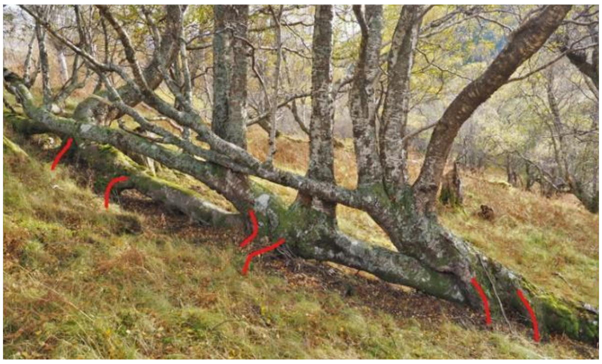
<u>The Ecology of Scotland's Wonderful Recumbent or "Phoenix" Trees</u>



Richard Worrell

Commissioned by Patsy Wood Trust, Scottish Forestry Trust and Sustainable Forestry SCIO

2019

Contents

Acknowledgements
This project was funded by Patsy Wood Trust, Scottish Forestry Trust, and Sustainable Forestry SCIO. The report is dedicated to the memory of Patsy Wood, who would have taken huge delight in phoenix trees. I wish to thank my wife Elizabeth Leighton and James Reny for help with fieldwork; and Ormugandr Melchizedek for interesting discussions about weird aspects of tree physiology. I am grateful to Peter Quelch for showing me the site at Taynish and Gordon Gray Stevens for hosting us at Old Poltalloch. Our work was also supported by Falkland Stewardship Trust who handled the finances.

Summary

Mature trees in Scotland's windy climate blow over, and a proportion continue to grow in this new "recumbent" position. These develop unusual and intriguing structures, and survive courtesy of unlikely physiological adjustments in their new positions. The term "phoenix tree" has been coined to describe them. This report makes the case that phoenix trees represent a useful and significant adaptation; akin to the critical ability of broadleaved trees to coppice.

The project investigated the occurrence, structures and ecological significance of phoenix trees based on 141 examples from 8 sites in the Scottish Highlands. The aim is to establish a basic understand phoenix trees, increase awareness amongst professionals and the public, and encourage appropriate management practices. The project focusses on native broadleaved trees, but other species were recorded when encountered.

Three aspects fundamentally determine the characteristics of a phoenix tree i.e.: 1) the manner of failure of the stem or roots when it falls; 2) the new position of the stem – whether it is lying on the ground, propped by its branches or suspended by a tree or rock; and 3) the structure of the re-growing crown and stems i.e. what growth forms these adopt. Data were recorded to capture these main aspects, and to describe the characteristics of the root plate; any new adventitious rooting; the estimated time period of trees in their new position; and the site type and habitat. In addition, basic information on the value of phoenix trees for lichens was recorded.

Most trees fail by the rooting plate lifting (58%). Usually 50-75% of the roots are severed in this process. Another 25% of trees collapse gradually over time into a new position without fracturing the soil surface ("wrenched trees"). One unusual form of failure is for the stems of upright trees to split in half longitudinally then collapse ("half-trees" - 2% of trees). About 7% of tree were collapsed coppice, where stems fail at the point of union with the stool. Fallen trees sustain damage as a result of falling, by breakage of stems and branches, browsing of the prostrate crown; by shading from surrounding trees and bracken.

Fallen trees can be supported in their new positions in 3 ways i.e.: 1) "grounded" i.e. the original stem lies in contact with the ground (64%); 2) "propped" off the ground by the trees own branches (27%); and 3) "suspended" off the ground usually by another tree or a rock (9%). Being grounded is important for those trees that can form adventitious roots from grounded stems. The resistance of grounded stems to rot appears to be remarkable, with trees thriving in this state for at least 50-80 years, including unlikely species like birch, alder and willow where the timber is known to be non-durable. For a structure designed to be vertical and surrounded by air, the stems of phoenix trees appear to function surprisingly well horizontal on the ground and permanently damp. In propped trees, the branches often remain alive despite many having no twigs nor foliage, and respond to the loading they are under by continuing to thicken.

The new regrowth of trees can take several forms depending mainly on:

- where the new growth emerges ; i.e. from the stem, major branches, or by reorientation of the existing crown.
- the density of new stems: many new stems give the appearance of a hedge; fewer stems take the form of new trees.
- the degree to which new growth comes to dominate over the original tree crown.

Five main categories of phoenix tree structure are proposed. "Hedge phoenix" trees (22%) are where a large number of new upright shoots / stems appear from the trunk. "New-tree phoenix" is where new upright stems develop in the form of a new tree. New-tree phoenix trees can grow to be very large and old, and stems were recorded 15-22 m tall old since falling. "Crown phoenix" trees (30%) are where most of the new growth develops from the original crown, with only subtle changes of overall structure. "Double phoenix" trees are where trees blow over and regrow, then blow over a second time and start to regrow again (9% of trees). These remarkable trees were first recorded in this study and interestingly seem to remain serviced mainly by the original rootplate, which survives both windblow events. "Complex phoenix" trees were seen a small proportion of trees (6%); these expand in several directions, with stems and branches developing multiple new rooting positions.

In most phoenix trees, most of the roots are severed when the tree falls, and those remaining are bent or twisted at right angles. Despite this, and despite the crown also being in a completely new orientation,

somehow the roots manage to continue to function. In recently fallen trees there is often little or no sign of any trauma to the crown as a result of this severe of root damage, which appears to contradict basic physiological principles. Obvious new (adventitious) rooting from grounded stems and branches was recorded in downy birch, alder, hazel, grey and goat willow, rowan, lime, sweet chestnut, horse chestnut and very occasionally in oak. This clearly is an advantage, allowing trees to service the crown and provide stability. It does seem remarkable that large old tree trunks (up to 60 cm in diameter) are able to producing new roots and so re-organising the flow of water and nutrients in fundamental ways. Oak appears least adept at producing new rooting from stems, which is rather odd considering how common oak phoenix trees are.

Phoenix trees that produce well developed new rooting positions, typically a few metres from the original rootplate, end up with sections of horizontal stem between these rooting positions. The term "rooting bridges" is proposed for these features. It is hard to imagine the physiological status of a stem joining two functional rootplates. In complex phoenix trees this pattern can be repeated multiple times. In some trees, the original rootplate eventually ceases to function and starts to rot (= rotted rooting bridge), and the eventually severs. This can lead to the strange sight of a healthy living tree with a totally severed trunk. In a few severed trees, sections of stem between different parts of the tree also fail and rot away, leaving independent genetically identical (clonal) phoenix trees.

Phoenix trees are frequent in oak, downy birch and alder. Smaller numbers were observed in: goat willow, grey willow, silver birch, wild apple, hazel, rowan, lime, sweet chestnut, horse chestnut and elm. The author has also observed occasional phoenix trees in Scots pine, European larch, bird cherry, holly, aspen, wild cherry and hawthorn. Oak with stems at time of falling measured up to 85 cm diameter and 23 m tall were observed regrowing as phoenix trees. Phoenix regrowth was recorded up to 46 cm in diameter and 22 m in height – the size of a large tree. The average estimated age since falling varied between 39 years oak and 12 years (hazel), with a range between 2 and about 85 years. Nearly 20% of oak phoenix trees had blown over twice, which is very surprising. Downy birch is a specialist at thriving wet and windy sites where the risk of windblow is high and forming phoenix trees seem to be part of a survival strategy. About 7% of downy birch are double phoenix trees – which is another measure of their capability of withstanding windblow. Downy birch is particularly adept at forming new rooting positions (59% of trees). Alder phoenix trees are most frequent on wet flushed soils on steep slopes; with wrenched trees being quite common (38%). Goat and grey willow both seem to fall over easily and at relatively young ages, and thrive very well as phoenix trees. Hazel forms phoenix trees/bushes very readily, with regrowth up to 10 m tall in older examples. Wild apple is particularly adept at forming phoenix trees and seems to be able to withstand all sorts of trauma. Ash, silver birch, aspen and Scots pine appears to form phoenix trees less frequently than most species. Lime, horse chestnut and sweet chestnut clearly form phoenix trees easily, with stems and branches re-rooting extensively.

The point at which a phoenix tree crown starts to re-orientate is marked by a sudden change of angle in the twigs or branches, usually fairly close to 90 degrees, and this point can be used to identify when the tree fell. Phoenix trees can also be aged by the changes in rootplate characteristics. It appears that recruitment of phoenix trees is currently increasing in native woodland and wood pasture, as woodland that originated in the late 19th and 20th centuries reach heights at which they are more susceptible to windblow.

Phoenix trees are important because the process extends the lives of what are often already quite old trees. In their new more stable position phoenix trees can grow to be very old trees, with many veteran characteristics, and provide continuity of micro- habitat for many species. One important aspect is that veteran and young growth micro-habitat can occur in close proximity on the same tree, providing habitat for a very wide range of epiphytic plant.

Life-threatening fungal disease seems relatively infrequent and was generally only observed in a few downy birch trees. However many trees in this study were clearly engaged with fending off more minor fungal attack. Dead phoenix trees do occur, showing that trees eventually succumb on a scale of decades.

People seem to react universally positively to phoenix trees. Older phoenix trees resemble works of sculpture, with beautiful, interesting and puzzling shapes. The fact that these arise naturally, with the trees obviously trying to "sort themselves out" after falling over, adds another element of wonderment.

This project sets out evidence that phoenix trees are a serious ecological phenomenon. They are also attractive and interesting trees that foresters and ecologists should appreciate better, and should bring to the attention of the wider public. The process of forming a phoenix rejuvenates the tree (like coppicing does) and ensures several decades of further growth and seed production. It seems the formation of phoenix trees is a particularly important manifestation of the ability of mature trees to regrow following damage. The processes is clearly allied to coppice regrowth, and uses similar mechanisms. All the focus in the literature has been on coppicing (presumably because it carried out by, and is useful for, people), and the regrowth as a result of trees falling over has barely been studied. The ability to coppice is known to be under strong genetic control, so it is likely that this is also the case for the ability to form phoenix trees.

The fact that phoenix trees tend to occur in older woodland obviously makes them a good means of identifying particularly old native woodland and wood pasture. The value of phoenix trees has been appreciated by ancient (veteran) tree specialists. Extending research on veteran trees to encompass phoenix trees could usefully add a dimension centred more on natural landscapes and the natural process of phoenix tree formation.

The management needs of phoenix trees are very straightforward and only require minor adjustments to management practice. These are:

1. ***Awareness***: - Owners and managers need simply to be aware of phoenix trees.
2. ***Survey: -*** Surveyors to note their existence during woodland surveys and mention them in woodland management plans.
3. ***Spare the saw***: - The urge to clear them up at the first available opportunity by converting them to firewood needs to be resisted; trees should be assessed after a year or two, and if they show signs of forming phoenix trees, they can be helped simply by trampling down any bracken around them.

What is needed more than anything else is just a general awareness raising effort about the value and significance of phoenix trees. Phoenix trees combine several compelling elements: their enigmatic sculptural beauty, their obvious efforts to survive against the odds, and the unlikely stories of how they adjust themselves to their recumbent positions. On top of this, a case could be made that they are an emblem of Scotland's (and the UK's) strange wet, windy climate, where trees have very little option in old age other than to fall over.

1. Introduction and aims

Mature trees in Scotland's windy climate often blow over, and a proportion continue to grow in this new "recumbent" position. These develop unusual and intriguing structures, and survive courtesy of unlikely physiological adjustments in their new positions. The term "phoenix tree"[1] has been coined to describe them, reflecting the way that they "rise from the ashes" following the potential catastrophe of windblow (Quelch 2001). Whilst windblow is the bane of foresters' lives, in the case of phoenix trees something rather wonderful can arise from the devastation.

Phoenix trees can be seen as emblematic of the struggle to grow and survive in Scotland's oceanic environment - where frequent gales and shallow and wet soils make windblow almost an inevitability. Being able to regrow as a phoenix tree, and so survive and produce seed for many more decades is clearly an advantage. This report makes the case that phoenix trees represent a useful and significant adaptation; akin to the critical ability of broadleaved trees to coppice.

This project investigates the occurrence, structures and ecological significance of phoenix trees based on 141 examples from 7 sites in the Scottish Highlands. Casual observation suggests that these trees occur across many woodland habitats, and involve most broadleaved tree species to varying degrees, plus several conifers, notably larches. They are most noticeable in western and upland native woodlands and wood pastures. Indeed, in sparsely wooded areas they are sometimes the only surviving trees of previous woodland (Peter Quelch *pers. comm*.). Phoenix trees have had virtually no coverage in mainstream forestry and ecological literature. However they do feature in publications on veteran trees (e.g. Read 2000) and they are regarded as evidence of past woodland or wood pasture (Quelch 2001, 2010, Rotherham 2012).

At best, foresters and ecologists regard phoenix trees as a passing curiosity stumbled over during the survey of a wood. They are generally ignored by owners and managers. A common response is to convert them to firewood, which if the tree was to survive, constitutes a considerable ecological loss. Indeed in the course of this project a superb recent phoenix oak tree suffered this fate (see figure 5). This report sets out the case that phoenix trees are interesting and valuable, and can be accommodated in management via very minor adjustments to attitudes and practice.

Many of our mature native broadleaved woodlands date from the late 19th and early 20th centuries, and are now reaching the stage where they are increasingly likely to blow over. This makes it a good time to draw attention to the phenomenon, so as owners and managers can be on the lookout for likely phoenix trees and can adjust management accordingly. Phoenix trees are less well known to the public, which is a shame, because they are universally interesting and attractive trees, and more could be done to understand and celebrate them.

1.1 Aims and approach

The aim of this project was to establish a basic understand phoenix trees, increase awareness amongst professionals and the public, and encourage appropriate management and conservation practices. The project focussed on native broadleaved trees, but other species were recorded when they were encountered.

[1] The name "phoenix tree" is also used for as a common name for several species of tree around the world, notably China Parasol Trees when planted in the US

2. Methods

Sites were located in Highland Scotland, and split between woods:

- with frequent phoenix trees in windy areas of western Scotland or near treelines; and
- more standard lowland native woodland on lower lying sites in the central Highlands.

Sites were chosen on base on the author's personal knowledge or on the recommendation of other professionals. Locations and site details are shown in table 1. The sites covered a range of elevations from near sea level in Argyll and Sutherland, to 450 m in Highland Perthshire. It is not possible to say how representative this suite of sites is; but the survey certainly gives a good snapshot of the occurrence and characteristics of phoenix trees across a range of site types.

Table 1 Main sites surveyed

Name	Local authority	NGR	Species		Elevation	Characteristics
			Main	Other		
Cross Craigs and Coille Mhor, Rannoch	Perthshire	NN 535 530 NN 542 564	Downy birch	Alder, rowan, goat willow	380-500 m	High elevation birch woodland
Taynish Oakwood NNR	Argyll	NM737 848	Oak		10 m	Hyperoceanic woodland/ wood pasture
Old Poltallach,	Argyll	NR 806 008		Horse & sweet chestnut, lime, alder, ash, elm	40 m	Policy woodland
Dundonnell Bruthach na Garbh Choille Gleann Chaorachain	Highland	NH 118 853 NH 106 836	Downy birch	Alder, willow, wild apple	100-150 m 150-350 m	Hyperoceanic and high elevation woodland/ wood pasture
Loch a'Mhuilinn, Sutherland	Highland	NC163 392	Grey willow		5 m	Hyperoceanic coastal woodland at edge of loch
Ledcroisk Wood, Aberfeldy	Perthshire	NN 899 510	Downy birch	Silver birch	200 m	Birch woodland within conifer woodland
Old Grantully Castle Wood, Grandtully, Perthshire	Perthshire	NN 895 523	Downy birch		100 m	Oak-birch woodland
Tummel catchment, Perthshire	Perthshire	Various		Oak, rowan, alder, willow, hazel, wild apple	100-200m	Mixed native woodland

A total of 141 trees were recorded. On smaller sites all trees were recorded. On large sites, a representative sample of trees were recorded. It was found that sampling on larger sites needed to be subjective in order cover, in the limited surveying time available, the wide range of tree structures, species and ages (since falling) that were encountered. There may have been a tendency for larger, older, more spectacular trees to be over-represented in the sample. The following aspects were recorded:

1. Location of each tree: National Grid Reference

2. Characteristics of the original stem of the tree: number of stems, length (m) and diameter (cm) of currently living former stem (m)[2], direction of fall.

