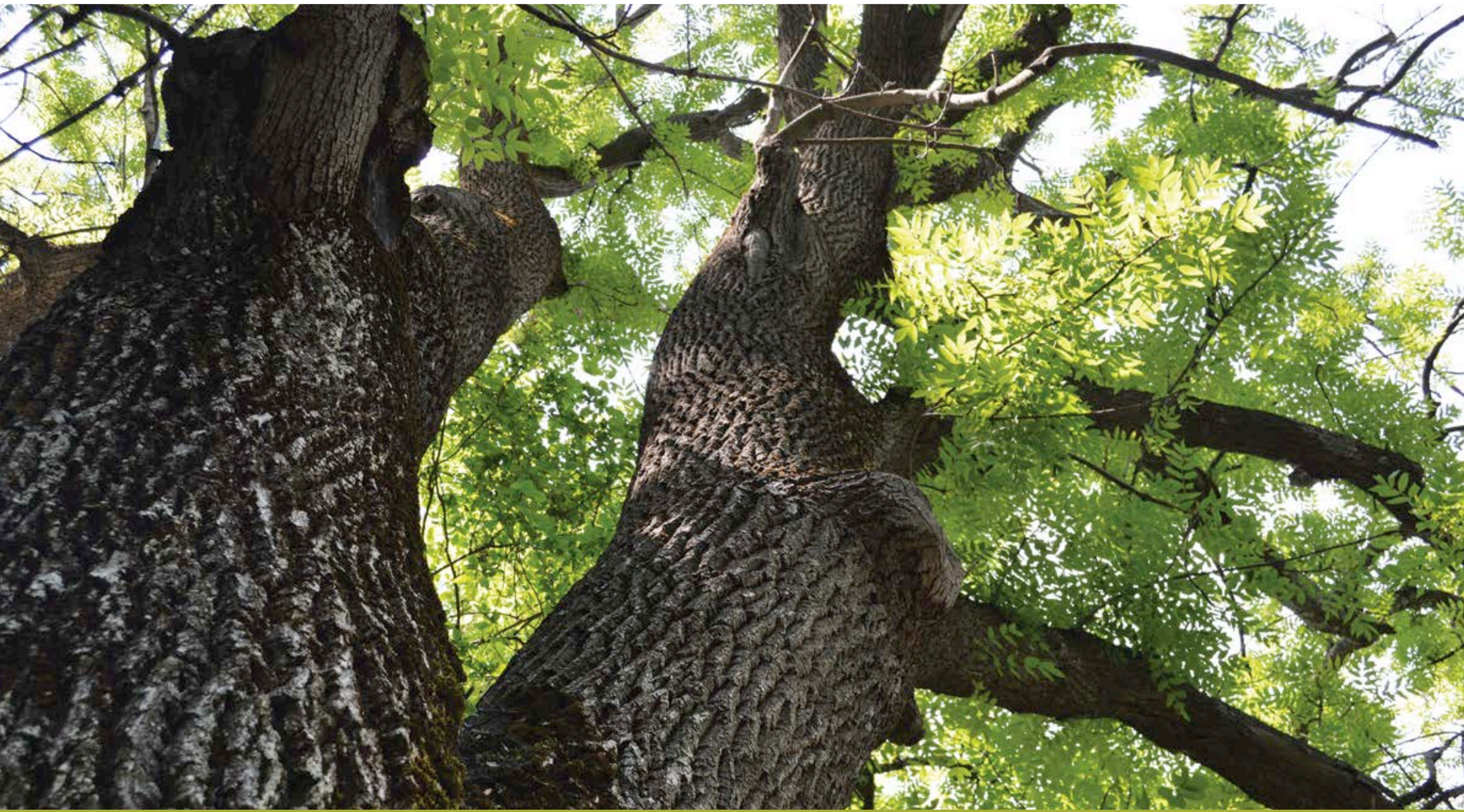
Forestry Commission



Research Note

Ecological impacts of ash dieback and mitigation methods

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July 2017

Ash is a widespread species which makes a substantial contribution to many landscapes. Ash trees are affected by ash dieback, a disease caused by a fungus. It is clear from the European experience of the disease that a significant number of ash trees could be lost from woodlands in the UK over the course of perhaps the next 20–30 years. The ecological implications of the loss of ash trees encompass the biodiversity supported by the tree itself, as well as the ecosystem functions the species provides. This Research Note summarises recent research on the ecological value of ash, on tree and shrub species as alternatives to ash, and on the interpretation of this information for woodland management. The ground flora community associated with ash woodland is distinct and diverse and the species exerts a significant effect on habitat composition. Other tree and shrub species which occur in UK broadleaved woodlands, or are suitable for planting there, support many ash-associated species such as lichens, insects and fungi. However, the alternative species that support most ash-associated species do not replicate the ecosystem functions provided by ash. Various options are available for broadleaved woodland management, from relying on natural succession to planting specific species or mixtures of species to meet objectives of either ash-associated species conservation or ecosystem functioning and habitat maintenance. Encouraging the establishment of alternative tree and shrub species that are ecologically similar to ash may offer options to mitigate against the ecological implications of ash loss.

