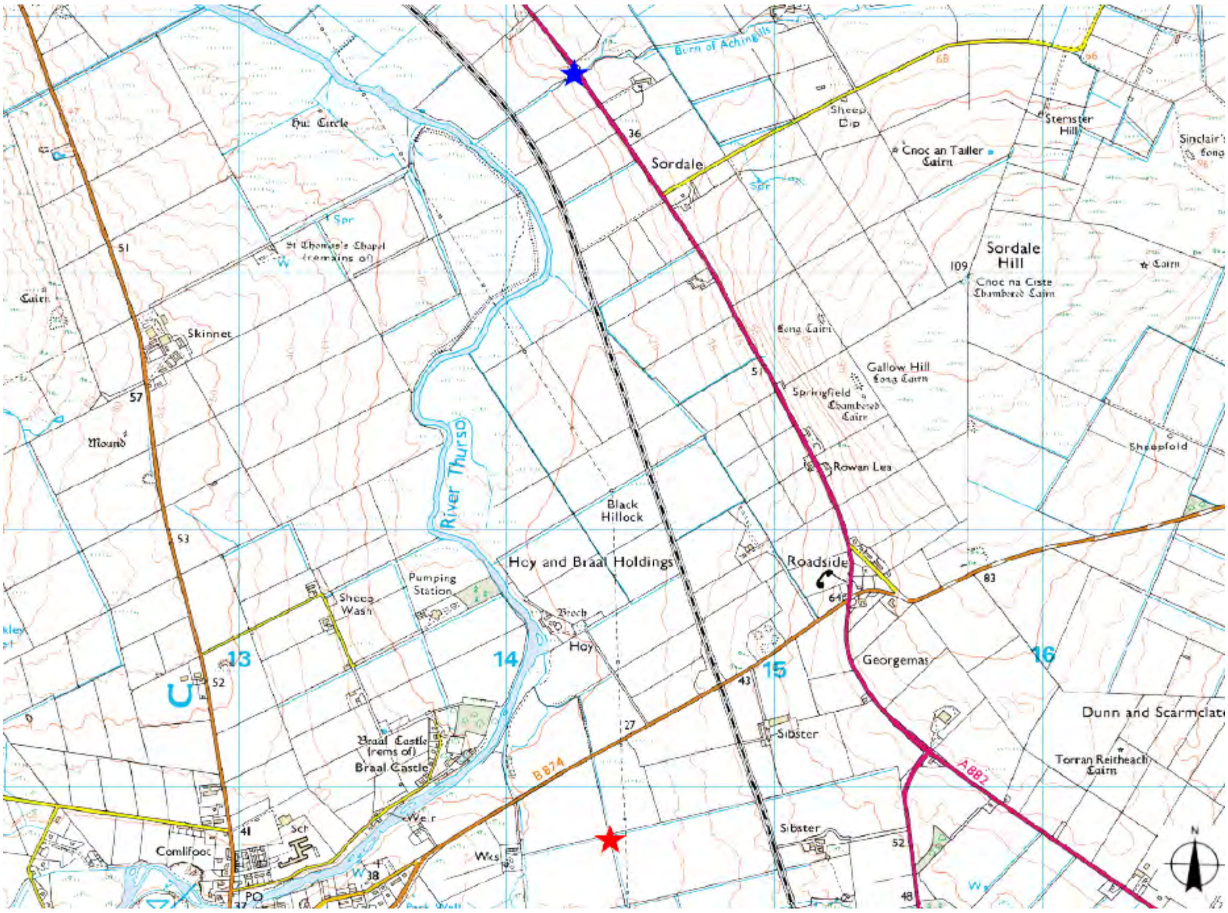


Figure 8 Sibster water quality experiment – Location of water sampling points and water level recorders in operational area on Sibster Farm (ND143 597) and control catchment unaffected by SRF planting (ND142 627).