[2] The diameters of multi-stemmed trees were converted to equivalent diameters as if they were single stemmed.

3. Manner of fall: lifted rootplate; gradual rooting failure (wrenched trees), stem failure, “half-trees” or collapsed coppice (for definitions see box 1 below).

4. Characteristics of phoenix tree stem:

- Position of stem: “grounded”, “propped” or “suspended”.
- Presence / absence of adventitious rooting i.e. new roots develop on grounded stems or branches.
- Rooting bridges and rotted rooting bridges (for definitions see below box 1).

5. Structure of the new crown: “hedge phoenix” “new-tree phoenix” “crown phoenix”, “double phoenix” or “complex” (for definitions see below box 1).

6. Dimensions of new crowns:

- Crown width parallel and perpendicular to the original stem (m).
- Height of the highest shoot of the tree (original growth plus phoenix growth) (m).
- Length of phoenix regrowth in new orientation (m).
- Maximum diameter of the phoenix regrowth in new orientation (cm).

7. Characteristics of the roots:

- Size of exposed roots still visible – small (< 1 cm diameter) medium (1-3 cm diameter) large > 3 cm diameter.
- Degree of revegetation – little, moderate, largely revegetated, completely revegetated.
- Signs of new secondary rooting positions.
- Presence of “air-roots”, rooting bridges and pipe roots (see box 1 for descriptions).
- Presence of tree seedlings and saplings on the upturned rootplate.

8. Time period of tree in new position: This was estimated to the nearest 5-year classes from 0-20 years, and 10 year classes thereafter; and was estimated from the size of shoots or stems growing in the new orientation and the characteristic of the root plate. For oak, birch and ash, the grow rates of new stems could be compared with the growth rates shown in yield models to try to help fix an approximate age. For less common species such as willow and rowan, the estimates were little more than educated guesses, especially for older trees.

9. Site type and habitat: location and elevation of site, woodland / wood pasture; and NVC type.

10. Information on the value of phoenix trees for lichen was assembled as an example of the micro-habitats they provide for lower plants. This was done by photos supplied to a lower plant expert (Andy Acton).

11. On large sites, approximate estimates were made of the proportion of trees that were phoenix as opposed to upright trees.

3. Characteristics of phoenix trees

A phoenix tree was defined for this project as a tree which, as a result of rooting or stem failure, is lying more or less parallel with the ground, with new growth having developed in this new orientation. Three aspects fundamentally determine the characteristics of a phoenix tree:

1. **The manner of failure** of the stem or roots.
2. **New position of the stem –** whether it is lying on the ground, propped by its branches or suspended by a tree or rock.
3. **The structure of the regrowing crown and stems –** what growth forms these adopt.

Variations in these three factors lead to a very wide array of different “designs” seen in phoenix trees and understanding these factors allows the origin and processes involved to be unravelled.

Box 1 The characteristics and structures of phoenix trees turned out to be surprisingly varied and required a terminology to be developed to describe them.

TERMINOLGY TO DESCRIBE THE CHARACTERISTIC OF PHOENIX TREES

Manner of fall

- **Lifted rootplate**: This is the usual form of windblow where the root plate is torn from the ground and left suspended roughly at right angles to the surface, with a hinge of bent roots left in place.
- **Wrenched trees**: Trees that collapse over an extended time period as roots are loosened and wrenched into a new position, but the root plate does not lift.
- **Collapsed coppice** – individual coppice stems collapse at the point of union with the stool.
- **Half-trees** - These are formed of half of the tree where the stem has split and collapsed as a result of either having gone hollow; or a co-dominant fork in the lower crown failing.
- **Failure of the lower stem** –the stem partially fracturing over a section of a metre or so near the base.
- **Relaxing stem -** stems that end up at an angle, then slowly bend towards the ground over times tissues fail through "creep".

Position of phoenix tree stem

- **Grounded stem** – the original stem is lying in contact with the ground.
- **Propped stem** – the original stem is propped off the ground by the original branches.
- **Suspended stem** – the stem and crown suspended off the ground usually by another tree or a rock but very occasionally just supported horizontally by its own stem.

Structure of the new crown

- **Hedge phoenix**: Frequent upright new shoots developed along the former stem(s) of the tree, giving a hedge-like appearance.
- **New-tree phoenix:** New upright trees developed from the original lying stem, branches or rootplate.
- **Crown phoenix:** The shoots and branches of the fallen crown re-orientate, with only subtle changes of overall structure.
- **Double phoenix:** Trees that have blown over and regrown, then blown over a second time and started to regrow again.
- **Complex phoenix:** Trees with complex structures resulting from multiple rooting positions, multiple new stems and sometimes several sequential collapse events.

Root features

- **New rooting positions:** New (adventitious) roots developed on the grounded stems or branches.
- **Air roots:** Live roots left in the air after the soil and vegetation erode away from the rootplate.
- **Rooting bridges:** Sections of stem between the original rootplate and new rooting positions formed from adventitious rooting. These stem sections are often lifted off the ground – hence "bridges". In some species these eventually rot away, leading to the tree adopting a wholly new rooting position, and the original rootplate disappears (rotted rooting bridges).
- **Pipe-roots:** Roots that grow into the rotting stem of the fallen tree from the base of developing stems, then remain alive above ground after the stem rots away.
- **Rootplate saplings:** saplings growing above the browseline on rootplates.

This definition of phoenix trees is a little stricter than others, which have extended to include other forms of regrowth such from layering of branches from upright trees (e.g. Read 2000).

3.1 The manner of fall - how stems and roots fail

Upturned rootplate

The most usual form of failure leading to windblow is for the roots to fail suddenly leading to an upturned rootplate more or less at right angles to the ground surface (see figures 1, 2). Usually 50-75% of the roots are severed in this process. The roots left in the ground are bent or twisted more or less at right angles forming a hinge. It is these roots that must adapt and continue to supply the needs of the tree if it is to survive. This form of failure was recorded in 58% of the trees surveyed, and was almost the exclusive form in oak.

Figure 1. Birth of a phoenix tree - a recently fallen downy birch tree showing the upturned rootplate. The crown has not yet started to re-orientate. Note the effects of deer browsing on the lower part of the crown.

NOTE ON PHOTOGRAPHS: Photos are formatted to be viewed in Word at a zoom scale of about 170% and are as important as the text.

Figure 2. A downy birch which fell about 4 years ago, propped on a rock, and with the crown starting to re-orientate and take on a “hedge” structure. The branches of the lower crown have been browsed by deer and have died. The rootplate is still largely unvegetated.

Figure 3. A downy birch after about 15 years, showing the re-orientation of the crown in process. In this case much of the soil has been lost from the root plate and revegetation has stopped.

Figure 4. A phoenix downy birch tree with a mature “new-tree” form, Dundonnell. It fell without lifting its rootplate, as a “wrenched tree” or due to “stem failure”. The main rooting point is now immediately below the new stems.

Figure 5 Giant collapsed oak coppice stems in process of regrowing after they fell about 12 years ago – note the figure for scale and the new growth left and right. A third stem of similar size lay away from the viewer - or it did until it was removed for firewood. It is a good example of the ability of very old coppice oaks to regrow following failure – the largest regenerating stem (left) is 23 m tall and 87 cm diameter. In a few decades time this will be a remarkable tree. Near Loch Tummel, Perthshire.

Figure 6. The upturned rootplate is still visible on this phoenix oak tree, which has been in its new position for maybe 100 years. Note the large new stem formed at the union of the former trunk and rootplate, and further “new trees” emerging from the original stem. High Ardwall, Galloway.

Wrenched-trees

This is where the tree collapses gradually over time, with the roots away from the direction of fall apparently gradually loosening and being wrenched into a new position without fracturing the soil surface (see figs 4, 7). This was first described in this study and gives rise to puzzling trees which appear to emerge growing more or less parallel to the surface, but without any sign of an exposed rootplate. This usually occurs downhill on steep slopes, though it can happen on exposed uplands sites in any direction. Roots in the direction of fall get bent at right angles, and even further where the tree falls downslope. This was recorded in 25% of trees, and included all species except oak.

Half-trees

One surprising form of failure first identified in this study is for the stems of upright trees to split in half longitudinally then collapse. This can occur in two ways. Firstly a tree can become hollow, with the stem then splitting into two or more segments, and with the weight of the crown then pulling the “half-tree” down to the ground, branches first. Alternatively the stem can split as the result of the failure of a codominant fork; in this case one half of the fork typically breaks off completely and dies, leaving the remaining stem so weak that it then collapses. “Half-trees” can be identified by their semi-circular stem sections, the exposed timber on one side of the original stem, and the impressive way that branches re-orientate themselves upwards from the lower side of the stem (see fig 9). Half-trees only accounted for 2% of the trees surveyed (downy birch, rowan, alder), but were very characterful.

Figure 7. A downy birch “wrench tree” that fell without lifting its rootplate and appears to emerge and grow parallel with the ground surface. The tree is propped up by one of its former branches, which in this case has rooted. Note the rope-like twisted structure of the stem due to heavy loading.

Figure 8. An ash “wrench tree”, which fell without lifting its rootplate, and gave rise to 2 new stems over 20m tall. Most of the original stem has rotted. Old Poltalloch, Argyll.

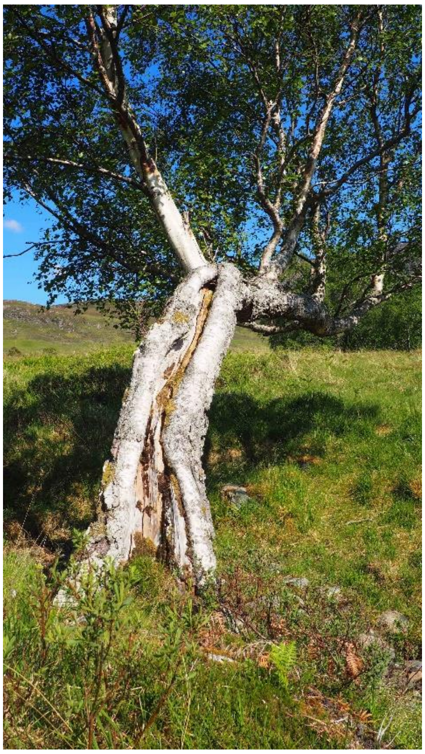


Figure 9. Above and left - a downy birch “half-tree”. The stem has partially failed several years ago by splitting from ground level and the branches have then re-oriented themselves upwards. Lower branches were lost to browsing. Right – a more typical half-tree, a wild apple in flower, showing another part of the formerly hollow tree having broken off and died (right)

Figure 10. A phoenix alder tree formed by collapsing coppice stems. Of the 9 original stems, 4 have collapsed and regrown in their new orientation and two of these have now rooted in situ. Dundonnell, Highland.

Figure 11. A young wild apple phoenix tree developing from collapsed coppice. The surviving parts are those above browsing level and all of this tree would probably have survived in the absence of browsing. Tummel, Perthshire.

Figure 12. Stem failure in a downy birch. Cross Craigs, Rannoch. Perthshire.

Collapsed coppice

Coppice stems are vulnerable to failure at the point of union with the stool (see figures 5, 10, 11). Phoenix trees with multiple coppice stems can become very characterful. This form of failure was recorded in 7% of trees. The large collapsed coppice oak in figure 5 is a surprising example of this.

General Stem failure

In a few trees, the lower stem simply fractures over a section of a metre or so near the base causing the tree to flop over, presumable as a result of wind or snow damage (see figure 12). Sometimes stem rot is part of the cause and in a few cases roots near the surface can break as well. This form of failure was recorded in 6% of trees. Sometimes, instead of stem failure being sudden, it happens gradually over a longer time period with the stems "relaxing" downwards into their new positions. This is initiated when the stem adopts sufficient angle of lean such that the stem (and sometimes the roots) slowly fail by virtue of the tissues deforming under mechanical stress (=creeping).

Impacts on the crown when trees fall

Fallen trees can sustain damage as a result of falling, firstly by breakage of stems and branches, then by browsing of those parts of the prostrate crown within reach of livestock and deer; by shading from surrounding trees; and lastly by swamping by bracken, which will kill low-lying parts of the crown. Fairly frequently these impacts can kill fallen trees, and for a phoenix tree to emerge requires enough of the crown to survive to sustain the tree and allow it to grow back above the height of browsing and bracken impacts.

3.2 How phoenix trees are supported

Fallen trees can be supported in their new positions in 3 ways, which help determine the future development of the tree.

Grounded stem

The original stem is lying in contact with the ground. This was the case in 64% of the trees surveyed. This relies on any branches on the groundward side of the stem disappearing either by breaking, becoming buried, or rotting away. Becoming grounded is important for those trees that can form adventitious roots from grounded stems. However being in contact with the soil presumably exposes the stem to a higher risk of rot and in some species sections of stem do indeed rot away (see section 3.5). The resistance of the stem of phoenix trees to rot appears to be remarkable, with trees apparently thriving in this state for at least 50-80 years, including unlikely species like birch, alder and willow where the timber is known to be non-durable. For a structure designed to be vertical and surrounded by air, the stems of phoenix trees appear to function miraculously well horizontal on the ground and permanently damp. Grounded trees are shown in many of the figures in this report.

Propped stem

The stem is propped off the ground by the trees own branches (see figures 13 and 14). This was the case in 27% of the trees surveyed. It is more usual in large-crowned open grown trees, especially oak. The branches doing the propping often remain alive despite many having no twigs nor foliage, and respond to the loading they are under by continuing to thicken. In these cases the propped position becomes very stable. In some alder and lime trees, propping branches sometimes develop peculiar growths at ground level comprising burr-like growth covered in twigs, like hairy feet. In a few species the branches doing the propping can form roots where they come in contact with the soil; and in other cases propping branches produce new upward growing shoots from near ground level. Sometimes propping branches appear to die and rot away and the tree gradually becomes grounded.

Suspended stem

The stem and crown is suspended off the ground usually by another tree or a rock (see figure 15). Suspended trees are relatively rare (9% of trees), and occur most frequently in woodland where trees are close enough together for this to happen. In a few rare cases trees are suspended horizontally by the strength of their own stem, without being supported (e.g. the birch half tree in figure 9); trees like this are common on steep slopes and overhanging watercourses. Being suspended excludes the possibility of adventitious rooting and so trees have to rely on their original root systems.

Fig 13. A propped downy birch tree. Most of the propping branches are still live, although they have no leaves. The tree is estimated to have been in this position from probably 20-30 years. New stems have regrown from the rootplate junction and major branches of the original tree (in “new-tree” structure). This is a rare case where the phoenix regrowth (RH side) is affected by a fungal dieback.

Figure 14. A propped oak, estimated to have been in this position for 60 years with strong regowth in “new tree” structure, from the lower stem. The tree is now dominated by growth in its new position.

Figure 15. A large former coppice oak, suspended in another small oak tree to left and regrowing as a hedge-phoenix.