Forest Research

Introduction

Ash dieback is a tree disease caused by an invasive fungus (*Hymenoscyphus fraxineus*) from East Asia which has spread through most eastern, central and northern European countries and Russia during the last decade, killing many ash trees (mainly common ash, *Fraxinus excelsior*) (Pautasso *et al*., 2013). Evidence from continental Europe suggests that there could be rapid spread of the disease and a high level of tree death in the UK (Enderle *et al*., 2013). For example, the disease has been present for 20 years in Lithuania, where all stands of ash are damaged and tree health continues to deteriorate (Lygis *et al*., 2014). In Britain, ash dieback was first confirmed in the wider environment in October 2012 in a small number of trees and woodlands in Norfolk and Suffolk. Since then, the disease has been found more extensively and, in October 2016, the disease was present in 36% of the 10 km squares in the UK (www.forestry.gov.uk/ashdieback). The disease causes crown dieback and root collar necrosis often through secondary infections and, for affected trees in a woodland setting, usually leads to tree death (e.g. Lygis *et al*., 2014; Marçais *et al*., 2016).

Current UK policy on managing ash dieback (Defra, 2013; Forestry Commission, 2015a; Forestry Commission Scotland, 2015; Welsh Government, 2015) encourages biosecurity measures to control the spread of the disease. In young stands (less than 25 years old) removal of recently planted material and selective thinning is encouraged where disease levels are low or where there is a high density of ash trees. In older stands, an individual tree monitoring approach is suggested.

Ash trees provide a significant timber resource and are a feature in many landscapes (Figure 1). Across the UK, the abundance and distribution of ash, and the woodland communities in which ash occurs, are largely driven by variations in soil and climate (Box 1). Ash trees are an important and widespread component of our broadleaved woodlands, occurring in a range of densities from occasional groups of trees through to being the dominant species in the canopy over small areas of woodland. There are about 150 000 ha of woodland composed of ash in the UK, with a standing volume of 40 million m^3 that comprises about 12% of total broadleaved woodland area and 16% of broadleaved standing volume (Forestry Commission, 2015b).

Ash is a component of woodlands which provide habitats for a wide variety of other plant and animal species. Consequently, loss of ash could have significant effects on woodland biodiversity. Several studies have predicted that the loss of ash due to ash dieback could drive changes in the populations of associated species (Jönsson and Thor, 2012; Pautasso *et al*., 2013; Mitchell *et al*., 2014b). Monitoring in Eastern Europe has recorded the first local extinctions of lichen species due to the loss of ash (Lohmus and Runnel, 2014). While loss of timber production may be of greater concern to individual owners, the maintenance of biodiversity in broadleaved woodlands affected by ash dieback is an important policy goal and is the focus of this Research Note.

Recent research has been carried out on the potential ecological impact of ash dieback on UK woodlands and species, and how adverse effects might be minimised by woodland management. An understanding of the ecological impacts and the mitigation options available through alternative species is important to deliver the current UK policy on managing ash dieback and minimising its impact on woodland ecosystem function and biodiversity.

This Research Note summarises the findings from two research contracts (Mitchell *et al*., 2014a, 2014c) and four associated journal papers (Mitchell *et al*., 2014b; Broome *et al*., 2014; Mitchell *et al*., 2016a, 2016b). The research has used a variety of approaches: literature review, expert ecological knowledge synthesis, field testing and multivariate statistical methods. Details of these approaches can be found in the source literature.

This Research Note aims to:

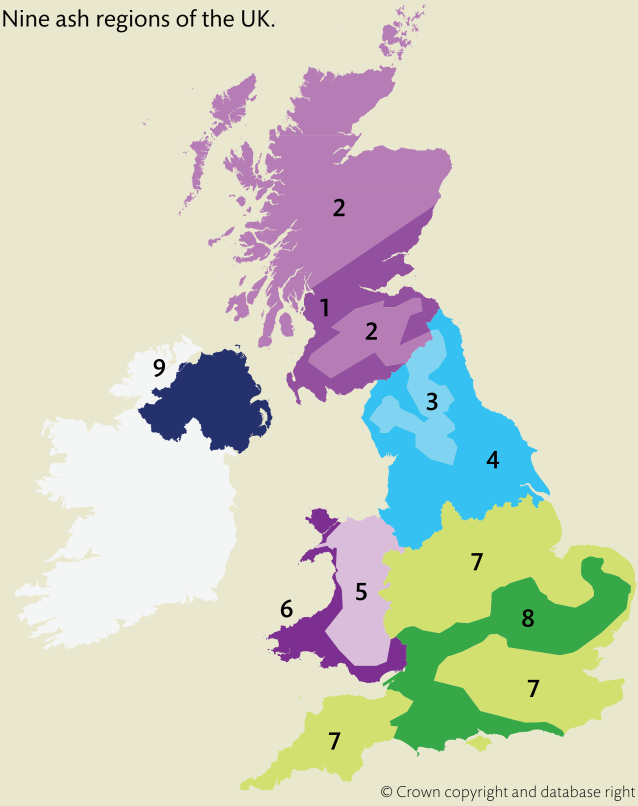
- summarise a study of the ecological value of ash based on the attributes of ecosystem function, associated habitat and support of biodiversity;
- summarise the results of an investigation into the use of alternative tree species to mitigate the ecological impact of ash loss;
- relate the results of this research to broadleaved woodland management, providing advice on options to mitigate the impact of the loss of ash.