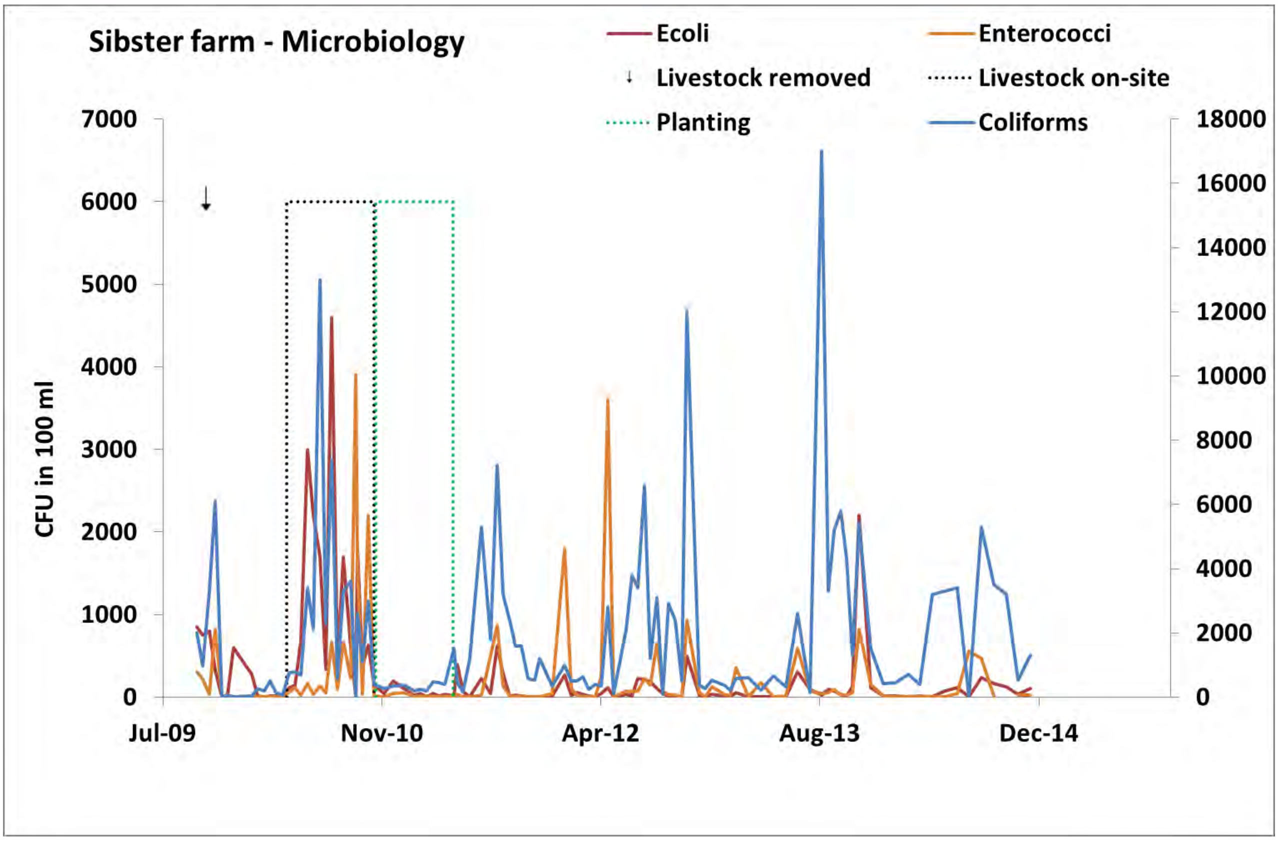


Figure 9 Microbial concentrations in colony forming units per 100ml at the Sibster Farm SRF site. Analysis runs until December 2014.

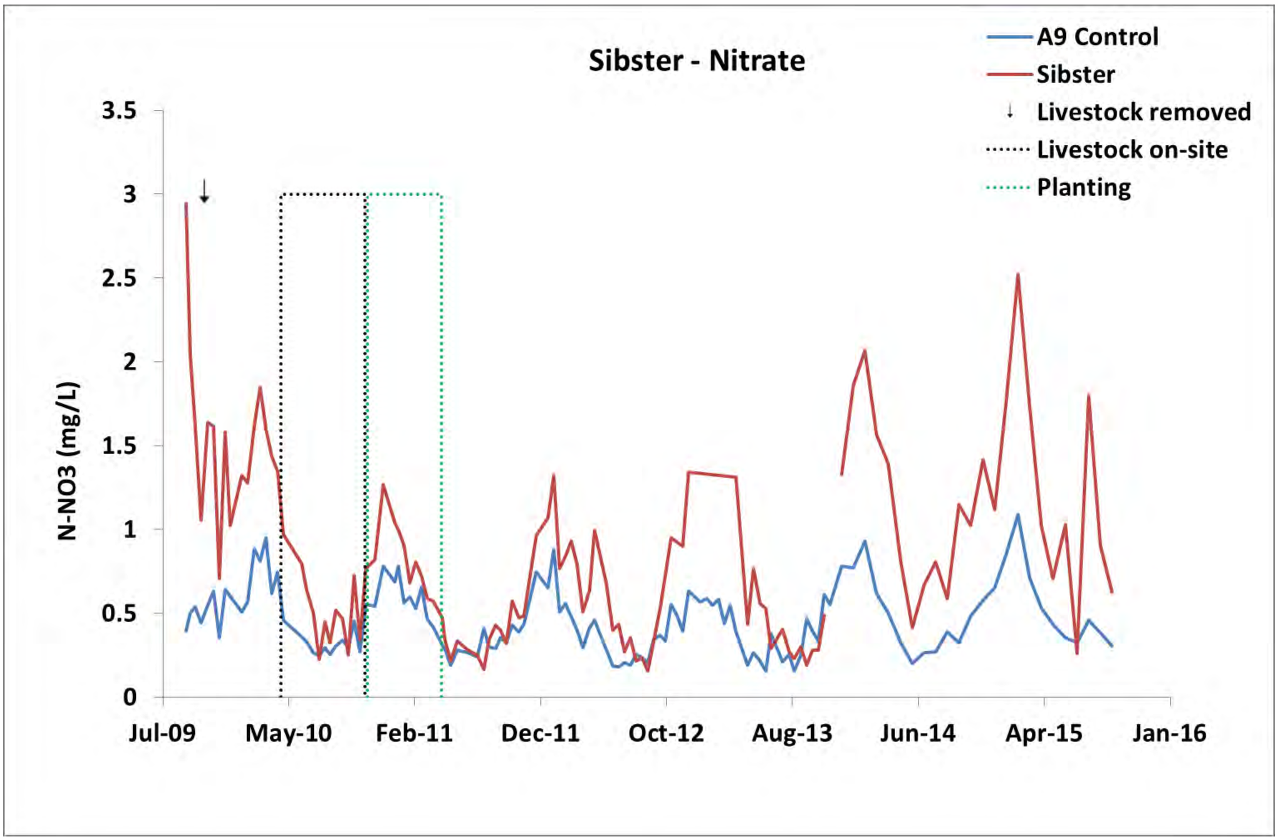


Figure 10 Nitrate concentrations at the Sibster Farm SRF site and the A9 control site.