How tree crowns respond

Various parts of the horizontal tree can initiate shoots because the dominance previously exerted by the upper crown is lost, and large sections of the original stem and branches are exposed to full light. The new regrowth of trees can take several forms depending mainly on:

- **where the new growth emerges** ; i.e. from the stem, the major branches, and/or by the reorientation of the existing twigs.
- **the density of new stems**: if many new stems appear the crown becomes like a hedge; if fewer new stems emerge, these quickly take the form of new trees.
- **the degree to which new growth comes to dominate over the original tree crown**. In some trees wholly new stems appear and become dominant, and the original crown loses its identity. In others, the existing crown slowly re-orientates and remains dominant.

Five main categories of phoenix tree structure are proposed.

Hedge phoenix

A large number of new upright shoots / stems appear from the trunk and sometimes the major branches of the fallen tree; whereas the original crown shows very little response. This leads to a hedge-like appearance (see figures 2, 15-17). This was recorded in 22% of trees and was seen in all species except goat willow.

New-tree phoenix

New upright stems appear from the original stem and sometimes the major branches of the fallen tree, with each developing the form of a new tree (see figures 4, 6, 8, 18, 19). The most usual numbers of these

Figure 16. Above, a young developing oak hedge-phoenix, Taynish, Argyll; and below, a large alder hedge-phoenix at Dundonnell

Figure 17 Details of branch formation in oak (left) and alder (right)

new trees are 2-5, though as few as 1 and as many as 11 have been observed. New-trees can grow to be very large and old, with stems 15-20 m tall and/or 80 years old (since falling) observed (see figure 4 for oak and 33 for downy birch). New-tree structures were the most common form of phoenix tree, recorded in 33% of trees; and were observed in all species except hazel and grey willow. They were very common in oak (48% of trees) and downy birch (38% of trees).

Usually the size of individual "new trees" decreases in the further way from the root plate the new tree is growing – in a similar way to the original crown. In a proportion of trees, new-tree stems develop from the union of the rootplate and original stem, presumably as a result of similar processes to coppice regrowth (figure 18). These can grow to be very substantial, and sometimes send new roots down through the original rootplate or stem. In a few cases these shoots start life on the lower side of the rootplate and have to bend upwards in J-shape in order to grow upwards (figure 20). New-tree and hedge phoenix trees share a similar process of development to "comb" pollard trees as described by Quelch (2001).

Crown phoenix

Most of the new growth develops by existing twigs re-orientating themselves, with only subtle changes of overall structure. These are typically trees in which the crowns were large and healthy at the point of falling. Crown structures were recorded in 30% of trees, and include all species.

Double phoenix

Remarkably a significant number of trees blow over and regrow, then blow over a second time and start to regrow again (9% of trees). Even more remarkably, these trees seem to remain serviced mainly by the original rootplate, which survives both windblow events, because any adventitious rooting developing on the original stem gets torn out as a result of the second fall. These trees can be identified by a characteristic right angle bend in the stems (see figures 21, 22, 23) and odd columnar rootplates. The process comprises:

- The original tree blows over then regenerates, usually as a new-tree phoenix.
- Eventually the new growth reaches sufficient height that the tree becomes unstable again. The only direction that the tree can fall is at right angles to the first direction of fall. This forms a right angle between original stem and the newly recumbent stem(s).
- New growth develops from the newly recumbent stems usually in hedge or new-tree form.

The rootplate adopts a characteristic form with two flattened faces and a more or less columnar structure– the original exposed underside of the rootplate on one side, then more or less at right angles, another smaller flattened face where roots have been wrenched out of the ground for a second time (see figure 22 upper photo). In some trees, the second collapse exposes adventitious rooting from the under surface of the original stem. Double phoenix trees were most common in oak (19%), but were also recorded in downy birch, alder and goat willow and have been observed by the author in wild apple.

Figure 18. An oak new-tree phoenix, with a large new stem at the rootplate union (left) and smaller ones from the major branches (right). All these appear to be serviced by the original rooting system. Note the high numbers of phoenix trees in the background. Taynish, Argyll.

Figure 19. A new-tree phoenix in downy birch, in which the crowns of the new trees have now matured. The original root plate is on the far left. Cross Craigs, Rannoch, Perthshire.

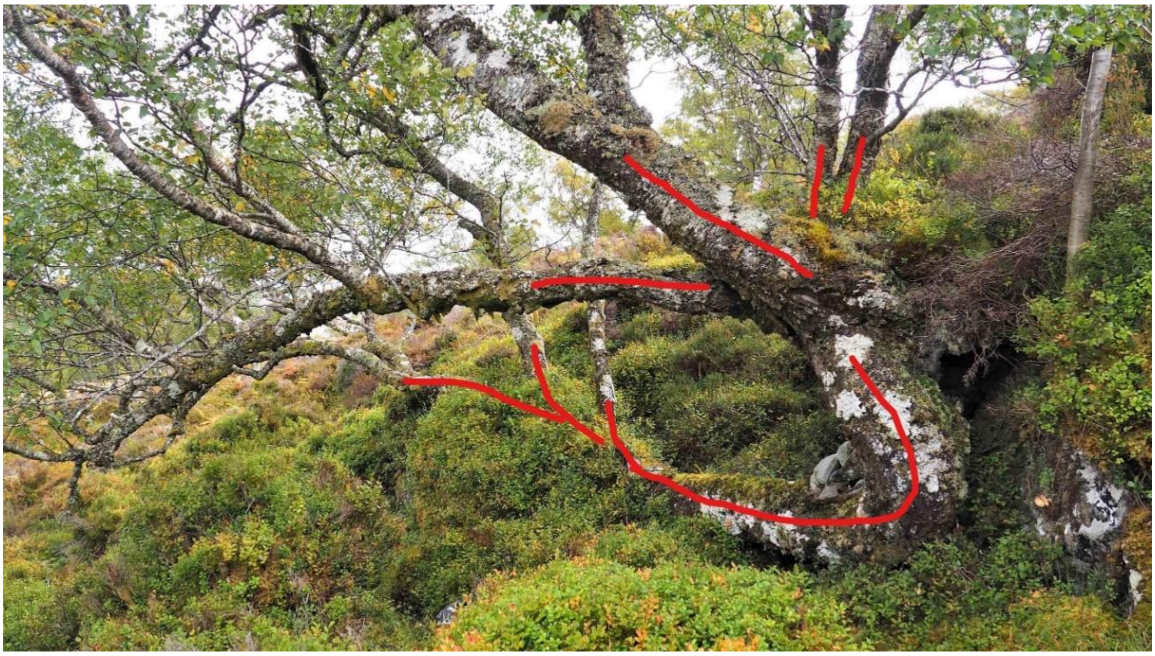


Figure 20. A puzzling structure of new-tree phoenix tree which has gradually fallen off a small rock ledge; withone stem developing upwards at and angle from the union of the rootplate and original stem, and another developing in a curious downwards loop. It is not clear which might have been the original stem.

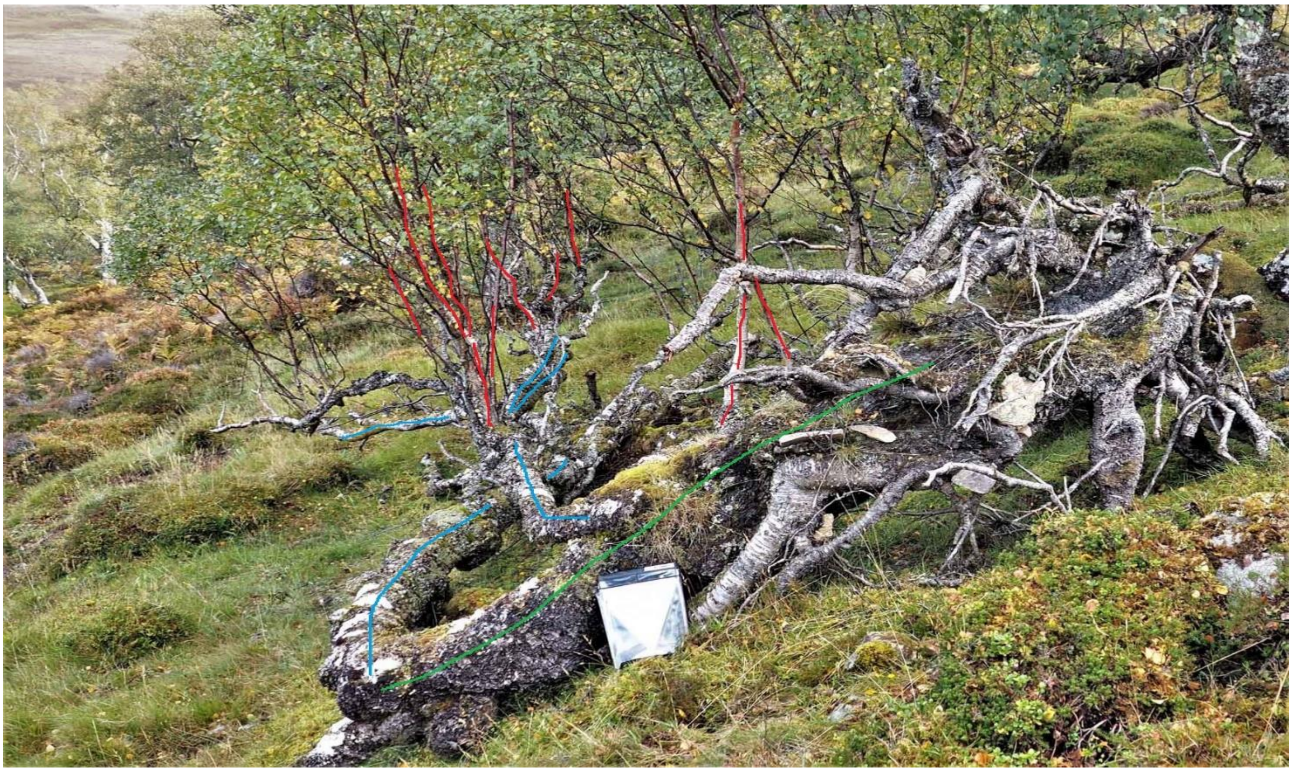


Figure 21. A recent double-phoenix downy birch viewed from the rootplate, Cross Craigs, Perthshire. The original stem of the tree is show with green lines, the first phase of phoenix regrowth is shown in blue, and the second phase in red. The tree first fell right to left, then it reformed its rootplate before it then fell again away from the viewer. It shows the characteristic right angle bend between the original stem and the first phase of phoenix regrowth (green and blue).

Figure 22 Two pictures of the same double-phoenix oak tree, Taynish, Argyll. The original stem of the tree is show with green lines, the first phase of phoenix regrowth is shown in blue, and the second phase in red. The right angle is between the green and blue stem sections, though it does not show up well from these angles. In the top photo, the tree first fell right to left, then subsequently fell away from the viewer. The second fall has lifted the original stem off the ground. Note the odd columnar rootplate structure.

Figuree 23. A double-tree phoenix wild apple showing the characteristic right angle bend between the original stem and the first phase of phoenix regrowth. The original stem of the tree is show with green lines, the first phase of phoenix regrowth is shown in blue, and the second phase in red. The right angle is between the green and blue stem sections. The tree has re-rooted and the rooting bridge (foreground) is in the process of rotting. Loch Lomond islands, Stirlingshire.

Complex phoenix

In a small number of trees complex structures develop in which the events leading to their formation are hard to decipher. These trees expand in several directions, and stems and branches may develop multiple new rooting positions (see figures 24, 25). Sometimes the original main stem is hard to identify. The term "medusa trees" has been coined for certain trees of this type where the spreading branches appear like tentacles (Ian Rotherham *pers. comm*.). Complex structures come about when:

- Grounded stems and side branches continue to grow along the ground surface in several directions and put up successive new stems.
- New rooting positions form which can sustain different parts of the tree.
- New trees develop which themselves can fail and start to regrow.
- Former coppice trees produce grounded branches in several different directions and at different times.

Complex structures were recorded in 8% of trees, especially downy birch and willow; and the one horse chestnut recorded was a spectacular complex phoenix (see figure 50). Downy birch complex phoenix trees are very characterful, with multiple stems and new rooting positions giving puzzling structures (see figures 24, 25). They are common in grey willow trees, formed when several coppice stems have fallen in different directions, and then all regrown in a tangled mass. Complex phoenix trees are very characterful. Some develop large crowns, in excess of 200 m^2. Complex structures can be seen as an advantageous growth form, because the tree occupies a large amount of space and is very stable.

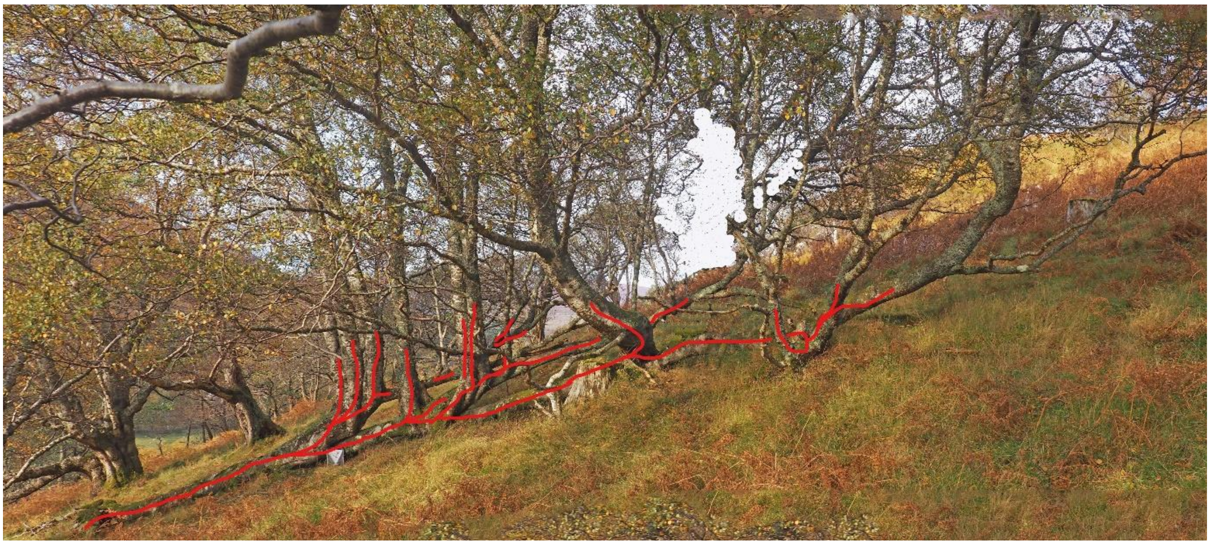


Figure 24. A complex phoenix downy birch tree. The 7 upright stems are 30-40 cm diameter and appear to be developing successively as the tree extends along the ground. There are 9 major new rooting postions. Dundonnell, Highland.

Figure 25. A complex phoenix downy birch tree where the structure is hard to intepret and even the original tree cannot be identified. The two large horizontal stems at the right are broken, and it is unclear what they were formerly attached to. Dundonnell, Highland.

Factors driving development of different structures

The occurrence of the 5 forms adopted by phoenix trees is summarised by species in table 2; and demonstrates that these growth forms occurred in most species. Which structure a tree adopts is probably partly determined by the form of the tree when it first falls, and partly by the genetic characteristics of individual trees. Trees in which the crown is small, or badly damaged when it falls have a greater propensity to regrow in hedge or new-tree structures. Trees which retain large intact crowns following the fall are more likely to regrow in crown structure. However adjacent, similar trees often regrow in different forms in ways that suggest this is partly genetically determined.

3.4 How roots respond

The roots of phoenix trees tolerate considerable damage but nevertheless adapt remarkably to their new positions. In the majority of phoenix trees, most of the roots are severed and those remaining are bent or twisted at right angles. Despite this, and despite the crown also being in a completely new orientation and frequently damaged by the fall, somehow the roots manage to continue to function. In recently fallen trees there is often little or no sign of any trauma to the crown as a result of this severe of root damage, which appears to contradict basic physiological principles.