Figure 1 Ash woodland.

Box 1 – Composition of woodland communities containing ash and their distribution in the UK

Differences in woodland composition are driven by underlying environmental factors such as soil or climate and management history. The National Vegetation Classification (NVC) (Rodwell, 1991) recognises seven woodland communities and 19 sub-communities, of which ash makes up more than 10% of the canopy. For nine of these sub-communities, ash is the most frequently occurring canopy species but in the remainder beech (*Fagus sylvatica*), oak (*Quercus petraea* and *Q. robur*), birch (*Betula pubescens* and *B. pendula*), alder (*Alnus glutinosa*), grey willow (*Salix cinerea*) and rowan (*Sorbus aucuparia*) are generally more frequent than ash. The communities are variably distributed in the UK on base-rich, very moist soils and can be generally split into those occurring in the upland or lowland zones.

Nine ash regions of the UK.



Map key

- 1 Lowland Scotland
- 2 Upland Scotland
- 3 Upland Northern England
- 4 Lowland Northern England
- 5 Upland Wales
- 6 Lowland Wales
- 7 Clay South England
- 8 Calcareous South England
- 9 Northern Ireland

Broadleaved woodland sites containing ash (occupying >10% of canopy) in the UK ash regions (see Figure 1) and associated National Vegetation Classification (NVC) types.

Region	Canopy occupied by ash (%)[1]	Proportion of broadleaved woods in region (%)[1]	Main canopy species	Main associated NVC sub-community
1 Lowland Scotland	≥10 to ≤20	10	Alder/oak/ash	W9b; W7a, b, c; W10e; W8f
	>20	15	Ash	W9a; W8b, e
2 Upland Scotland	≥10 to ≤20	6	Alder/oak	W9b; W7b; W10e
	>20	4	Ash	W9a
3 Upland Northern England	≥10 to ≤20	12	Alder/oak	W7b; W9b; W10e
	>20	13	Ash	W9a; W8e
4 Lowland Northern England	≥10 to ≤20	10	Oak/alder	W10b, c, e; W7a, b, c; W6a
	>20	19	Ash	W8b, e, g
5 Upland Wales	≥10 to ≤20	6	Oak/ash/alder	W10c, e; W8f; W7a, b, c; W6a; W11a
	>20	18	Ash	W8b, e; W9a
6 Lowland Wales	≥10 to ≤20	10	Oak/ash	W10b, c, e; W8f
	>20	48	Ash	W8b, d, e; W9a
7 Clay South England	≥10 to ≤20	12	Oak/beech/ash	W10b, c; W12c; W8f; W6a
	>20	30	Beech/ash	W12a; W8a, b, c, d, e
8 Calcareous South England	≥10 to ≤20	12	Ash/alder/oak	W8f; W6a; W10b, c
	>20	41	Ash	W8a, b, c, d, e
9 Northern Ireland	≥10 to ≤20	10	Alder/oak/ash	W9b; W7a, b, c; W10e; W8f
	>20	15	Ash	W9a; W8b, e

1. Information taken from Forestry Commission, 2012.

Ecological value of ash

Ecosystem function of ash

Ecosystem function is defined here as the properties of the ecosystem composed of the stocks of resources, e.g. mineral nutrients and carbon, and the rate of processes, e.g. those controlling fluxes of matter between trophic levels. The definition does not encompass ecosystem goods or ecosystem services (Hooper *et al*., 2005). Ash trees will influence the environment around them by casting shade, adding leaves and dead twigs and roots to the woodland floor and through below-ground interactions between soil organisms and the tree roots. These in turn influence litter decomposition, nutrient cycling, hydrology and the interactions between other organisms and successional processes within the woodland. These ecosystem functions of ash help to maintain the typical set of site conditions and communities associated with ash.

Three soil quality measures have been used to assess the ecosystem function of ash (details in Mitchell *et al*., 2014a): litter decomposition rate, litter quality and nutrient cycling.