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 severely affected.

Appendix 2: Full report on the Orkney SRF trials

REPORT TO FORESTRY COMMISSION SCOTLAND ON THE MONITORING OF SHORT ROTATION FORESTRY TRIALS IN ORKNEY DURING 2015

Muddisdale Short Rotation Forestry Trial in Orkney in June 2015

By
Peter Martin
Agronomy Institute
Orkney College (University of the Highlands and Islands)
December 2015

Contents

Executive Summary

- Monitoring of two short rotation forestry (SRF) trials, established in Orkney in 2013, was carried out in 2015 by the Agronomy Institute at Orkney College UHI. The trials are located at Muddisdale (Orkney mainland) and Newfield (on the island of Shapinsay),

- Both trials contain the same 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*.

- At each trial there are 6 plots (each containing 25 plants) of each of the 9 tree species, arranged in a randomised block design with 6 replicates (54 plots in total). Four of the replicates comprise a species trial and the others are single replicate observation blocks, one planted at 1.0 x 1.0 m (instead of the 1.5 m spacing used in the rest of the trial) and the other using a polythene mulch square (0.6 x 0.6 m) around each tree at planting to reduce weed competition.

- Tree survival and height were recorded on the 9 innermost plants of each plot at the end of the 2015 growing season.

- Tree survival over the 6 replicates continued to be high (98%) at Muddisdale but has dropped considerably at Newfield, from 96% in 2014 to 76% in 2015. Survival at Newfield was lowest in sycamore (31%), beech (57%), mountain ash (61%) and whitebeam (67%).

- Averaged over all species, trees in the species trial were taller at Muddisdale than Newfield (97 cm compared with 76 cm). At Muddisdale, the tallest species were Italian alder, common alder and goat willow with mean heights ranging from 146 to 148 cm and these were followed by aspen (135 cm) and whitebeam (124 cm). The 4 tallest species at Newfield were common alder (112 cm), goat willow (98 cm), aspen (95 cm) and downy birch (85 cm). At both sites, sycamore, mountain ash and beech were the shortest species (40-53 cm at Newfield and 55-73 cm at Muddisdale).

- Compared with growth during 2013 and 2014, increases in height of most species were much less in 2015, particularly at Newfield. At this site, the height of goat willow was considerably reduced by die back. There has been almost no increase in height of sycamore, whitebeam and mountain ash at Newfield over the 3 years.

- Poor growth in 2015 can probably be attributed to wind, low temperatures, high rainfall and low sunshine hours during the first half of the growing season. At Newfield, it is likely that these effects were aggravated by the greater exposure of the site, poorer weed control and possibly by very high soil moisture over much of the growing season.

- At both sites, the mean heights of species in the replicates planted with a 1.0 x 1.0 m spacing and with polythene mulch were similar to those in the main species trials.

- There are some interesting differences and similarities in the performance of tree species starting to appear at the two Orkney sites:
    - There are common species at both sites amongst the tallest and shortest species (tallest: goat willow, common alder and aspen; shortest: sycamore, beech and mountain ash).
    - While survival is still good amongst the shortest species at Muddisdale, it is much lower amongst them at Newfield.
    - Relative to the growth and survival of species at Muddisdale, downy birch has performed better at Newfield while Italian alder and whitebeam have performed worse.

1 Introduction

Between November 2011 and December 2013 Forestry Commission Scotland (FCS) provided funding to the Agronomy Institute (AI) at Orkney College UHI to work with local stakeholders to start investigations into the potential of short rotation forestry (SRF) in Orkney. Protocols for establishing trials, including the selection of species, were developed with the Orkney Woodland Group (OWG) and FCS and in 2013 two trials were established - one at Muddisdale (near Kirkwall on Orkney mainland) and one at Newfield (on the island of Shapinsay). Survival and growth of the trees were monitored and reported at the ends of 2013 and 2014. The current report provides information on the growth and survival of trees in 2015, their third field season.

2 Trial Sites, Management And Experimental Design

2.1 Trial Sites And Management

The trial sites were located at Muddisdale (HY 435 110) on land owned by Orkney Islands Council and Newfield (HY 516 181) on land belonging to Balfour Mains farm. Over the winter 2014/15, the residual herbicide Kerb Flo was applied at both sites at 3.75 l ha^{-1}. At Muddisdale, weeds were further controlled by topping and strimming in June-July 2015 so that weed control was good for most of the growing season (see cover photo and Photo 1, p. 13). No further weed control was carried out at Newfield and, by July, there was vigorous growth of grass and creeping buttercup (Photo 2, p.13). Over the winter 2014/15, the majority of the spiral guards were removed at Newfield because of the problem which several species (beech, mountain ash and sycamore) had in growing out of them. At Muddisdale, these were removed, where necessary, early in summer 2014. This problem was described in the 2014 report.