Figure 26. This downy birch lost about 75% of its roots when it blew over on top of this rocky knoll in Perthshire 2 years previously. Despite the loss of so many roots, almost the entire remaining crown is in good health and twigs are starting to re-orientate. The only crown damage appears to have been caused by the fall itself, and subsequent browsing.

Where rootplates are exposed (lifted rootplate trees), they undergo a series of changes that are predictable enough that they can be used to help determine the period since falling. These are:

1. Loose soil and rocks fall away from among the roots, exposing the roots further.
2. Damaged roots start to rot and disappear; smallest roots first and large roots last.
3. Exposed soil starts to revegetate – lichens, mosses and vascular plants will grow wherever it is possible.
4. Tree seedlings take root on the upper surfaces where these are above browse height and become “rootplate trees”.

Figure 27. A phoenix wild apple tree, which fell 4 years previously, as a result of stem failure. The crown, which is largely healthy and now regrowing, though with some dead branches, is serviced by a small sliver bark about 3 cm wide at the point where the stem failed.

The progressive loss of soil from rootplates leads to the formation of “air-roots” i.e. living roots in which the first section from the tree, usually 50 cm – 5m, is in air rather than soil (figure 28). In a few trees these air roots can be extensive. It is interesting that roots appear to be able to cope perfectly well with these unusual conditions.

Revegetation of rootplate is a variable process, depending on how much soil and vegetation is lifted with the rootplate. Some rootplates shed a lot of soil and vegetation at the point of falling, and so take longer to revegetate; whilst others carry more and revegetate quickly. The revegetation process also depends on the final resting position of the rootplate. Where the lower surface of the rootplate is vertical or even turned upwards, revegetation of exposed soil will proceed steadily; where the lower surface remains overhung, revegetation will be confined to the upper surface and will barely happen on lower ones, with the exception of some mosses. In some trees virtually all the soils lost, and only a few lodged rocks remain in the rootplate (see figure 28).

Figure 28. A phoenix downy birch (centre tree) that has lost most of the soil from its rootplate, with only lodged rocks and moss remaining. Note the long air-root on the right, which is fully alive.

New rooting positions

Obvious new (adventitious) rooting from grounded stems and branches was recorded in downy birch, alder, hazel, grey and goat willow, rowan, lime, sweet chestnut, horse chestnut and very occasionally in oak. This clearly is an advantage, allowing trees to develop new roots to service the crown and provide stability. The process is similar to layering, where branches and twigs are pinned to the ground and induced to root. However it does seem more remarkable when it is large old tree trunks that are producing new roots, and so re-organising the flow of water and nutrients in fundamental ways.

Downy birch is the expert species in this regard, with pencil-sized roots developing after only 5 years (figure 29), and large rooting structures continuing to develop the longer the tree remains in its new position. This was observed in tree stems up to 60 cm in diameter and probably 50-80 years old. Some complex downy birch phoenix trees develop as many as 9 major new rooting positions (figure 24). Hazel also readily roots forms new roots. Lime, horse chestnut and sweet chestnut root strongly, though note that this study included very few samples of these species. Grey willow is interesting because they frequently form phoenix trees with many grounded stems and branches, but adventitious rooting remains very modest in extent. It is as if the trees are able to form these new roots, but does not have particular need of them. Goat willow is rather similar, but does eventually produce substantial new rooting positions in old trees.

Figure 29. New rooting developing on grounded downy stems of: above - a downy birch stem about 45 years old, 5 years after falling; and below - a grey willow stem 25 cm diameter, where the root has started on the top of the stem, growing under the moss layer, before entering the soil.

The species which appears least adept at producing new rooting from stems appears to be oak, which is rather odd considering how common and well-developed oak phoenix trees are. Some oak phoenix trees have grounded stems that have been in place maybe 80 years, and which support large new tree structures up to 15 m tall, but nevertheless appear devoid of obvious adventitious roots, relying on the original rootplate. New rooting was observed in two cases, the most obvious being on a double phoenix, where the second fall revealed broken roots on a stem section previously grounded as a result of the first fall. The apparent reluctance of oak to form new roots fits with the general difficulties of vegetative propagation in oak. Note that in this study only obvious signs of rooting were recorded, that were either apparent on the grounded stems or found by running a hand under the stems. Excavation of stems would provide a more comprehensive picture and would reveal more rooting.

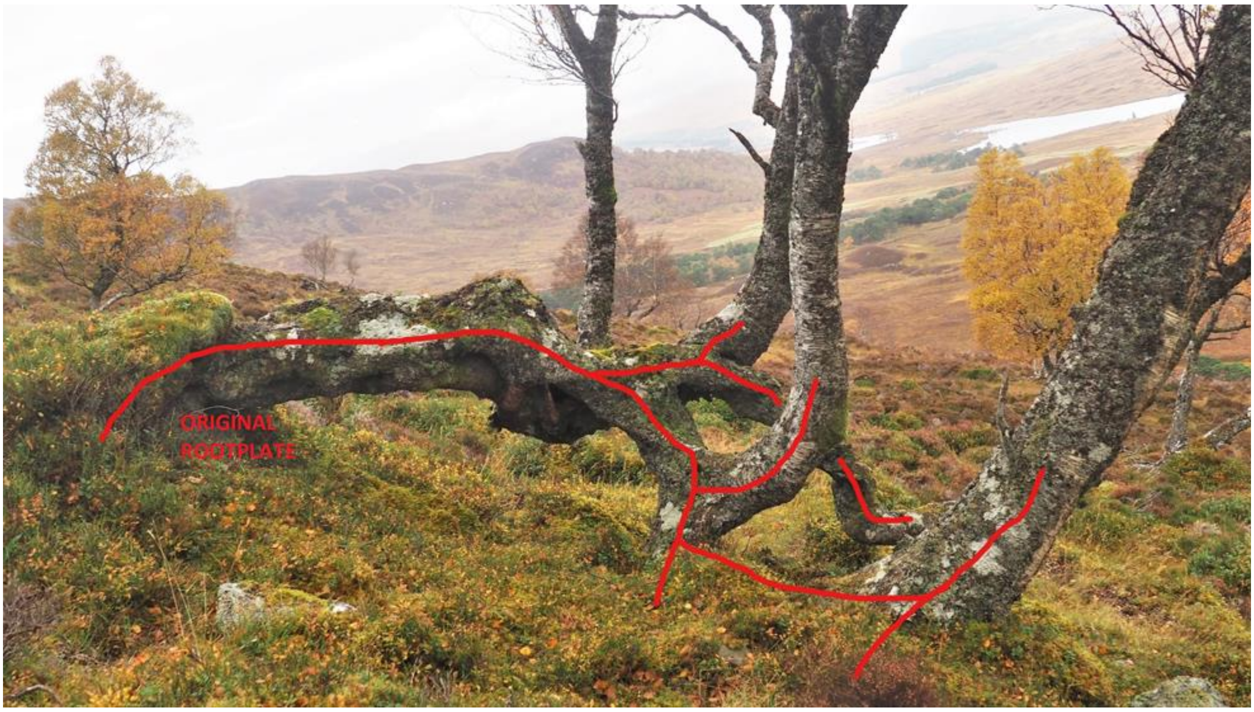


Figure 30. A phoenix downy birch tree with 2 new rooting positions and a “rooting bridge” between the original rootplate (left) and the new rooting positions (right). The section of stem between the two new rooting positions is partly buried.

Figure 31. Multiple major new rooting positions on a complex phoenix downy birch tree; which in total has 9 new rooting positions and multiple rooting bridges. Dundonnell, Highland.

Rooting bridges

Phoenix trees that produce well developed new rooting positions, typically a few metres from the original rootplate, end up with sections of horizontal stem between the original rootplate and these new rooting positions. The term rooting bridges is proposed for these features. These can either lie along the ground surface or can end up lifted off the ground (see figure 30-34).

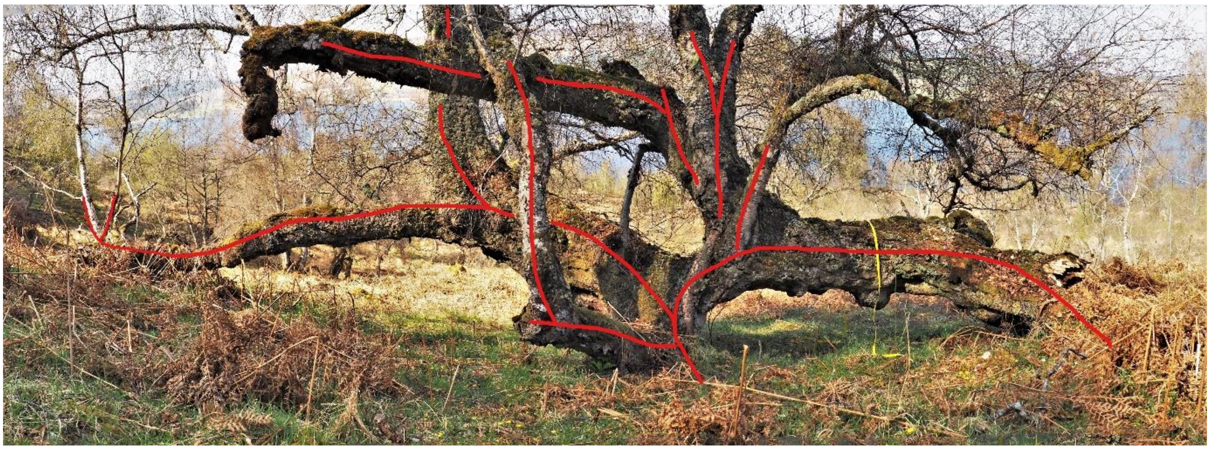


Figure 32. A rooting bridge on a complex downy birch phoenix tree, Rannoch. The original rooting position is on the far right, and a substantial new rooting position in the middle, with the rooting bridge between the two. The rooting bridge is starting to rot near the old rooting position and will eventually decay away. The tree has recently rooted at the far left, and so is in the process of forming a second rooting bridge.

Rooting bridges typically do not carry any crown between the rooting positions, but the new rooting positions themselves often have new trees above them. It is hard to imagine the physiological status of a stem joining two functional rootplates; but somehow the tree appears to organises itself to use both rooting positions to supply the crown, at least for a time. In complex phoenix trees, this pattern is repeated multiple times (see figure 31). It appears that rooting bridges grow only slowly in diameter and can end up more slender than other sections of stem, suggesting that as if they are not prioritised by the tree. This occasionally leads to surprising trees where stem diameter is smaller near the roots than further up the stem (see figure 47).

In some trees the original rootplate eventually ceases to function and starts to rot (= rotted rooting bridge), suggesting that once the new rooting positions are sufficiently developed the tree dispenses with original root plate. The decay appears to spread from the original roots to the rooting bridge eventually causing it to fail (as in figs 32, 33, 34); such that the tree becomes entirely dependent on the new rooting positions. In some cases (such as figure 32), the net effect is for the tree to slowly proceed across the ground by abandoning its old rooting position and acquiring new ones.

Pipe roots

In a few trees, roots developing from the base of new phoenix stems grow preferentially into the rotting stem of the original tree, only entering the soil where the stem comes into contact with the ground (figure 35). Once the stem rots away, this leaves roots in a very puzzling orientation; essentially a pipe-like line of roots above the soil surface, formed when they were confined in the “pipe” of the former stem.

Figure 33. A rooting bridge in the process of rotting. The original rootplate is to the left, and it has been entirely replaced by the roots developed at the base of the new tree. Cross Craigs, Rannoch.

Figure 34. A rotted rooting bridge beside a substantial new downy birch tree (13 m tall). It is only the rooting bridge that gives away the fact that this tree started life as a phoenix tree. In a few more year the rooting bridge will rot away and the tree will appear to be a normal upright tree. Cross Craigs, Rannoch.

Figure 35a. This shows “pipe roots” developing by growing down the rotted former stem of a rowan phoenix tree. The original stem lies on the ground, and new root from the new upright phoenix stems have grown along the rotting stem.

Figure 35b. In this old downy birch, all that is left of the former stem are “pipe-roots” running above ground for 4 or 5 m (right of picture)

Fig 35c. The same tree as figure 35b, with the red lines showing the orientation of the original grounded stem, now rotted away and replaced with pipe-roots. New regrowth from the base of the original tree near the rootplate union has formed a very large new tree. The other phoenix tree to the left is a wild apple. Frenich, Perthshire

Rootplate saplings

The large, long-lasting rootplates of phoenix trees provide good opportunities for seedlings to germinate and saplings to develop above browse height (see figure 36). Across all species 20% of phoenix trees hosted rootplate saplings, with rowan and birch saplings being the most frequent, and oak being the best host. The largest saplings were 10 m tall, and some had even suffered windblow themselves. Those on the rootplates of double phoenix trees, sometimes show adjustments following the change to the position of the rootplate following the second windblow event.

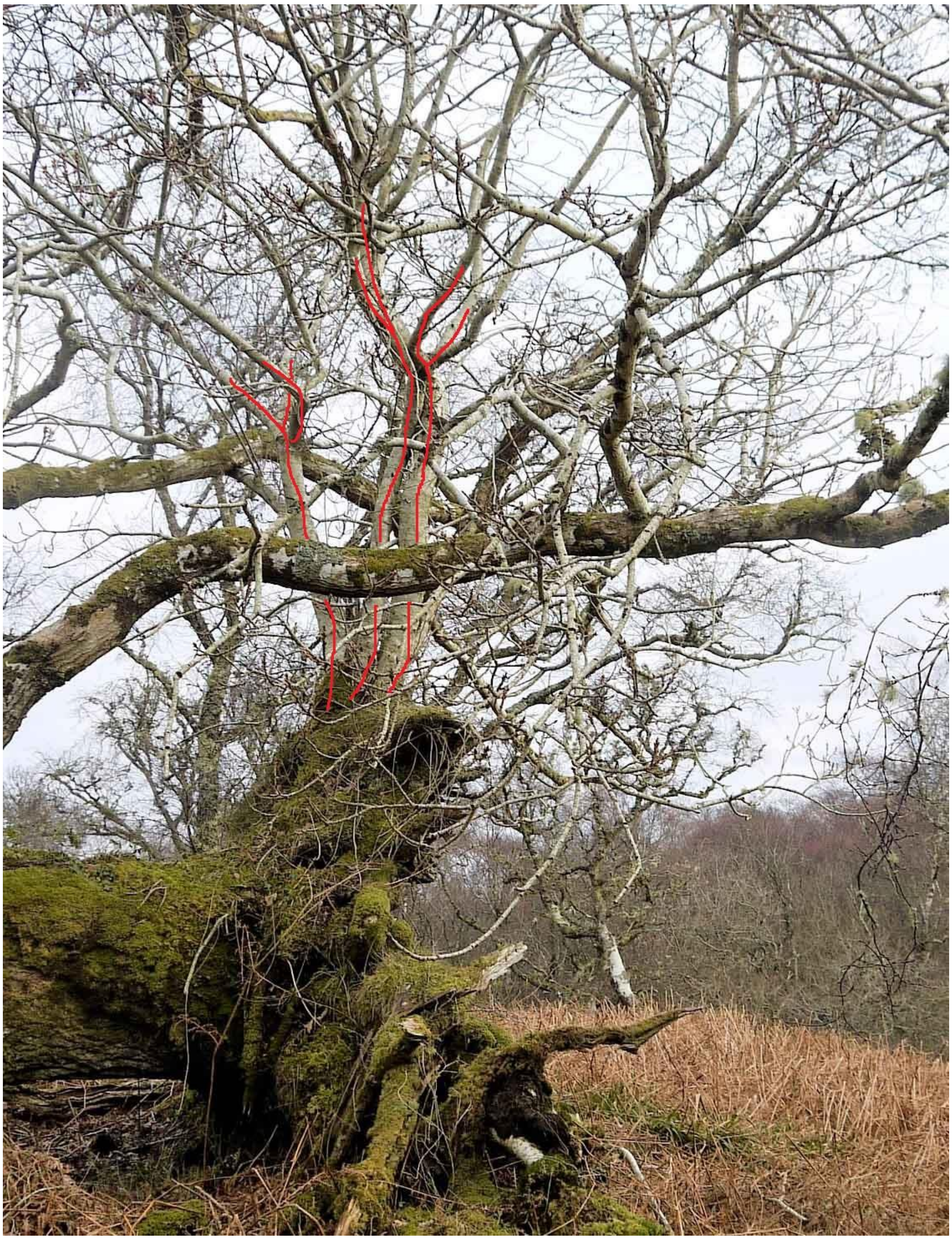


Figure 36. Large rootplate saplings of rowan on an oak rootplate.