Litter decomposition

Ash produces a labile and readily degradable litter. The high rates of decomposition (mass of litter broken down over a given time) are associated with the density of bacteria, fungal mycelia, protozoa and nematodes. Decomposition has been shown to be also affected by earthworm abundance and the chemical characteristics of the litter. A lower rate of litter accumulation on the forest floor occurs with concomitantly lower soil acidification and ash litter forms soil organic matter with a high pH.

Litter quality

Ash has a high litter quality. Low amounts of nutrients from leaves are reabsorbed by the tree before senescence and leaf fall. Consequently, litter is high in nitrogen, phosphorus, potassium and sulphur. Ash litter is also noted to be rich in magnesium, manganese, calcium and low in carbon and lignin. In general nutrient and carbon cycling in the soil are enhanced by (i.e. positively correlated with) higher nutrient contents in litter, but cycling is delayed where litter contains more structural materials such as lignin in the leaves.

Nutrient cycling

There is a fast cycling of nutrients and carbon within ecosystems where ash is present. The fall of litter and its decomposition is, along with root inputs, one of the primary routes of nutrient and carbon recycling and impacts on soil fertility.

The relatively large losses of potassium, magnesium, nitrogen and sulphur from ash via litterfall transfers nutrients to the soil and contributes to a high nutrient content. A relatively high proportion of the nutrients leach directly from the litter into the soil prior to litter decomposition. These dynamics are of significance to the characteristic rapid nutrient flows and rates of recycling of nutrients through the tree–soil system for ash.

Ash woodland habitat

Within woodland communities the composition of the ground flora is influenced by the nature of the tree canopy and underlying site characteristics (lithology, climate, etc.). Ash woodlands are characterised by high light penetration which, along with the three soil quality measures outlined above, shape the distinctive ground flora communities.

Ash woodland vegetation communities

Typical ash woodland communities tend to be relatively rich in vascular plants and are characterised by dog's mercury (*Mercurialis perennis*), with the addition of species such as wild garlic (*Allium ursinum*) and bluebell (*Hyacinthoides non-scripta*) in lowland zone communities, and wood sorrel (*Oxalis acetosella*) and male fern (*Dryopteris filix-mas*) in upland zone communities. While many of the ground flora species found in ash woodlands also occur as part of other plant communities, 47 species have been identified (Mitchell *et al*., 2016a) as being particularly associated with 'ash woodlands' (Table 1). Many of these are recognised as ancient woodland indicator species (AWIS) and five appear on the Vascular Plant Red Data List for Great Britain (Cheffings and Farrell, 2005).

Impact of ash loss on vegetation communities

Loss of ash is predicted to influence ground flora composition and in the short term this may favour some of the bulkier, light-demanding species at the expense of species that require damp shady conditions such as lady fern (*Athyrium filix-femina*) and dog's mercury. Although seven of the ground flora species preferentially associated with ash woodland are grasses (Table 1), it is the other, more commonly occurring grasses such as false oat-grass (*Arrhenatherum elatius*), and the grazing-tolerant slender false-brome (*Brachypodium sylvaticum*) which are expected to increase rapidly in frequency with the increase in light. Where ground disturbance occurs along with loss of ash, ruderal species such as tufted hair-grass (*Deschampsia cespitosa*) and bramble (*Rubus fruticosus* agg.) are expected to spread rapidly, outcompeting the typical ash woodland ground flora. However, some species such as wild garlic, preferentially associated with ash woodlands, may show little change in abundance due to their vernal growth. Species which prefer

Table 1 Ground flora species particularly associated with ash woodlands.