2.2 Experimental Design

This was described fully in previous reports and only a brief summary is provided here.

Both trials (see Appendices 1 and 2) had the same layout and consisted of plots of 25 trees (5 x 5) of 9 different 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*). The trials used a randomised block design in which plots were arranged in 6 replicates (each containing one plot of each species) as follows:

- A species trial consisting of 4 replicates.
- An observation block (1 replicate) with trees planted at a closer spacing (1.0 x 1.0 m, instead of the 1.5 x 1.5 m used in the remainder of the trial).
- An observation block (1 replicate) with each tree planted in the middle of a polythene mulch square (0.6 x 0.6 m) to reduce weed competition.

2.3 Methods Of Measurement

As in previous years, tree height was measured from ground level to the tip of the top leaf or shoot. In each plot of all replicates, tree height and survival were recorded on the 9 plants in the centre of each plot. Data were collected on 28 September at Muddisdale and 16 October at Newfield. For presenting data, the mean height of surviving trees was calculated for the measured trees in i) the species trial (reps 1 to 4); ii) the replicate planted at 1.0 x 1.0 m spacing; and the polythene mulch replicate.

3 Results

Observations On Trials

Frequent visits were made to the Muddisdale site but Newfield was only visited in July and October 2015.

Cold weather and strong winds in the early part of the growing season resulted in leaf scorch and a die back of new shoots on Italian alder and aspen at Muddisdale, but by July trees were recovering from this. Many of the downy birch trees also experienced a partial loss of foliage but it was not clear what caused this. Weed control at Muddisdale was good and the grass between trees was strimmed in July.

As in previous years, growth of grass and other plants was much denser throughout the season at the Newfield site. When the site was visited at the end of July, dieback of new shoots was common on willow (Photo 4, p.14), aspen, Italian alder and whitebeam (Photo 6, p. 15). Downy birch also suffered from the same partial defoliation which occurred at Muddisdale. Visually, most species at Newfield appeared to be challenged by the 2015 growing conditions, but the best canopy development was in common alder (Photo 2, p.13). Socketing of some of the goat willow trees was observed in October and so it is likely that some of these trees will be lost in future years.

Although not included as a formal part of the trial, a perimeter windbreak of 3 rows of biomass willows was planted at Newfield in the same year as the trial was planted. Establishment of these plants has been good and growth is good with an average height of about 1.6 m and a maximum height of about 2.2 m (Photo 3, p.14).

3.2 Tree Survival And Growth At Muddisdale

Averaged over all core trees in the species trial, the average height and survival at Muddisdale was 110 cm and 98%, respectively. Fig. 1 shows the survival of trees at Muddisdale in September 2015 and their average height at the end of each season since planting. The trends established in previous growing seasons continued and Italian alder (Photo 8, p. 16), common alder, aspen (Photo 7, p. 16) and goat willow were the tallest species; sycamore, beech and mountain ash were the shortest, and whitebeam (Photo 5, p.15) and downy birch were intermediate. Most species, except whitebeam, had a much smaller increase in height during 2015 than in 2014. Survival of all species was good and was above 95%.

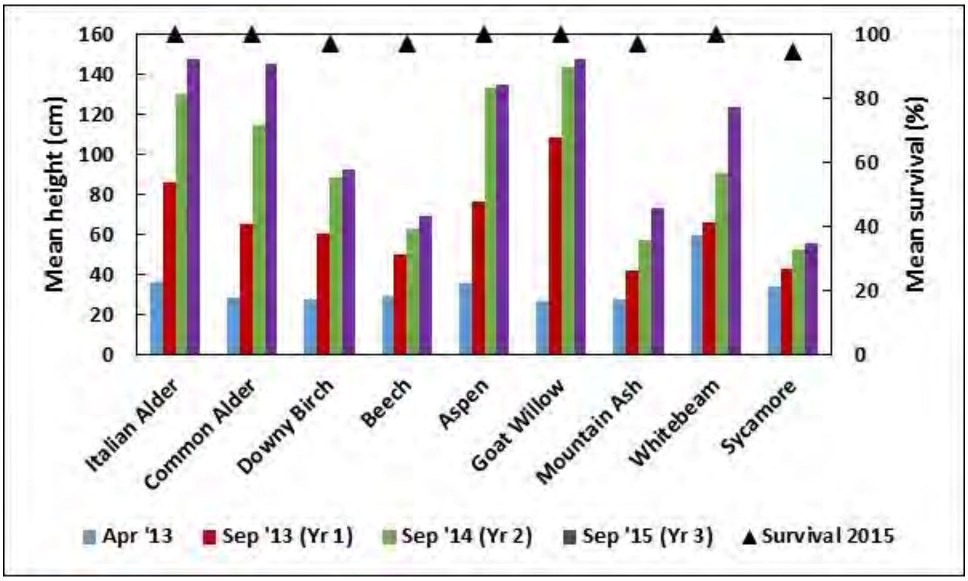


Fig. 1. Mean tree height in the species trial at Muddisdale at the end of each season since planting and survival in September 2015.