3.5 Severed and clonal phoenix trees

In a few interesting cases the failure of a rooting bridge can lead to the strange sight of a healthy living tree with a totally severed trunk (see figure 37). Such trees are service by several new rooting positions and remain perfectly healthy. This was recorded only in downy birch, but an incipient case of this was observed in wild apple (figure 23).

Figure 37. This downy birch has a broken stem (right in upper photo, left in lower photo), where the "rooting bridge" between the original rootplate and new rooting positions has failed. The tree is perfectly healthy and is now served by its new rooting positions - essential a crown lying on the ground.

In a few severed trees, sections of stem between different parts of the tree also fail and rot away leaving two living parts of the tree essentially as independent genetically identical (clonal) trees (figure 38). With time it will become unclear that these were once part of the same phoenix tree.

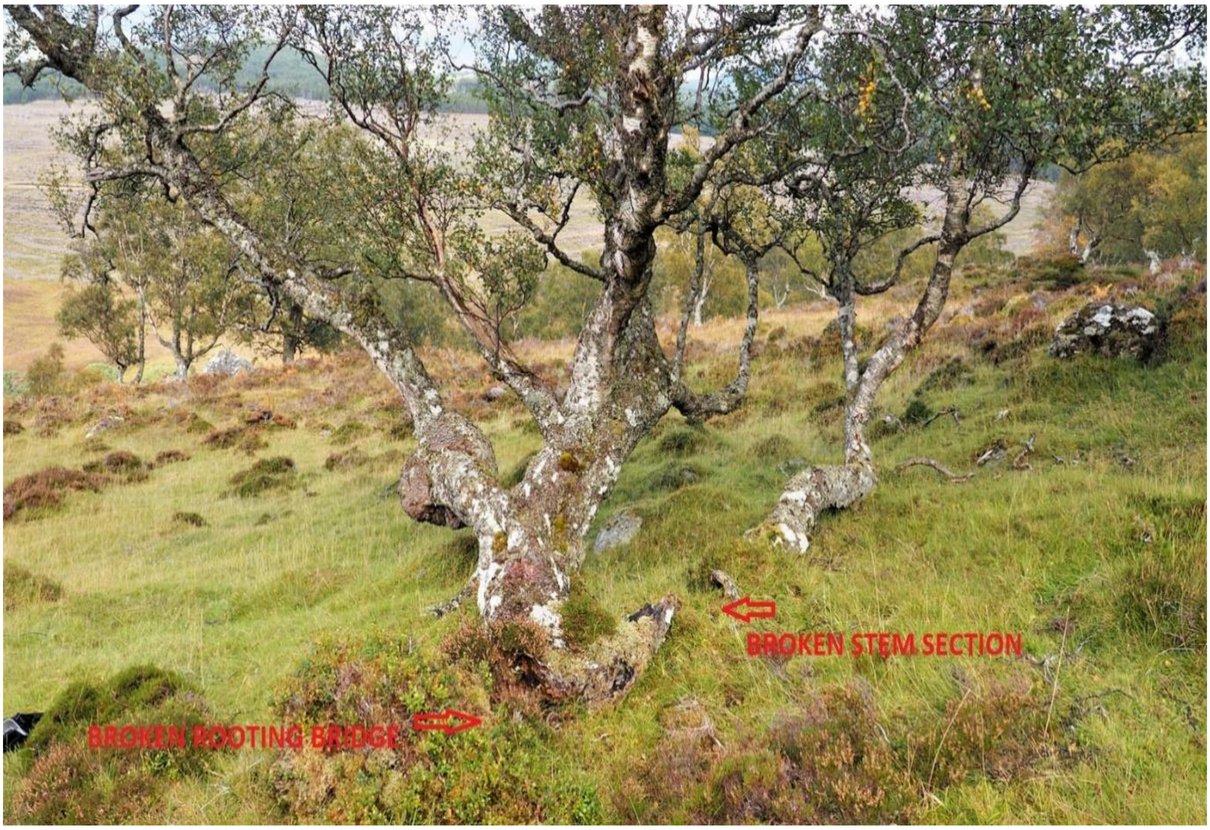


Figure 38. Clonal trees: the two parts of this tree, the larger part to the left and the smaller to the right, are now independent trees served by different rooting positions. The original stem has severed and the rootplate has disappeared. Both parts are perfectly healthy.

This was only recorded in downy birch, but an incipient case was observed in rowan (see figure 47).

4. Species

A total of 141 phoenix trees were recorded in this study, across 14 broadleaved species. They are most frequently encountered in 3 species - oak, downy birch and alder; partly because these species are themselves are common. In goat willow, grey willow, wild apple and hazel, numbers of phoenix trees are fewer because they are less common species; however they still comprise a significant proportion of older trees in these species, especially on damp and/or sloping sites. Phoenix trees are far rarer in silver birch, ash and rowan, though they do occur (see tables 2 and 3)[3]. Single interesting examples in were recorded for lime, sweet chestnut, horse chestnut and elm in a policy woodland (Old Polltalloch, Argyll). The author has also observed phoenix trees in native Scots pine, bird cherry, wild cherry, holly, wych elm and hawthorn. European larch phoenix trees also occur on exposed sites.

4.1 Oak

Oak provides some particularly spectacular phoenix trees, due to them typically being large trees when they fall, and then going on to develop equally large new crowns in their new orientation. Trees whose stems at time of falling measured up to 87 cm diameter and 23 m tall were observed regrowing as phoenix trees, and the *average* (original) stem diameter of oak phoenix trees was 63 cm. Phoenix regrowth was recorded up to 46 cm in diameter and 18 m in height, which is indeed the dimensions of a fairly large tree; and the average crown area was a little over 100 square metres, with the largest being over 400 m^2. The average estimated age since falling was 39 years, with a span between 5 and about 80 years. There were areas of the study site in Taynish Oakwood where phoenix trees made up 30- 50% of trees of the woodland (see figure 18 as an example).

Oak is a specialist at both at "new-tree" phoenixes (48%) and double phoenixes (19%). The fact that nearly 20% of oak phoenix trees at Taynish had blown over twice is very surprising. Even more surprising is the low incidence of apparent secondary rooting (7%), meaning that these trees were thriving often for decades using only the original rooting, including those that had been blown over twice. A frequent feature of oak phoenix trees are large new stems emerging from where the root plate joins the former stem (see fig 18). Oak is unusual in that trees fails almost exclusively by windblow involving a lifted rootplate (97% of trees). It shows high proportion of propped trees (32%) compared with other species, because of the substantial branches in oak supporting the trees after they fall.

4.2 Downy birch

Downy birch is a specialist at thriving wet and windy sites and on poor soils where the risk of windblow is high. It seem no accident that it is so capable of forming phoenix trees in these situations. In both main study sites there were areas where the proportion of phoenix trees was between 30% and 60% of all trees; though it was generally about 5-10%. After spending time at these sites the author began to suspect that some of the upright trees may well have started life as phoenix trees, but eventually lost the tell-tale signs (the tree in figure 34 is close to that point). Phoenix regrowth was recorded up to 17m tall, and 60 cm diameter.

Downy birch phoenix trees develop the full range of types of structures, with new-tree and crown structures being most common. Across all sites 7% were double phoenix trees (blown over twice) – which is another measure of their capability of withstanding windblow. Most stems are grounded (69%), probably reflecting the light branching which is not best suited to propping. The stems being in ground contact helps secondary rooting to develop, which downy birch is particularly adept at (59% of trees,

[3] Ash is excluded from tables 2 and 3 because of insufficient numbers. Silver birch is excluded because it was recorded on a non-typical site.

though this is a minimum estimate). Secondary rooting develops quickly and soon forms obvious structures.

The ability of downy birch to re-root is a factor in allowing complex phoenix trees to develop (7% of trees), with multiple rooting positions and the crown expanding both along the ground and upwards. Downy birch displays most of the types of failure leading windblow; the most interesting of which is “wrench trees” where the trees collapse without the rootplate lifting (34% of trees). On steep slopes, trees falling downward can give the impression of trees “stepping” downslope (figure 40).

4.3 Silver birch

Silver birch is amongst the least likely native trees to form phoenix trees. Five trees were located on one small site where trees had fallen as a result of adjacent conifers having been clearfelled. Silver birch seem quite likely to die as a result of falling, either due to the trauma, or swamping by bracken or infections from wounds. Furthermore the crown seems reluctant to re-orientate and the pendulous twigs remain pendulous after falling. The contrast with downy birch is very obvious.

4.4 Alder

Alder phoenix trees are most frequent where wet flushed soils and steep slope coincide. Wet flushes on the sides of a gulleys in ancient woodland will often have alder phoenix trees. Wrench trees are quite common (38%), which may be a function of the wet soil conditions allowing slippage of the roots. In the limited sample in this project trees were fairly evenly split among hedge, crown and new-tree structures. One double phoenix was recorded, including an example of pipe-roots. Alder phoenix trees were younger than other species, but this may be an artefact of the small sample size.

Figure 39. An alder new-tree phoenix, Loch Tummel, Perthshire.

Table 2. The frequency of the different phoenix tree structures, stem positions and types of stem failure, for the eight main species (percent). The values for the species in italics should be regarded as only being indicative, because the sample numbers are low – but they nevertheless bring out some important features. Silver birch was excluded from the analysis because the site was non-typical.

Tree species	**PHOENIX TREE STRUCTURE**						**STEM POSITION**				**TYPE OF STEM FAILURE**							**No of trees**
	New-tree	Hedge	Crown	Double	Complex		Grounded	Propped	Susp-ended		Lifted rootplate	Wrench	Stem failure	Half tree	Collapsed coppice	Not known		
Oak	48%	19%	13%	19%	0%		52%	32%	16%		97%	0%	0%	0%	3%	0%		**31**
Downy birch	38%	15%	33%	7%	7%		69%	25%	6%		61%	30%	4%	2%	0%	3%		**54**
Alder	25%	33%	33%	8%	0%		54%	31%	15%		46%	38%	0%	8	8%	0%		**13**
Goat Willow	*20%*	*0%*	*20%*	*20%*	*40%*		*80%*	*0%*	*20%*		*0%*	*60%*	*20%*	*0%*	*20%*	*0%*		***5***
Grey willow	*0%*	*11%*	*33%*	*0%*	*56%*		*83%*	*17%*	*0%*		*22%*	*11%*	*11%*	*0*	*56%*	*0%*		***9***
Rowan	*20%*	*60%*	*20%*	*0%*	*0%*		*80%*	*20%*	*0%*		*0%*	*20%*	*40%*	*20%*	*20%*	*0%*		***5***
Hazel	*0%*	*57%*	*43%*	*0%*	*0%*		*71%*	*29%*	*0%*		*29%*	*43%*	*14%*	*0%*	*14%*	*0%*		***7***
Wild apple	*17%*	*17%*	*67%*	*0%*	*0%*		*50%*	*50%*	*0%*		*33%*	*33%*	*17%*	*0%*	*17%*	*0%*		***6***
ALL SPECIES	**32%**	**21%**	**29%**	**9%**	**8%**		**64%**	**27%**	**9%**		**58%**	**24%**	**6%**	**2%**	**8%**	**1%**		**130**

Table 3. The age since falling; the dimensions of the remaining stem; the dimensions of the phoenix regrowth, and the incidence of obvious secondary rooting for the eight main species. The values for the species in italics should be regarded as only being indicative because the sample numbers are low – but they nevertheless bring out some important features. Silver birch was excluded from the analysis because the site was non-typical.

	ESTIMATED AGE SINCE FALL (YRS)	**REMAINING STEM OF ORIGINAL TREE**		**PHOENIX REGROWTH**				**Proportion Showing Clear Secondary Rooting**	**Number of Trees**
	Mean age yrs (max, min)	Mean diam. cm (max, min)	Mean length m (max, min)	Mean regrowth height m (max, min)	Mean total tree height m (max, min)	Regrowth diameter cm (max, min)	Mean crown area m^2 (max, min)		
Oak	39 (80, 5)	63 (87, 28)	8 (23,1)	9 (18, 0)	10 (18 ,3)	20 (46, 1)	110 (433, 11)	6%	31
Downy birch	32 (85, 2)	36 (61, 18)	7 (19, 0)	6 (17, 0.75)	8 (17, 2)	16 (60, 1)	53 (198, 7)	59%	54
Alder	15 (35, 5)	39 (81, 20)	6 (16, 1)	4 (8, 1)	6 (10, 1)	11 (28, 1)	52 (153, 7)	38%	13
Goat willow	*26 (37, 26)*	*55 (69, 44)*	*6 (12, 2)*	*7 (11, 3)*	*8 (13, 4)*	*24 (26,20)*	*88 (212, 19)*	*40%*	*5*
Grey willow	*20 (37, 12)*	*40 (63, 19)*	*10 (15, 5)*	*5 (7, 3)*	*6 (8, 4)*	*11 (19, 7)*	*140 (271, 28)*	*67%*	*9*
Rowan	*18 (32, 12)*	*49 (65, 32)*	*5 (12, 1)*	*6 (11, 4)*	*7 (11, 4)*	*13 (22, 8)*	*47 (86, 7)*	*60%*	*5*
Hazel	*12 (22, 5)*	*36 (55, 22)*	*6 (8, 4)*	*5 (10, 2)*	*7 (10, 3)*	*7 (18, 3)*	*50, (104, 25)*	*57%*	*7*
Wild apple	*16 (55, 1)*	*37 (50, 22)*	*7 (12, 1)*	*3 (9, 0)*	*5 (7, 3)*	*7 (23, 1)*	*47 (82, 21)*	*17%*	*6*