Scientific name	Common name	AWIS	Rare	Red Data List
Allium ursinum	Ramsons	✓		
Anemone nemorosa	Wood anemone	✓		
Athyrium filix-femina	Lady-fern	✓		
Bromopsis benekenii	Lesser hairy-brome	✓	✓	
Campanula latifolia	Giant bellflower	✓		
Campanula trachelium	Nettle-leaved bellflower	✓		
Cardamine impatiens	Narrow-leaved bitter-cress	✓	✓	Near threatened
Carex digitata	Fingered sedge	✓	✓	
Carex strigosa	Thin-spiked wood-sedge	✓	✓	
Carex sylvatica	Wood-sedge	✓		
Circaea x intermedia	Upland enchanter's-nightshade	✓		
Convallaria majalis	Lily-of-the-valley	✓		
Daphne laureola	Spurge-laurel	✓		
Daphne mezereum	Mezereon	✓		Vulnerable
Dipsacus pilosus	Small teasel	✓	✓	
Elymus caninus	Bearded couch grass	✓	✓	
Equisetum sylvaticum	Wood horsetail	✓		
Euphorbia amygdaloides	Wood spurge	✓		
Festuca altissima	Wood fescue	✓	✓	
Festuca gigantea	Giant fescue	✓		
Gagea lutea	Yellow star-of-Bethlehem	✓	✓	
Galium odoratum	Woodruff	✓		
Helleborus viridis	Green hellebore	✓	✓	
Hordelymus europaeus	Wood barley	✓	✓	Least concern
Lamiastrum galeobdolon	Yellow archangel	✓		
Lathraea squamaria	Toothwort	✓	✓	
Melica nutans	Mountain melic	✓		
Melica uniflora	Wood melic	✓		
Mercurialis perennis	Dog's mercury			
Myosotis sylvatica	Wood forget-me-not	✓		
Narcissus pseudonarcissus	Daffodil	✓		
Orchis purpurea	Lady orchid	✓	✓	Endangered
Paris quadrifolia	Herb-paris	✓	✓	
Phyllitis scolopendrium	Hart's-tongue	✓		
Platanthera chlorantha	Greater butterfly-orchid	✓		
Polygonatum multiflorum	Solomon's-seal	✓		
Polygonatum odoratum	Angular Solomon's-seal	✓	✓	
Polystichum aculeatum	Hard shield-fern	✓		
Polystichum setiferum	Soft shield-fern	✓		
Potentilla sterilis	Barren strawberry	✓		
Primula elatior	Oxlip	✓	✓	Near threatened
Ribes rubrum	Redcurrant	✓		
Stachys sylvatica	Hedge woundwort	✓		
Veronica montana	Wood speedwell	✓		
Viola odorata	Sweet violet	✓		
Viola reichenbachiana	Early dog-violet	✓	✓	
Viola reichenbachiana x riviniana (V. x bavarica)		✓	✓	

For definition of 'ash woodlands' see Box 1.
AWIS: Ancient Woodland Indicator Species.
Rare: not common enough to be recorded in the National Vegetation Classification (NVC) samples but identified as associated with ash woodland from a literature search (Mitchell *et al.*, 2016a).
Red Data List: species are listed in 'The Vascular Plant Red Data List for Great Britain' (Cheffings and Farrell, 2005).

lighter conditions and are typically found on the woodland edge or in clearings are expected to increase in abundance following the opening up of the canopy caused by the loss of ash. This is most likely for the preferential ash woodland shrub species, e.g. common spindle (*Euonymus europaeus*) and guelder-rose (*Viburnum opulus*) rather than ground flora species, although the shallow-rooted vernal wood anemone (*Anemone nemorosa*), itself valued as an AWIS, would also be likely to spread rapidly.

Biodiversity supported by ash trees (ash-associated species)

Ash-associated species are those that use ash trees as a food source (e.g. many insects and some mammals), a place to breed/nest (e.g. some birds), a habitat in which to live (e.g. epiphytic bryophytes and lichens) or in which to hunt for food (e.g. insects and birds that feed on other ash-associated insects). A literature review was conducted to find out how many ash-associated species occurred in the UK (full details and subsequent analysis in Mitchell *et al*., 2014a).

Numbers of species using ash trees

There are 955 ash-associated species occurring in the UK, more than half of which are lichens (Table 2). Species vary in their level of association with ash, but few are very closely linked to ash, with only about 5% having an obligate requirement and a further 6% being classified as highly associated on the basis that they rarely use other tree species. However, for most species the association with ash is only partial or weaker as they are able to use alternative tree species.

Vulnerability of ash-associated species

Species conservation status (e.g. as listed in the 'Red Data Book' or 'Birds of Conservation Concern') was combined with level of association to assess conservation impact of ash loss on species (Table 3). A precautionary approach was followed for species with 'unknown' conservation status by weighting them the same as if they had a known conservation status. Seventy-one species (Mitchell *et al*., 2014c) are assessed as high risk (red-coded) and considered to be in danger of either going extinct or subject to severe populations declines due to projected impacts of ash dieback. One hundred and seventy species are assessed as medium risk (amber-coded) and may decline in abundance following loss of ash, while 383 species are assessed as low risk (yellow-coded) and may also decline but are unlikely to be as greatly affected by the loss of ash. Green-coded species, 330 in total, are defined as those which are cosmopolitan in their use of ash and considered unlikely to be impacted by the loss of ash.

Table 3 Number of ash-associated species classed as high risk (red), medium risk (amber), low-risk (yellow) and negligible risk (green) with respect to the predicted impact of ash loss.

Level of association	Conservation status		
	None	Unknown	Yes
Obligate	35	3	7
High	36	7	19
Partial	284	8	52
Uses	99	13	61
Cosmopolitan	284	8	38

Table 2 Number of ash-associated species and level of association with ash trees for six types of organism.