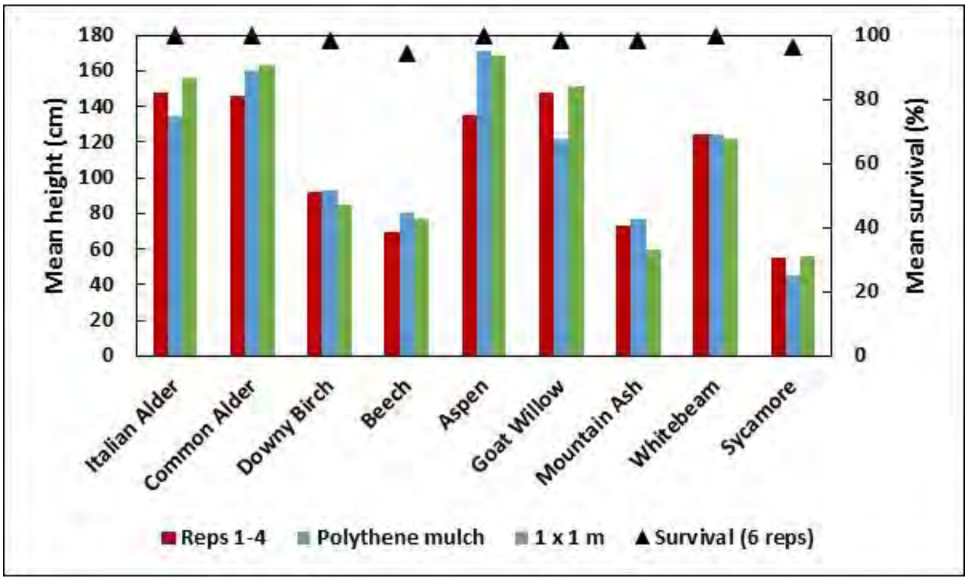


Fig. 2. Mean tree height in the species trial (Reps 1-4), polythene mulch and 1.0 x 1.0 m spacing replicates at Muddisdale in September 2015 and survival over the 6 replicates.

Fig. 2 compares mean tree height for each species in September 2015 in the species trial (Reps 1-4) with that for the polythene mulch and 1.0 x 1.0 m spacing replicates. For each species, mean tree heights were similar in the three treatments. Survival in Fig. 2 was calculated for the 54 core trees of each species across the 6 replicates and was lowest for beech (94%) and sycamore (96%).

3.3 Tree Survival And Growth At Newfield

Averaged over all core trees in the species trial, the average height and survival at Newfield was 73 cm and 75%, respectively. Fig. 3 shows the survival of trees at Newfield in September 2015 and their average height at the end of each season since planting. The tallest species were common alder, goat willow, aspen and downy birch; Italian alder and whitebeam were of intermediate height while beech, mountain ash and sycamore were the shortest species. Tree survival was highest for goat willow, aspen, common alder, downy birch and Italian alder (all above 80%) and lowest for beech and sycamore (44% and 31%, respectively); survival in mountain ash (61%) and whitebeam (69%) was intermediate. Most species made very little growth over 2015; the loss of height of goat willow compared with 2014 was caused by dieback of the main shoots (Photo 4, p.14). It is also clear that sycamore, whitebeam and mountain ash have hardly increased in height since they were planted.

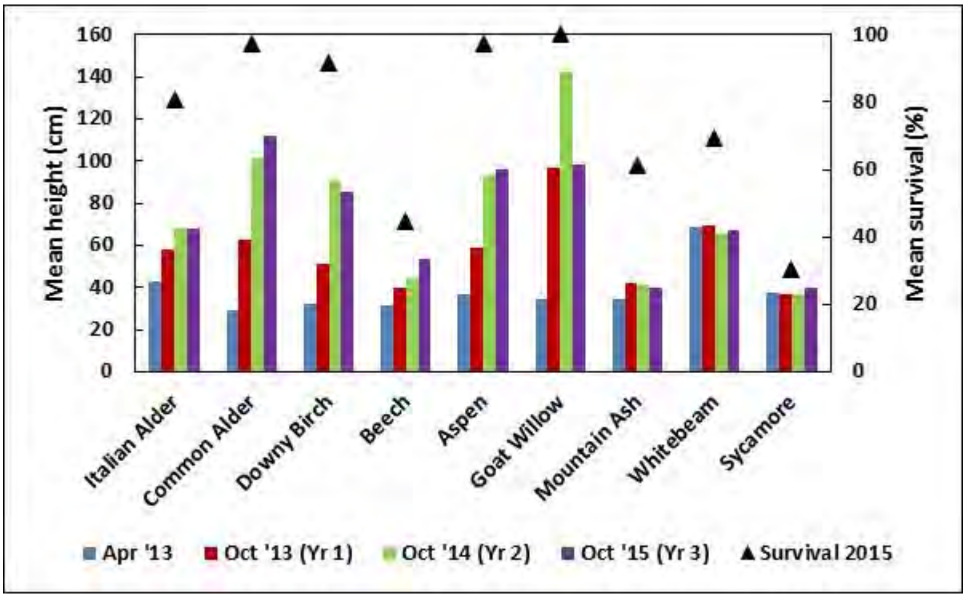


Fig. 3. Mean height of trees in the species trial at Newfield at the end of each season since planting and survival in September 2015.