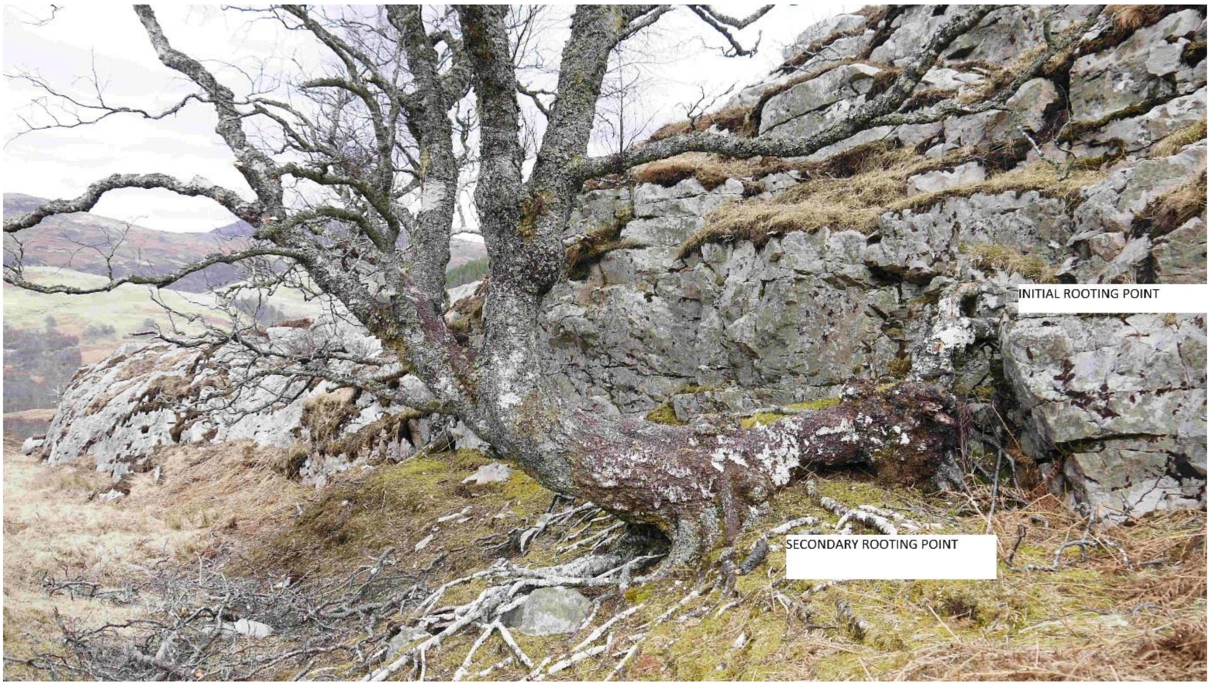


Figure 40. An example of secondary rooting in a downy birch that has fallen away from a rock ledge, then re-rooted, with the roots exposed by soil erosion, Dundonnell

4.5 Goat and grey willow

Both these species seem to fall over easily and at relatively young ages, and thrive very well as phoenix trees (see figs. 41-43). A high proportion of older willow trees growing on wet peaty soils adopt this growth form, to the extent that it seems like this is part of the strategy of these species. Wet pockets and flushes, and fens on floodplains and around lochs often host these interesting trees. The site at Loch a'Mhuilinn had an area of grey willow wet woodland (NVC W2) which comprises the interlinking crowns of multiple phoenix trees. Most willows are wrench trees or collapsed coppice and fewer are uprooted. Many trees, especially grey willow, are already multi-stemmed when they fall, and these multiple stems readily develop complex forms as they re-grow (40% of goat willow and 56% of grey willow trees were complex structured). These can end up covering large areas – several trees surveyed reached about 200 m^2 in extent (figure 41); which is significant size for otherwise small trees. They eventually produce significant new rooting from grounded stems, but seem only do this to a relatively limited extent. Oddly, some of this rooting seems to emerge from the top side of moss-covered grounded stems, apparently having developed under the moss layer.

4.6 Hazel

Hazel forms phoenix trees/bushes very readily, with regrowth up to 10 m tall in older examples (see figs. 44-46). Phoenix trees form as a result of old coppice stools collapsing, or by uprooting due to wind. Hazel is commonly seen falling downslope on steep gulley sides and sometime snow loading seems to be a contributory factor. Regrowth is mainly in hedge form, as multiple shoots develop from stems and branches. Hazel forms new roots easily - which fits with the known ability of the species to layer easily.

Figure 41. A complex grey willow phoenix, Loch a'Mhuilinn, Sutherland covering over 200 m^2 which is a good strategy for an otherwise small tree

Figure 42. A small goat willow wrench phoenix tree near the treeline, Rannoch, Perthshire

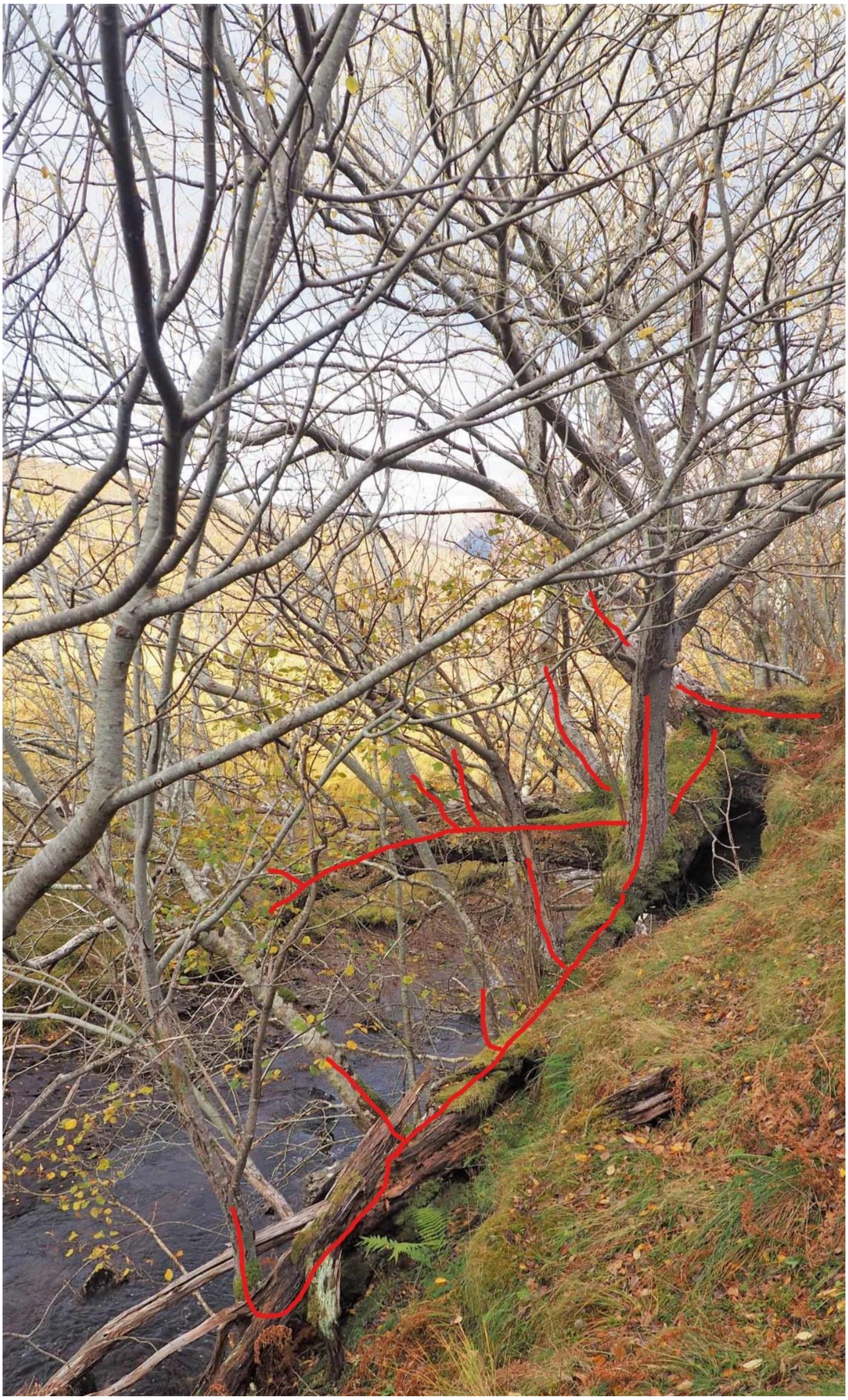


Figure 43. Part of a complex goat willow phoenix tree, Dundonnell, covering about 200 m^2.

Figure 44. In a phoenix hazel wood, Frenich, Perthshire

Figure 45. Phoenix hazel, Dundonnell showing multiple fairly old stems in hedge structure. Note the "fist".

Figure 46. New rooting from a fallen hazel stem

4.7 Rowan

Rowans appear to form phoenix trees fairly readily, even when they are large old trees, with one tree of 65 cm diameter being recorded. They also are adept at re-rooting from grounded stems (60% of trees) and one sample included a rooting bridge. Hedge structures are the most common (60%).

Figure 47. Rowan phoenix tree where the former main stem has re-rooted at the centre of the picture forming a rooting bridge from the original rooting position on the far right. Note how the diameter of the stem increases markedly after this point, which helps reveal that the stem has rooted.

4.8 Wild apple

Wild apple is particularly adept at forming phoenix trees. A recent study of 200 wild apple trees in Scotland revealed about 20% were phoenix trees (Worrell et al. 2019, see figures 48, 49). It is a species that seems to be able to withstand all sorts of trauma, and crowns will continue to grow with only the smallest strip of bark connecting it to the roots (figure 27). Trees fail in all the ways listed in this paper. They adopt most structures, with crown trees being common, but hedge trees and new-trees are rare. Double phoenix trees also occur (fig. 23).

4.9 Ash

Ash appears to form phoenix trees less frequently than most species, and only two ash phoenix trees were located in the course of this study. However these had developed impressive structures and one was the tallest phoenix tree recorded – 22 m tall (see figure 8).

Figure 48. A typical old wild apple phoenix in bloom in a gulley woodland near Loch Lomond. The original rooting point is out of picture to the right. Note the epicormics shoots covering the trunk.

Figure 49. An unusual wild apple phoenix on the shore of Inchfad, Loch Lomond with new grow emerging from behind the rootplate – the rootplate having remained shallow rooted because of the high watertable at the lochshore.

4.10 Lime, horse chestnut, beech and sweet chestnut

One site (Old Polltalloch, Argyll) included an area of policy woodland with specimen broadleaved trees (see figs. 50-51). These included a few spectacular examples of common introduced tree species which had adopted phoenix forms. Lime, horse chestnut and sweet chestnut clearly form phoenix trees easily, with stems and branches re-rooting extensively. The horse chestnut was one of the largest phoenix tree in this study covering over 300 m^2, with multiple large new rooting positions (figure 50). The site also included an area of sweet chestnut (figure 51) with multiple phoenix trees and several examples of large beech phoenix trees.

Figure 50. A very large complex horse chestnut phoenix Old Polltalloch, Argyll. Note the three people for scale.

Figure 51. Sweet chestnut phoenix, Old Polltalloch, Argyll

4.11 Holly

Holly phoenix trees are rare, but do occur (see figure 52).

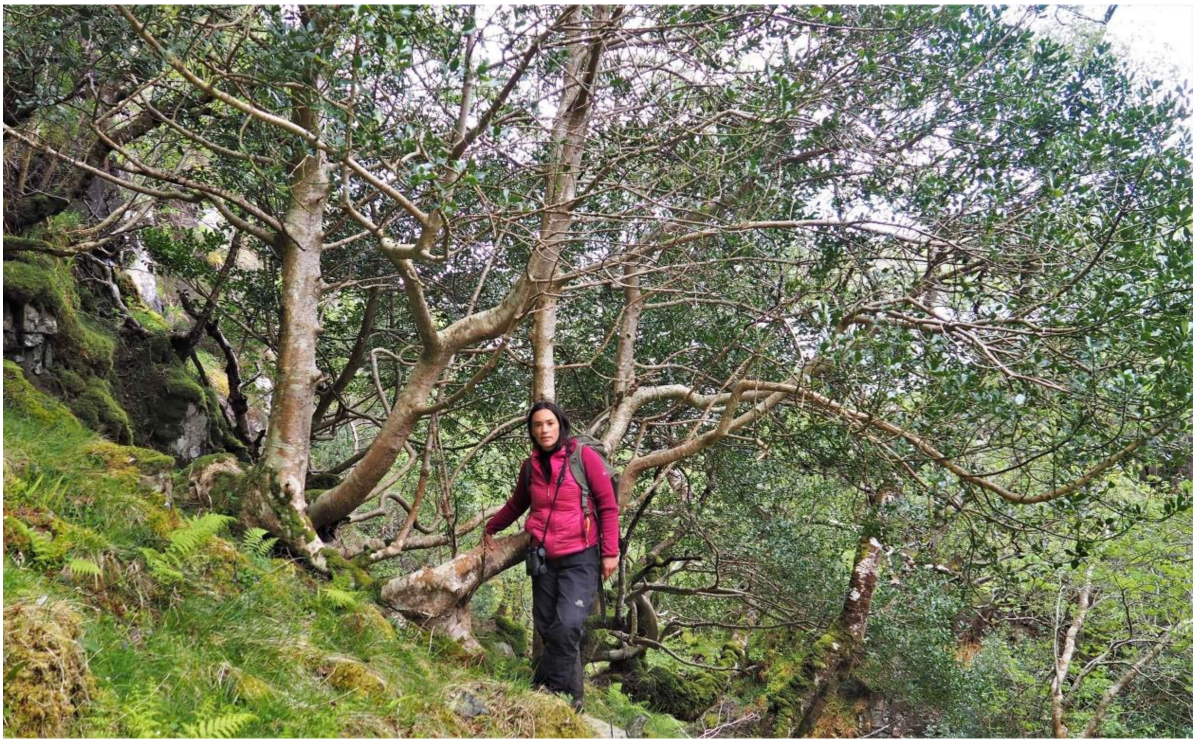


Figure 52. An old holly phoenix tree in a remote gully near Kylesku, Sutherland.

4.12 Scots pine and European larch

Scots pine phoenix trees do occur in Caledonian pinewoods (fig. 53), but seem infrequent.

Figure 53. Two old Scots pine phoenix trees in Caledonian pine woodland, Meggernie, Perthshire.

European larch forms phoenix trees, especially in windy situations and when planted at low density; and several hilltop in Perthshire are graced by such trees.

5. Development through time and aging phoenix trees

5.1 Aging a phoenix tree by shoot growth characteristics

The point at which a phoenix tree crown starts to re-orientate is marked by a sudden change of angle in the twigs or branches, usually fairly close to 90 degrees, and this point can be used to identify when the tree fell. The size of branches, stems and new-trees above this point can be used to estimate the age since the tree fell. For the first about 8 years, the age of the shoot can be estimated by identifying each year's growth from bud-scale marks on the stem, or other signs of annual growth cessation. Beyond that stage a "guestimate" of age can be made by comparing the size of the new growth with equivalent normal trees. In some ring-porous tree species (oak, alder, wild apple) age could be confirmed by cutting sections off lower branches just above the change of angle or by using an increment bore; though time did not allow this during this study and some owners were also reluctant to allow boring. It should be noted that the growth rates of re-orientated branches and stems almost always decreases the further from the original rootplate that they are growing, and that account needs to be taken of that.

5.2 Aging a phoenix tree by rootplate characteristics

A second means of estimating the period of time since the tree fell is to inspect the rootplate for the progressive rotting and disappearance of exposed, fractured roots, and the progress of re-vegetation. The maximum size of remaining roots is probably the best indicator. There were sufficient samples for downy birch and oak to estimate this (table 4). In downy birch rootplates where fine roots remain appear to be 1-8 years old, and those where the fine roots have rotted away but medium roots remain are typically in the range 11-22 years ; and rootplates with only large roots remaining are older than about 22 years. The equivalent cut-off ages for oak are about 12 and 25 years.

Table 4 Using the size of severed roots to estimate the age since falling of phoenix trees

Size of remaining roots on exposed rootplate	**Estimate age since the tree fell (years)**	
	Downy birch	Oak
Fine roots evident (< 10mm diameter)	1-8	1-12
Only medium roots evident (11-30 mm diameter)	11-22	9-25
Only large roots evident (> 30 mm diameter)	22+	25+

5.3 Age distribution

The age class distribution for all the trees in this study is shown in figure 54. This shows a reverse J curve with more younger trees than older ones. This can be interpreted in two ways. Either there is reasonably steady recruitment of trees, but a proportion of these then die as time progresses. Alternatively, more trees have actually been recruited in the last 40 year period than in the previous period one (which would have been approx. 1940-1980). Whilst both causes are probably operating, it seems likely that native woods are increasingly reaching the age and height at which windblow is likely to happen, such that recruitment is actually likely to be increasing.