Organism	Level of association					Total
	Obligate	High	Partial	Cosmopolitan	Uses	
Birds			7	5		12
Mammals			1	2	25	28
Bryophytes		6	30	10	12	58
Fungi	11	19	38			68
Lichens	4	13	231	294	6	548
Invertebrates	30	24	37	19	131	241
Total	**45**	**62**	**344**	**330**	**174**	**955**

Level of association: five different categories of association describing the strength of the dependency of the species that use ash trees. These are: **'Obligate'**, only found on ash; **'High'**, rarely uses tree species other than ash; **'Partial'**, uses ash more frequently than its availability; **'Cosmopolitan'**, uses ash as frequently as, or less than, its availability; **'Uses'**, uses ash but the importance of ash for this species is unknown.

Alternative tree and shrub species to mitigate the impacts of ash dieback

The increased use of mixtures of tree species and using more species overall are measures proposed for the adaptation of woodlands and forests to increase their resilience to environmental change. However, the current range of tree species planted in the UK may not be well adapted to the effects of climate change and pests projected to occur in the future. Including some species that may have a higher chance of survival, while monitoring and acquiring new knowledge, is one proactive response to the expected future pressures on woodlands.

One 'solution' to reduce the ecological impact caused by the loss of ash is to encourage the establishment of alternative, ecologically similar, tree and shrub species (Figure 2). In a recent analysis, 51 alternative tree and shrub species were selected for analysis as capable of establishing and growing on site types that currently support ash (for methods see Mitchell *et al*., 2014a, 2014c). The group of alternative species is composed of 37 broadleaved species (24 of which occur in native broadleaved woodlands in the UK), six conifer species (two of which occur in native broadleaved woodlands in the UK) and seven native shrubs (Table 4). These were assessed for the support they provide to ash-associated species and the ecosystem function performed, and the results and management implications of this analysis are discussed below.

Figure 2 Oak trees support the greatest number of ash-associated species.

Ash-associated species use of other tree and shrub species

The results from Mitchell *et al*. (2014a, 2014c) suggest that some tree and shrub species make better host species as alternatives to ash than other species.

There is great variability in the number of ash-associated species supported by the 51 alternative tree or shrub species. For example, of the alternative trees and shrubs which occur in UK broadleaved woodlands (Figure 3a), sessile and pedunculate oak are known to support 640 of the 955 ash-associated species, with beech (*Fagus sylvatica*), English elm (*Ulmus procera*)/wych elm (*U. glabra*), sycamore (*Acer pseudoplatanus*), hazel (*Corylus avellana*) and birch (downy and silver) all known to support more than 400 ash-associated species. English and wych elm are no longer common and widespread mature tree species within the UK due to Dutch elm disease (*Ophiostoma* spp.) and young elm rarely grows to maturity. Elm is therefore unlikely to be a suitable alternative to ash. Alder, rowan, aspen (*Populus tremula*) and hawthorn (*Crataegus monogyna*) are known to support over 300 ash-associated species. Crab apple (*Malus sylvestris*), field maple (*Acer campestre*), holly (*Ilex aquifolium*) and large-leaved lime (*Tilia platyphylos*) support over 200 ash-associated species. Douglas fir (*Pseudotsuga menziesii*) and wild service tree (*Sorbus tomentalis*) are known to support the least number of ash-associated species (10 or less). Of the alternative trees that could be planted but are not widely present in UK broadleaved woodlands (Figure 3b), Scots pine (*Pinus sylvestris*) and horse chestnut (*Aesculus hippocastanum*) are all known to support over 200 ash-associated species. Italian alder (*Alnus cordata*), shagbark hickory (*Carya ovata*) and Caucasian wingnut (*Pterocarya fraxinifolia*) are all known to support fewer than ten ash-associated species from available data, but data quality is low with many associations with these tree species scored as 'unknown'.

Non-native ash species

Four ash species (other than common ash (*F. excelsior*)) were included in the assessment: manna ash (*Fraxinus ornus*), American ash (*F. Americana*), green ash (*F. pennsylvanica*) and Manchurian ash (*F. mandschurica*); these tree species are known to support only 29, 12, 12 and 6 ash-associated species, respectively (Figure 3b). However, it is thought likely that they will support a substantial number of associated species including the obligate and highly associated species. This would make them viable alternatives to common ash for some of the obligate ash-associated, and highly ash-associated species, which have few alternative hosts among the UK flora.

Table 4 Number of ash-associated species supported by potential alternative trees and shrubs.