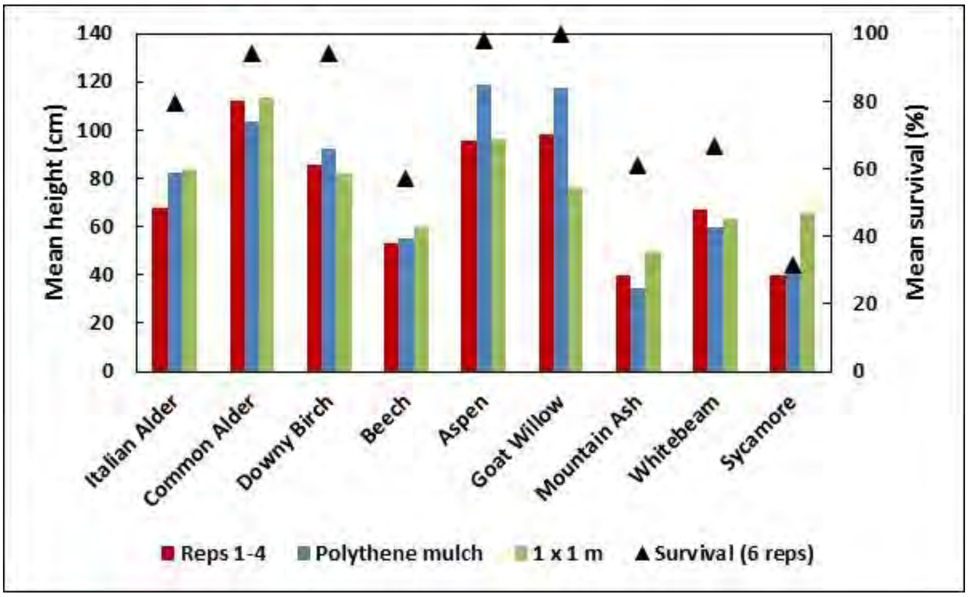


Fig. 4. Mean height of trees in the species trial (Reps 1-4), polythene mulch and 1.0 x 1.0 m spacing replicates at Muddisdale in September 2015 and survival over the 6 replicates.

Fig. 4 compares mean tree height for each species in October 2015 for the species trial (Reps 1-4) with that for the Polythene mulch and 1.0 x 1.0 m spacing replicates. For each species, mean tree heights were mostly similar in the three treatments, although aspen and goat willow grew tallest in the polythene mulch treatment. Survival in Fig. 4 was calculated for the 54 core trees of each species across the 6 replicates and was particularly low for sycamore (31%). Averaged over all species, survival has decreased considerably in the last year, from 96% in 2014 to 76% in 2015.

3.4 Comparison of Survival and Growth at Muddisdale and Newfield

Tree survival and growth in each of the species trials (replicates 1 to 4) at Muddisdale and Newfield are shown in Fig. 5. It is clear that most species have grown and survived better at Muddisdale. At both trials, the highest survival and best growth occurred with common alder, aspen and goat willow while sycamore, mountain ash and beech had the poorest growth. These last species also had much lower rates of survival at Newfield. Italian alder and whitebeam performed well at Muddisdale, but have not done as well at Newfield. Downy birch appears to have been least affected by differences between the two sites and its growth and survival were only slightly reduced at Newfield.

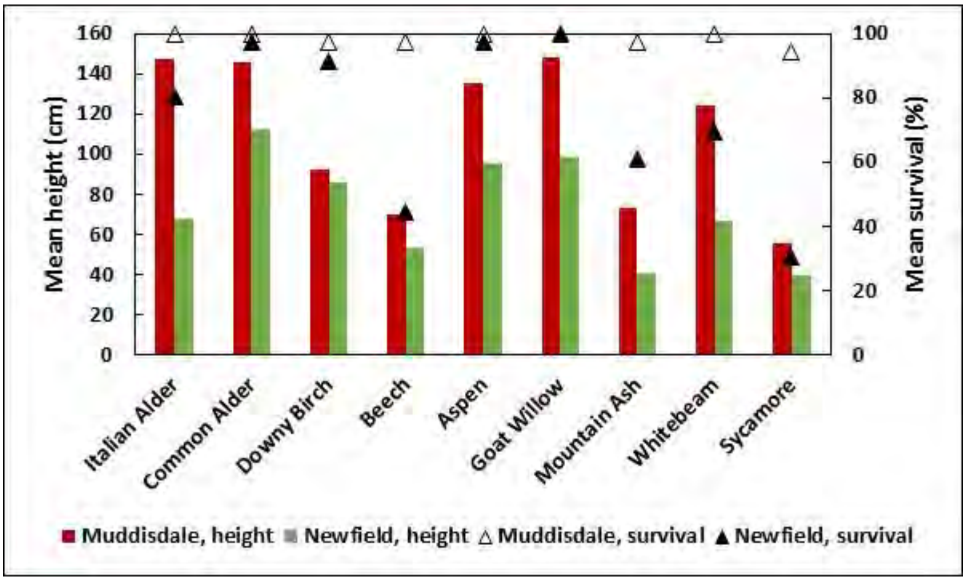


Fig. 5. Comparison of mean tree height and survival in the species trial (Reps 1 to 4) at Muddisdale and Newfield.