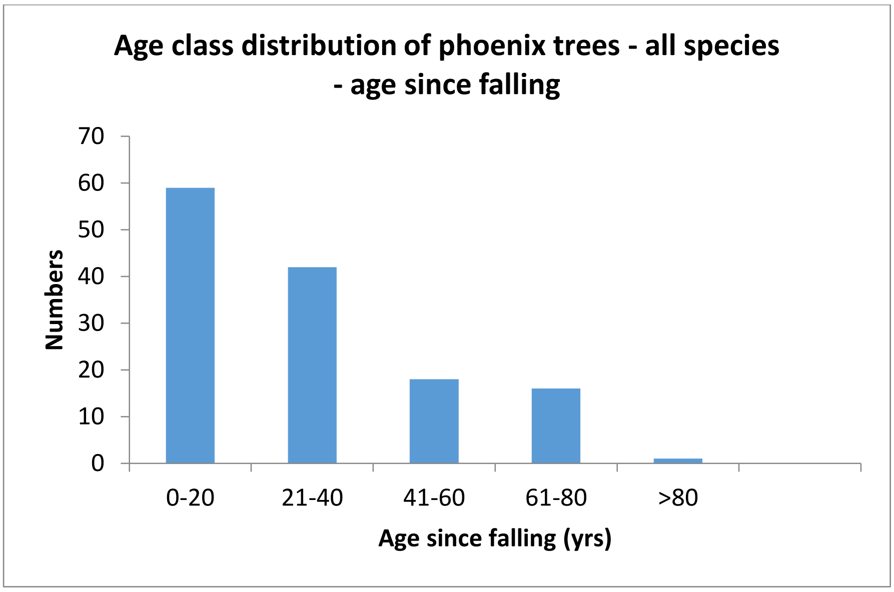


Figure 54. Age class distribution of phoenix trees (age since falling) – all species

The patterns are rather different for the two species in the study with sufficient samples to enable analysis of their ages. For oak, the class distribution suggests a surprisingly constant recruitment of trees starting about 80 years ago (see figure 55). In this case the main site was Taynish where trees were over 200 years old, and clearly at a stage where phoenix trees could have been forming for many decades.

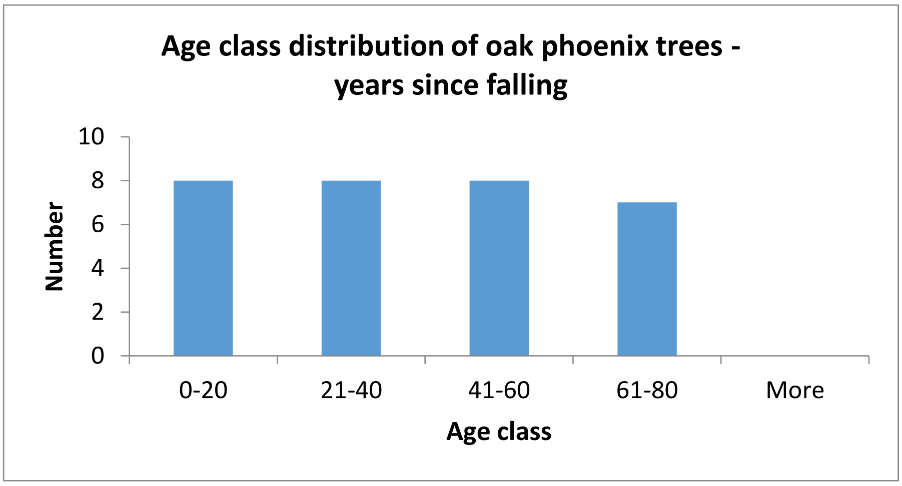


Figure 55. Age class distribution of phoenix trees (age since falling) – oak

For downy birch, which was recorded across several sites in woodland of various ages, recruitment of phoenix trees appears to be far stronger in recent decades than previously (figure 56). The lower number of more recent trees (0-20 years) is the a result of the subjective sampling approach adopted, in which the youngest trees were regarded as less interesting, and older ones tended to be preferentially selected.

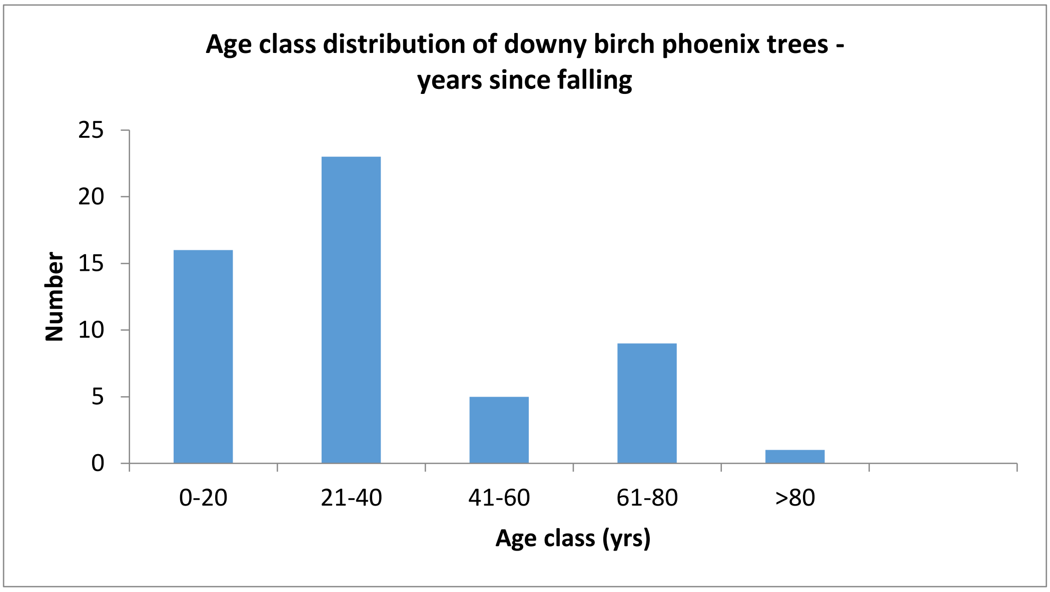


Figure 56. Age class distribution of phoenix trees (age since falling) – downy birch

6. Occurrence

Whilst phoenix trees can occur almost anywhere, they are most frequent, predictably, at higher elevation, in the west, and on wetter soils. Most woods on the lower slopes of hills in western Scotland will habour a good number of interesting trees. Shelves on slopes with waterlogged soils are often marked with a few tell-tale phoenix downy birches or willows. On shallow soils over bedrock, phoenix trees are more frequent and can strip the soil right back to the bedrock when they fall, and some pick up considerable amounts of rock (see figure 58). They are markedly more frequent on steep slopes, and are relatively common on gulleysides and near crags, where they add to the interest of upland native woodland remnants. Here they almost invariable fall downslope. Trees on crags and rock steps loose purchase and fall; and sometimes this process happens slowly, giving rise to peculiar bent trees (see figures 20, 59).

Phoenix trees occur in both woodland and wood pasture, but reach their highest densities and most spectacular forms in widely spaced grazed woodland and wood pasture. A tree falling in closed canopy woodland has to deal with the shade cast by surrounding trees, and typically these only survive when a particularly large canopy gap is formed or where the tree receives side-light from a woodland edge. As the spacing in woodlands increases, and the canopy becomes sparser, more phoenix trees are likely to survive. In wood pasture there is rarely any competition from surrounding trees. In ancient wood pasture phoenix trees are common and characteristic, and add greatly to the ecological and aesthetic value of these remarkable habitats.

Figure 57. Phoenix tree are common in windy western locations – here a wind-pruned oaks on the coast of Mull

The frequency of phoenix trees also increases as woodlands get older and taller and therefore more likely to blow over. Their frequency probably increases in a similar way and under the control of the same factors as windthrow hazard in commercial plantations.

Figure 58. Phoenix trees are frequent on shallow soils – though in this case at Taynish, Argyll the roots of this recent phoenix oak have taken up the bedrock as well as the soil.

Figure 59. This downy birch phoenix has been slowly peeling of a rocky bluff since it was quite young. The main stem is responding by forming a curve, and this new position has led to the formation of a new stem from just above the rootplate.

7. Conservation value

7.1 Veteran tree characteristics

Phoenix trees are important because the process extends the lives of what are often already quite old trees. In their new more stable position phoenix trees can grow to be very old trees indeed, with many veteran characteristics and providing continuity of micro- habitat for many species. One important aspect of phoenix trees is that veteran and young growth micro-habitat can occur in close proximity on the same tree, providing habitat for a very wide range of epiphytic plant. An eye-catching feature are small gardens of mosses, lichens and sometimes higher plants supported on horizontal stems (figure 60).

Figure 60. Small "gardens" of mosses, lichens and some higher plants on horizontal stems.

Lichens

Assessing the conservation value of individual phoenix trees was only attempted in this study at a basic level, using lichens as an example of their wider value. Lichenologists will often seek out phoenix trees as they are often some of the oldest trees, and have veteran tree characteristics and wide variety of niches for lichen (Andy Acton *pers. comm.*[4]). Phoenix trees can often be a key lichen habitat, though there are no lichens that are confined to phoenix trees. Older phoenix trees have had a long period to accrue a diverse lichen flora of species including:

- *general 'old woodland indicator' species* that require ecological continuity at the stand scale but can readily colonise mature trees (and even young maturing trees) in ancient woodlands if conditions are suitable (e.g. the Tree Lungwort *Lobaria pulmonaria*)
- *Specialist species largely confined to 'old growth' niches* that are generally absent from younger, or even mature, trees. These include dry sheltered crevices of rough old bark, the bare lignum of tree hollows and decorticate limbs (i.e. where the bark as disappeared), and wound tracks where there is nutrient enriched flushing as a result of damaged bark and rot holes.

As a tree ages, the abundance of niches for smooth bark lichens declines because the bark becomes rougher, or is colonised by bryophytes and larger leafy lichens. The development of shoots and stems on a phoenix tree can mean that old growth niches co-exist with niches younger and/or mature niches on the same tree. The unusual growth forms present a variety of niches subject to different levels of light/shade, ventilation, humidity and shelter/direct rainfall. This is often reflected in the epiphytic flora which can be very rich, especially on veteran phoenix tees and phoenix hazel

[4] Andy Acton prepared the paragraph on lichens based on his experience and photos of the trees in this study taken to illustrate the occurrence of lichens. The aim had been to engage a student to do this, but this turned out to be impractical.

bushes. The smooth bark of the new stems not only increases availability of niches for common and widespread colonising species, but can become important for some specialist smooth bark lichens. For example an 'old woodland' *Graphidion* community can develop on younger and maturing stems, with good populations of species, such as the old woodland Tree Barnacle (*Thelotrema lepadinum*). Lichen colonisation can occur much more readily on phoenix trees because dispersal distances can be very short between the stems of an individual tree than between trees (especially in more open wood pasture scenarios).

The process of phoenix regeneration results in changes in micro-habitat that have both positive and negative impacts on the lichen flora. When trees blow over conditions for lichens on the trunk changes drastically. Species on one side of the trunk now face the ground and on the opposite side faces skywards. If the tree collapses fully, lichens on this underside may be smothered by the trunk, and lichens on the tops and sides of the trunk may have increased competition from the more robust common and weedy woodland floor bryophytes such as feather mosses (e.g. *Hylocomium splendens, Pleurozium schreberi*), and even by vascular plants, especially if herbivore grazing is low. Prostrate trunks allow easier access for slugs which can graze on the lichens. Only common, more robust weedy lichens such as some common Dog Lichens (some *Peltigera* spp.) can cope with these conditions.

If a tree does not collapse fully, niches change as the underside becomes sheltered from direct rainfall and more shaded, whilst the top becomes subject to more direct rainfall and potentially more sunlight than previously. The sheltered underside may be less favourable for some light-demanding species (which may be lost from the underside), but can be important for species that do not tolerate direct wetting from rainfall. These include dry bark crustose species such as some 'powder' or 'dust' lichens (*Lepraria, Chrysothrix* spp.), and where shaded is not too deep, more interesting crustose species such as the old woodland indicator *Arthonia leucopellaea* (a type of 'Comma' lichen of old birchwoods and pinewoods) and specialist 'Pinhead' lichens (*Caliciales*) can occur. The increased rainfall on the top of trunks may favour bryophytes (mosses and liverworts) and those larger leafy lichens that can cope with any increased competition from mosses. In oceanic woods in the west of Scotland, leaning and more or less horizontal stems can be particularly important for old woodland Specklebelly lichens (*Pseudocyphellaria* spp.).

8. Aesthetics

People seem to react universally positively to phoenix trees. A large live tree in a horizontal position is a naturally intriguing phenomenon. Older phoenix trees resemble works of sculpture, with beautiful, interesting and puzzling shapes. The fact that these arise naturally, with the trees obviously trying to "sort themselves out" after falling over, adds another element of wonderment. They provide odd features not seem in other trees, such as roots apparently growing up to several metres in the open air; small gardens of epiphytic plants, and rootplate saplings piggy-backing on the mother tree. And many are obviously old and venerable. Unfortunately at present phoenix trees are currently hardly appreciated by anyone beyond a passing ecological surveyor.

9. Threats – natural and chainsaws

Once a phoenix tree has overcome any physical damage, browsing and shading from bracken, the only natural threat to its long term existence is fungal disease. Life-threatening fungal disease seems relatively infrequent and was generally only observed in a few downy birch trees, such as that in figure 13. However many trees in this study were clearly engaged with fending off more minor fungal attack as shown by fungal fruiting structures; and with old frequent damaged points, and stems and branches in contact with the soil, there are ample opportunities for ingress of fungal disease. Dead phoenix trees do occur, showing that trees eventually succumb on a scale of decades (figure 61).

Figure 61. A dead phoenix oak, Mull. It seems likely that the disease entered via the damage near the base.

There is a stage in the development of birch woods in particular when they reach a height at which they become susceptible to windblow and breakage, during which many windblown trees occur, and pathogen loadings appear to be high. At this stage some infected phoenix trees can be seen. Eventually the numbers of trees susceptible to windblow diminish and it appears that the incidence of disease also reduces. By the time a wood reaches wood pasture densities, serious fungal disease appears quite rare (presumable because susceptible trees have died and disappeared). Often phoenix trees are extremely stable, and seem able to resist all manner of impacts such as breakage of stems and branches, soil poaching, fraying, bark-stripping and browsing.

Spare the chainsaw

The principal threat to phoenix trees, at least in accessible locations, comes from firewood cutting. Understandably a downed tree is a welcome and easy target for those of us engaged with heating our homes with firewood... Ironically, a phoenix tree that had the potential to become one of the most remarkable trees in Scotland (figure 5) – with 3 huge coppice stems, 80 cm in diameter, each having fallen perfectly at 120 degrees and starting to regrow, became the victim of a firewood cutter a few months after it was observed in this study. An approach to the estate about conserving the remaining 2 stems elicited no response, presumable considering anyone lobbying on behalf of fallen trees to be mentally unsound.