Potential alternative tree species[1]		Number of ash-associated species (out of 955) supported			% for which information was available[2]
English name	Scientific name	Total	Highly associated with ash	Partially associated with ash	
Trees/shrubs present in UK native broadleaved woodlands					
Oak spp. (pedunculate/sessile)	*Quercus robur/petraea*	640	23	271	94
Beech	*Fagus sylvatica*	505	13	222	92
Elm spp. (English/wych)	*Ulmus procera/glabra*	477	21	248	86
Sycamore	*Acer pseudoplatanus*	473	17	228	88
Hazel	*Corylus avellana*	430	21	193	88
Birch spp.(downy/silver)	*Betula pubescens/pendula*	423	11	167	90
Alder	*Alnus glutinosa*	389	11	164	89
Rowan	*Sorbus aucuparia*	387	9	166	84
Aspen	*Populus tremula*	370	18	176	89
Hawthorn	*Crataegus monogyna*	302	9	155	88
Crab apple	*Malus sylvestris*	272	5	140	83
Field maple	*Acer campestre*	256	9	157	88
Holly	*Ilex aquifolium*	251	3	107	77
Large-leaved lime	*Tilia platyphyllos*	242	4	136	81
Hornbeam	*Carpinus betulus*	169	7	90	88
Blackthorn	*Prunus spinosa*	167	4	76	81
Sweet chestnut	*Castanea sativa*	148	5	61	88
Wild cherry	*Prunus avium*	116	1	48	88
Goat willow	*Salix caprea*	105	7	44	32
Whitebeam	*Sorbus aria*	100	1	51	82
Elder	*Sambucus nigra*	96	6	53	29
Bird cherry	*Prunus padus*	95	2	49	87
Privet	*Ligustrum vulgare*	92	8	61	75
Grey willow	*Salix cinerea*	91	4	39	31
Yew	*Taxus baccata*	89	0	53	86
Small-leaved lime	*Tilia cordata*	84	7	37	31
Black poplar	*Populus nigra*	76	4	45	30
Norway maple	*Acer platanoides*	60	4	26	31
Douglas fir	*Pseudotsuga menziesii*	8	0	3	29
Wild service tree	*Sorbus torminalis*	7	2	1	22
Trees/shrubs as options for planting on sites which support ash					
Scots pine	*Pinus sylvestris*	216	0	60	81
Horse chestnut	*Aesculus hippocastanum*	208	9	116	81
European larch	*Larix decidua*	166	0	50	79
Common walnut	*Juglans regia*	149	7	85	81
Black walnut	*Juglans nigra*	126	3	78	80
Plane spp.	*Platanus x hybrid*	96	2	60	76
Silver fir	*Abies alba*	74	1	26	30
Turkey oak	*Quercus cerris*	70	3	29	32
Manna ash	*Fraxinus ornus*	29	6	5	30
Red oak	*Quercus rubra*	28	1	13	29
Western red cedar	*Thuja plicata*	17			22
American ash	*Fraxinus americana*	12	1	5	29
Green ash	*Fraxinus pennsylvanica*	12	2	5	29
Hop-hornbeam	*Ostrya carpinifolia*	10	0	5	20
Italian alder	*Alnus cordata*	6	0	0	23
Manchurian ash	*Fraxinus mandschurica*	6	1	3	29
Shagbark hickory	*Carya ovata*	1	0	0	19
Caucasian wingnut	*Pterocarya fraxinifolia*	1	0	0	19

1. Where it was not possible to distinguish between particular pairs of alternative species in the use made of them by ash-associated species, these species have been grouped.
2. Percentage of ash-associated species for which information is available showing whether they use or do not use the alternative tree species. For tree species with a low percentage it was not possible to assess suitability for most ash-associated species, therefore caution is needed when selecting such tree species to replace ash.

Figure 3 Number of ash-associated species which use the 51 alternative tree/shrub species and the level of the association for (a) alternative trees/shrubs which are present in UK broadleaved woodlands, (b) alternative trees which may provide further options for planting on sites but are not widely present in broadleaved woodlands in the UK. See Table 4 for English names.

Ecosystem function of ash compared to other broadleaved tree species

Using the same three soil quality measures to assess the ecosystem function of trees, a comparison has been made between ash and 11 alternative broadleaved tree species (Table 5). Due to data limitations, only 11 alternative species were assessed. The results – outlined below – are clear that ash performs these ecosystem functions to a greater extent (e.g. faster rates of litter decomposition and nutrient cycling) than the other tree species. This suggests that if ecosystem function is an important management objective, then the ash alternatives will not be able to maintain the same level of soil quality function as ash itself can.

Litter decomposition

Alternative tree species assessed for litter decomposition formed three rough groupings based on relative decomposition rate compared to ash (Table 5):

- alder, small-leaved lime (*Tilia cordata*) and rowan have a rapid decomposition rate similar to that of ash litter;
- oak and beech litters are generally the slowest to decompose;
- sycamore, field maple and aspen have litter decomposition rates between these two extremes.

Table 5 Comparison of how well ecosystem function is performed by 11 native broadleaved species compared to ash in three categories: similar rate/quality (green); slightly lower rate/poorer quality (amber); much lower rate/poorer quality (red). No data (blank).