Discussion

Growing conditions in 2015 were markedly less favourable than in previous years, especially in the first half of the growing season. This can be seen from comparisons of 2015 values for temperature, rainfall and sunshine with the averages for 2000 to 2014[1]. The average temperature for May to July was 10.4^{o} C in 2015 compared with an average of 11.4^{o} C, rainfall from May to August was 439 mm in 2015 compared with an average of 218 mm and there were 643 h of sunshine from May to September 2015 compared with an average of 723 h. The poorer growing conditions in 2015 would have contributed significantly to the less vigorous growth of trees at both sites. The high rainfall may have had a more severe effect at Newfield as the soil seemed much closer to saturation (visual estimate) during site visits in July and October than at Muddisdale. It is also likely that the Newfield site is more exposed and, as in previous years, weed growth was more vigorous at Newfield throughout the growing season. These factors are all likely to have contributed to the poorer survival and growth of trees at Newfield.

There are some interesting similarities and differences in the relative performance of tree species emerging from the two trial sites. At both sites, the poorest performing species for height are the same - sycamore, mountain ash and beech - but, at Newfield, their survival has been much worse than at Muddisdale. At Muddisdale, the tallest species are Italian alder, common alder, goat willow and aspen. Italian alder has performed much poorer at Newfield, but common alder, goat willow and aspen are also the tallest species at this site. At both sites, downy birch and whitebeam fall in an intermediate category but while downy birch has performed similarly at both sites, the survival and growth of whitebeam has been much poorer at Newfield.

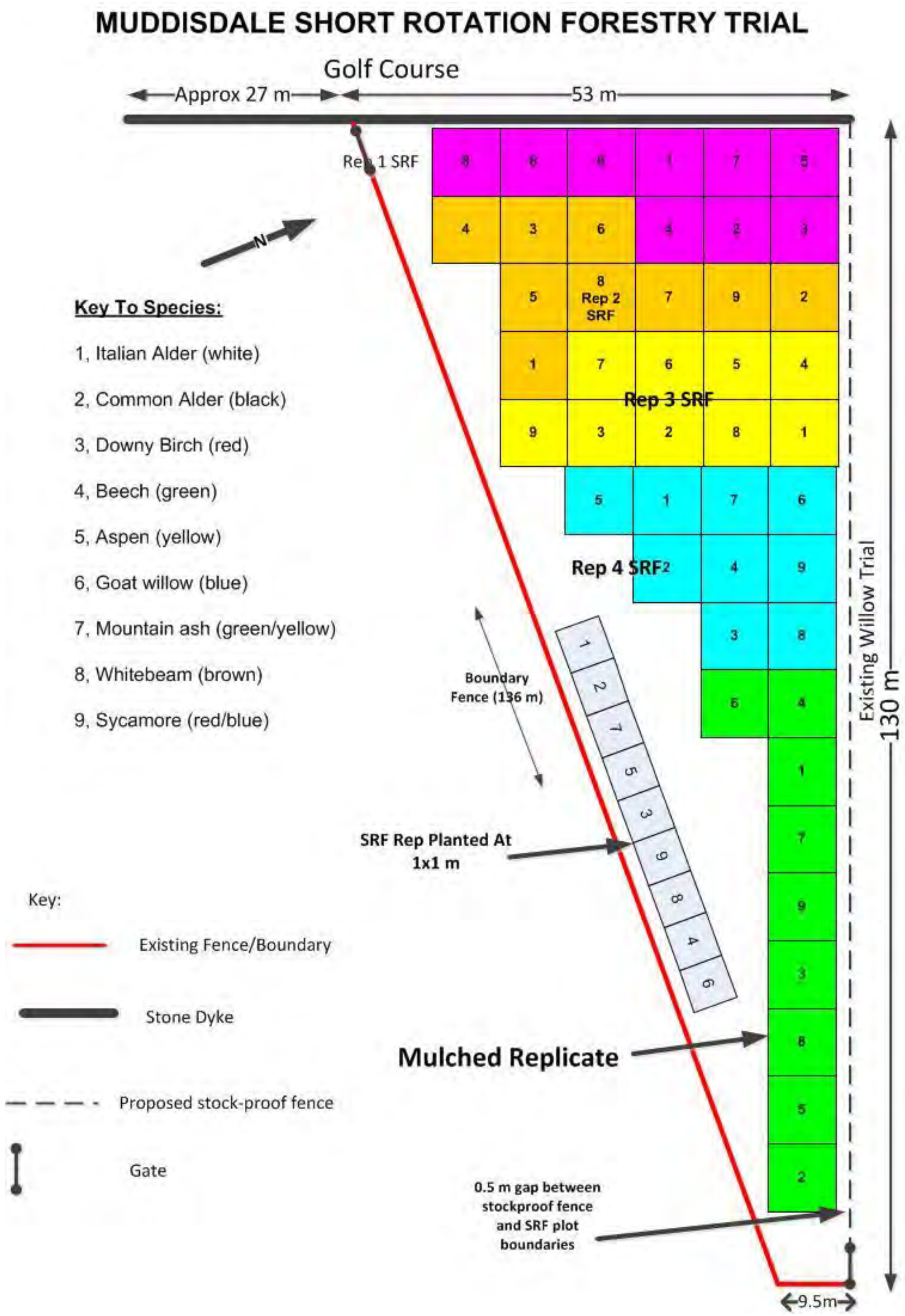
Although not a part of the trial, it is notable at Newfield that the biomass willows in the perimeter windbreak have grown well in comparison with other species.