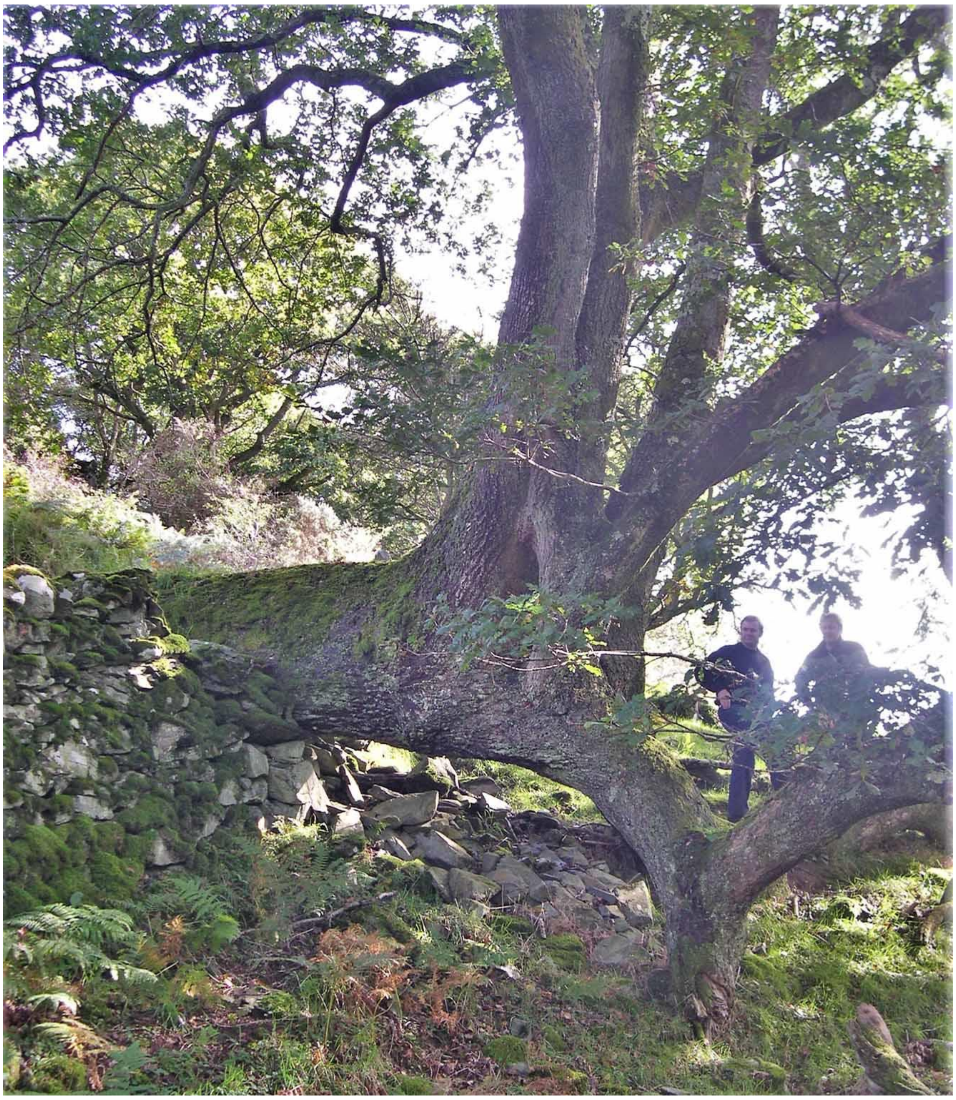


Figure 62. This propped oak phoenix tree has done well to avoid being cut up for firewood at any point over the 70 or so years since it fell through a wall in the Boreland Hills, Kirkudbrightshire (Photo credit: Peter Norman).

10. Discussion

This project sets out evidence that phoenix trees are a serious ecological phenomenon. They are also attractive and interesting trees that foresters and ecologists should appreciate better, and should bring to the attention of the wider public. They are widespread across Scotland, to the extent that most ancient woodland remnants will harbour some, and on some wet and windy sites they are common enough to be eye-catching. So what might their ecological significance be ? And if they are important, how can we look after them ?

10.1 Ecological significance

Surviving windblow as a phoenix tree prolongs the life, and importantly the reproductive life, of a tree. The process of forming a phoenix rejuvenates the tree (like coppicing does) and ensures several decades of further growth and seed production. Phoenix trees are relatively stable against further windblow events for several decades, and appear well protected against other common threats. As result, they continue to produce seed for decades after "normal" trees have blown over and died. This is clearly an advantage to the individual tree and its offspring. Other mechanisms that prolong the life of trees, such as the ability to regrow as coppice, or going hollow to increase stability, are regarded as important ecological attributes of broadleaved trees, and are referred to as adaptive advantages (Read 2000). A strong case can be made that the ability to form phoenix trees is part of the life strategy of many broadleaved tree species – i.e. that they are designed to regrow following falling in old age. This seems particularly obvious in species like willows, which often form phoenix trees at relatively early ages. It is clear from this study that trees of many species have the potential to live as long, or longer, in recumbent positions than they do upright.

This makes the formation of phoenix trees a particularly important manifestation of the ability of mature trees to regrow following damage. Other examples of this type of regrowth include trees resprouting from the base when they the main stem is affected by disease, and regrowth as coppice following felling by beaver, or by people. Elephants in Africa push trees over, and it is quite conceivable that post glacial megafauna might also have done this in temperate forests. It seems likely that phoenix regrowth uses similar mechanisms to those that occur as a result of these other types of damage; and that it is also allied to coppice and pollard regrowth caused by management of trees. It is interesting, looking at the literature, that all the focus has been on coppicing (presumably because it carried out by, and is useful for, people), and the regrowth of trees as a result of them falling over has barely been studied.

This project suggests, albeit on the basis of only a few survey sites, that phoenix trees become considerably more frequent on exposed sites where trees are particularly susceptible to windblow. What is unclear is if this is simply a reflection of the increasing frequency of windblow, or if the trees on these sites are also better adapted to form phoenix trees, and a result of past selection pressures. If there is a heritable genetic element to the ability to form phoenix trees, this is potentially quite an evolutionary advantage on such sites. The ability to coppice is known to be under strong genetic control, so it is likely that this could also be the case for the ability to form phoenix trees. However without genetic testing – which would be challenging to conduct (!) – this cannot be stated with certainty.

It is interesting that the few introduced trees species included in this study i.e. horse chestnut, sweet chestnut and lime appear (one the basis of a very limited sample), to be very capable at forming phoenix trees. This should be enough persuade us that trees native to far less windy and wet climates also have use of the mechanism, and that recovering from falling over is likely to be a fairly universal feature of broadleaved trees. However one can't help suspecting that in Scotland, with one of the windiest climates in the world and some very wet and shallow soils, the need to, and benefits of, forming phoenix trees might be greater than in many other parts of the world. It would be useful to research whether phoenix trees feature other forests in similar windy, oceanic climates.

10.2 Physiological conundrums

This project highlights some interesting physiological conundrums. Whilst plants are known to be hugely resilient to many types of physical damage, and able to adapt to all manner of changing circumstance – it is still surprising that large mature trees can cope so well with the multiple traumas involve with falling over. Most obvious is the fact that typically 50 - 80% of roots are suddenly severed and ones remaining in the ground are all either bent or twisted at right angles. At the same time the crown rests at a 90 degree angle to that of the previous day, and many of the branches on what is now the underside of crown are broken or bent. This is typically followed in Scotland by all the foliage below browse height disappearing courtesy of herbivores. Whilst many trees do indeed succumb as a result of all this, the fact that any recover is, to say the least, counterintuitive.

In some puzzling examples the entire crown appears to recover quickly, and one can only conclude that movement of water and nutrients in the roots and stem is suddenly re-organised in fundamental ways, which it would be interesting to know more about. In other trees, the original crowns are badly damaged and partly or wholly die, but this is compensated for by regrowth elsewhere, especially new stems forming near the junction of the former stem and rootplate (which is very like coppice regrowth). In these cases what is remarkable is that the former crown and stem can rot away, but the tree is able to compartmentalise this, and fully protect the new growth from fungal decay. In many cases, stems that have developed for decades or centuries in a vertical position and surround by air, appear to adapt quickly to function equally well lying horizontal on wet ground. Some of these stems develop new rooting positions, and therefore have stem sections devoted to connecting one set of roots with another, which is physiologically rather odd. In the process of recovery, the basal sections of some roots up to several meters long become exposed in the air, but seem to thrive in this new state for decades. Finally we see branches supporting propped phoenix trees which continue to grow and thicken in response to loading, even though they are partly buried and have no foliage. It would be interesting to engage tree physiologists in order to fully understand the mechanisms that allow all these remarkable adaptations.

In this project a number of new terms have had to be coined to describe the field evidence. This includes the terms describing the diverse structures of phoenix trees (new-tree, hedge, complex etc.) and a few structures described apparently for the first time (double phoenix trees, half-trees, wrenched trees, rooting bridges, pipe roots, severed and clonal phoenix trees). One benefit of this project is that we now have the vocabulary to allow us describe the multiplicity of phoenix tree features and decipher how these came about.

10.3 Why no very old phoenix trees ?

The ability of a trees to form phoenixes can radically prolongs their lives. Some of the older oak trees in this study appear to be in excess of 200 years old when they fell, and some have then thrived for a further 80 years as phoenix trees, and most are still going strong. Nearly 20% of oaks have fallen over for a second time, then regrown as “double phoenix trees”. Double phoenix trees in particular are very stable to further windblow, being supported on multiple large grounded stems; indeed once in this state the trees seem indestructible, except by disease or firewood cutting. So it is something of a mystery why we are not finding some very old trees of this type, i.e. ones that might be several hundred years old. The most likely explanation for this is historic cutting, carried out by large, impoverished, rural populations in previous centuries, which valued and used any easily accessible lying timber. It could also be speculated that pasturage of goats, that was common in earlier centuries, might also have impacted on phoenix trees.

10.4 Future recruitment

This project highlights than many phoenix trees are relatively recent – with mean ages since falling estimated to be 12-39 years (according to species) and with maximums estimated to be 22-85 years. They are continually being recruited. It seems likely that phoenix trees are currently becoming more frequent, as native woodlands that originated in the 19th and 20th century, or grew up after wartime fellings, reach ages where they are more likely to blow over. So it appears that we may be entering a stage in native woodland development in which phoenix trees will become more prominent in our woods and wood pastures, rather than less. This is an exciting prospect for those of us now quietly obsessed with horizontal trees.

In many woodlands there appears to be a time sequence, with phoenix trees only becoming prominent in older woodland. In a closed canopy woodland, phoenix trees are relatively rare because any fallen trees will need to contend with high levels of canopy shade, as well as the other hazards that beset a newly fallen trees. In older woods, conditions for phoenix tree formation appear to become much more favourable, with larger gaps and more widely spaced trees. As older grazed native woodland starts to take on wood pasture stocking levels, phoenix trees become far more apparent and conditions for them appear very favourable. It is this interesting stage that many woods Scotland are increasingly entering.

10.5 Phoenix trees as indicators of ancient woodland

The fact that phoenix trees tend to occur in older woodland obviously makes them a good means of identifying particularly old native woodland and wood pasture. Ancient woodland does not always comprise particularly old trees – that simply depends on when they were last felled. Many woods with useful timber were felled during the two world wars, oakwoods being a particular target. Prior to that, all manner of native woods were extensively managed on short rotations for centuries. Wood pasture was the main system that allowed significant numbers of trees to reach old age (Quelch 2001), so it is no surprise that that is where we find now the best populations of phoenix trees. What this means is that woods with a high incidence of phoenix trees are likely to be our oldest woodlands, and so important both ecologically and culturally.

The value and significance of phoenix trees, which has bypassed many foresters, has been very much appreciated by ancient (veteran) tree specialists. Phoenix trees are a recognised, though relatively minor, category of ancient tree (Read 2000); and specialists, mainly in England, but including Woodland Trust in Scotland, have done much to research, catalogue and publicise their values. Read (2000) lists the following species forming phoenix tree: lime, willow, alder, black poplar, medlar and bird cherry. The importance of veteran trees as hosts for a variety of species – invertebrate, fungi and epiphytic plants – has become apparent during recent years. However much of this effort has understandably been developed around more lowland sites in heavily managed landscapes, in which phoenix trees are rather less important. Extending this kind of effort to the study of upland phoenix trees could usefully feed into the work on ancient trees, adding a dimension centred more on natural landscapes and the natural process of phoenix tree formation.

10.6 How to manage

Thankfully the management needs of phoenix trees are very straightforward and only require minor adjustments to management practice. These are:

1. ***Awareness***: Owners and managers need simply to be aware of phoenix trees they might already have in their woods, and the potential for more to arise.
2. ***Survey:*** This requires surveyors to note their existence during woodland surveys as part of the "features of conservation value" and mention them in woodland management plans.
3. ***Spare the saw***: - Recently fallen trees should be noted and the urge to clear them up at the first available opportunity by converting them to firewood needs to be resisted. If they are not forming an obstacle to access and have the prospect for forming phoenix trees, they should be left for a year or two to see if they start to regrow.
4. **Go back and assess in a year or two**: - If fallen trees are showing signs of forming phoenix trees (crown still largely alive, twigs beginning to re-orientate upwards), they can be helped at this early stage simply by trampling down any bracken around them that may outcompete developing shoots. If they looking like they are dying, now is the time to convert to firewood.

Management of phoenix trees also arises in the context of regenerating grazed woods and wood pasture. Large reductions in grazing pressure will typically eventually lead to extensive growth of sapling trees, and these may ultimately come to threaten phoenix trees of all ages, but especially recent ones, by shading. Phoenix trees may need a helping hand by cutting away excessive regeneration, in the same way as for other veteran trees and special habitats. However a better route, though harder to achieve, is to reduce grazing to levels where recruitment of saplings occurs more sporadically over a longer time periods, in way that are less likely to impact veteran trees.

10.7 Further research

The research described in this report is fairly basic and could usefully be backed up with more detailed studies. Some priorities are to:

1. make better estimates of the ages of phoenix trees, using ring counts, to get a better information on their age class distributions and recruitment patterns for individual species.
2. get better information on their frequency in relation to site conditions, wind climate and woodland history.
3. engage tree physiologists to better understand the adjustments which take place to enable phoenix trees to develop and thrive.
4. help establish phoenix trees as part of wider research efforts on veteran trees.

10.8 Awareness raising

What is needed more than anything else is just a general awareness-raising effort about the value and significance of phoenix trees. This has the prospects of being fairly easy and needs to start with the forestry and ecology professions. Most foresters and ecologists know of their existence; and should hopefully find the types of information set out in this report interesting. If surveyors and managers could ensure that phoenix trees feature in woodland surveys and plans, that would lay the foundations for getting the word out to owners and other land use professionals.

Phoenix trees are potentially something that could easily engage the public. Veteran and other noteworthy trees have been promoted very successfully to the public in recent decades; now a similar effort needs to be made for phoenix trees. Phoenix trees combine several compelling elements: their enigmatic sculptural beauty, their compelling efforts to survive against the odds, and the unlikely stories of how they adjust themselves to their recumbent positions. On top of this, a case could be made that they are indeed an emblem of Scotland's (and the UK's) strange wet, windy climate, where trees have very little option in old age other than to fall over.

References

Forestry Commission Scotland 2009 Management of ancient wood pasture. 13 pp. Forestry Commission Scotland, Edinburgh

Quelch, P.R. 2001 Ancient Wood Pasture in Scotland. 2001 55pp. www.arborecology.co.uk/resources/Ancient%20W%20Pasture.pdf

Quelch, P.R. 2010 Upland Wood Pastures. Pp. 7-12 In: Rotherham, I.D., Agnoletti, M. and Handley, C. 2010 Landscape Archaeology and Ecology - End of Tradition Volume 8.

Read, H. 2000 Veteran Trees: A Guide to Good Management. English Nature & Veteran Trees Initiative. 167 pp.

Rotherham, I. D. and Handley, C. 2012 Shadow Woods and Ghosts Survey Guide.

Worrell, R., Ruhsam, M., Renny, J., Jessop, W., and Findlay, G. *in press*. Scotland's Native Wild Apple: Malus sylvestris - Ecology and Management. Scottish Forestry.