[1] Temperature and rainfall data were obtained for Kirkwall airport and hours of sunshine from the Loch of Hundland climate station.

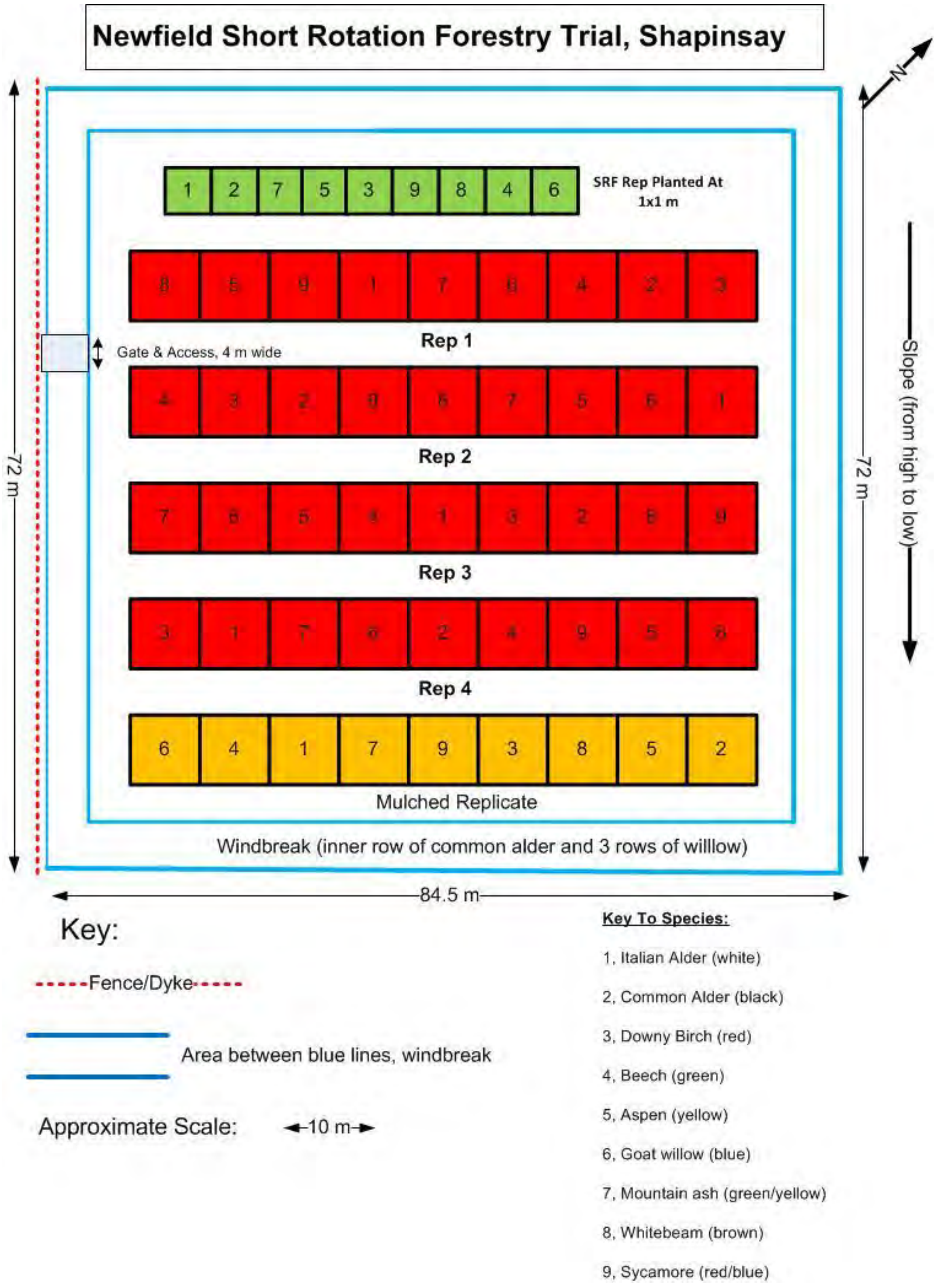
Acknowledgements

The author is very grateful to Forestry Commission Scotland and, in particular, John Risby for his enthusiastic support and interest in these trials. He would also like to thank John Wishart for management of the Muddisdale trial and Jean-Baptiste Bady at Balfour Castle for his help during visits to the Newfield trial.

Appendix 1. Plan Of The SRF Trial at Muddisdale



Appendix 2. Plan Of The SRF Trial at Newfield



Appendix 3. Photographs

Photos 1 (top) and 2 (bottom). The difference in weed growth in October 2015 at Muddisdale (top) and Newfield (bottom). Both photographs show common alder in the middle distance (1.0 x 1.0 m spacing at Muddisdale and 1.5 x 1.5 m spacing at Newfield)**.**

Photos 3 (top) and 4 (bottom). Willow windbreak at Newfield (top) and goat willow at Newfield (bottom) recovering from dieback.

Photos 5 (left) and 6 (right). Whitebeam growing at Muddisdale (left) and Newfield (right). Note the defoliation on the top branches of the Newfield tree.