Species	Decomposition	Litter quality	Nutrient cycling
Field maple (*Acer campestre*)			
Sycamore (*Acer pseudoplatanus*)			
Alder (*Alnus glutinosa*)			
Birch (*Betula pubescens/pendula*)			
Beech (*Fagus sylvatica*)			
Common walnut (*Juglans regia*)			
Aspen (*Populus tremula*)			
Wild cherry (*Prunus avium*)			
Oak (*Quercus robur/petraea*)			
Rowan (*Sorbus aucuparia*)			
Small-leaved lime (*Tilia cordata*)			

Litter quality

Confidence in ranking for litter quality varies due to the frequency with which species are covered in litter studies. The five species with most information provide a scale of litter quality rankings – ash is the highest in nutrients, followed by small-leaved lime, then oak, then birch, and with beech always with the lowest (or equal lowest) nutrient content. Birch is the most variable in its ranking, particularly with respect to oak, suggesting that its litter quality is more strongly influenced by local site conditions than other species.

Species with less information (alder, common walnut (*Juglans regia*), aspen, field maple, sycamore, rowan and wild cherry (*Prunus avium*)) have been aligned to the five ranking positions. Alder ranks above ash; aspen, field maple and sycamore fall between small-leaved lime and oak/birch; rowan is similar to oak and birch; and wild cherry is lower than beech.

Nutrient cycling

While underlying environmental factors such as soil and lithology influence soil nutrient levels, the input and rate of input of nutrients from the leaves and roots of trees also has an influence. Ash tends to have the highest nutrient content in the soil beneath it compared to the other species, although it often was at a very similar level to lime. Oak and birch tended to have lower soil nutrient contents and higher acidity and higher carbon:nitrogen ratios than soils under ash and lime. Beech usually had the lowest nutrient contents and highest acidity, while having the highest carbon:nitrogen ratios.

Of the species less commonly found in the studies, alder had similar soil nutrient levels beneath it as ash, and field maple and sycamore were intermediate between ash/lime and oak/birch.

Ecological value of alternative species and use of mixtures

As shown in Table 6, the assessment of ecological value of ash and potential alternative tree species suggests there is no one species which could act as a comprehensive replacement for ash. Of the 11 broadleaved species, small-leaved lime and alder best replicate the ecosystem functions of ash. Oak, birch and beech have the lowest rates of decomposition and nutrient cycling and the poorest litter quality. However, oak and beech support the greatest number of ash-associated species (94% and 92%, respectively) and small-leaved lime only a low number (31%). Alder emerges as a potentially useful alternative supporting 89% of ash-associated species. Sycamore, field maple and aspen offer some potential as they each support nearly 90% of ash-associated species and perform ecosystem functions at a slightly lower rate or quality.

Table 6 Eleven broadleaved tree species ranked from most suitable to least suitable as alternatives to ash as assessed by provision of ecosystem function (litter decomposition rate, litter quality and nutrient cycling) and used by ash-associated species.

Alternative tree species	Ecosystem function	Species use
Most suitable	Alder (*Alnus glutinosa*)	Oak (*Quercus robur/petraea*)
	Small-leaved lime (*Tilia cordata*)	Beech (*Fagus sylvatica*)
	Common walnut (*Juglans regia*)	Sycamore (*Acer pseudoplatanus*)
	Rowan (*Sorbus aucuparia*)	Birch (*Betula pubescens/pendula*)
	Field maple (*Acer campestre*)	Alder (*Alnus glutinosa*)
	Sycamore (*Acer pseudoplatanus*)	Rowan (*Sorbus aucuparia*)
	Aspen (*Populus tremula*)	Aspen (*Populus tremula*)
	Wild cherry (*Prunus avium*)	Field maple (*Acer campestre*)
	Birch (*Betula pubescens/pendula*)	Common walnut (*Juglans regia*)
Least suitable	Beech (*Fagus sylvatica*)	Wild cherry (*Prunus avium*)

Mixtures of alternative species may help to replace the ecological function of ash more effectively than single species. Different tree species will host a different range of ash-associated species and when combined together on a site support a greater total number of ash-associated species than if planted as pure species.

Hypothetical tree mixtures were tested using multivariate statistical procedures to combine values for ecological function and ash-associated species (Mitchell *et al.*, 2016b). This work suggested different mixtures for two different scenarios:

- Scenario 1: When replicating the ecological function of ash is given priority over support for ash-associated species, the best mixture appears to be 75% sycamore and the remaining 25% composed of equal proportions of oak and beech, with little further gain achieved with the addition of birch and aspen.

- Scenario 2: Where support of ash-associated species is prioritised over replication of ecosystem functions, the best three-species mixture was oak, beech and aspen in equal proportions; a five-species mixture (all species in equal proportions) with the addition of birch and sycamore improved the ecosystem function score, although only marginally increasing the number of species supported.

Under neither scenario is the ecological value of ash matched, although the scenario 1 mixture comes closer than scenario 2 (60% similarity with ash compared to 52% similarity). Further, these mixtures may not be possible to achieve in reality, given site constraints and differing site requirements of the alternative tree species.

Implications of findings to woodland management

Different approaches to mitigate against the ecological impacts of ash loss are available to woodland managers depending on management objectives.

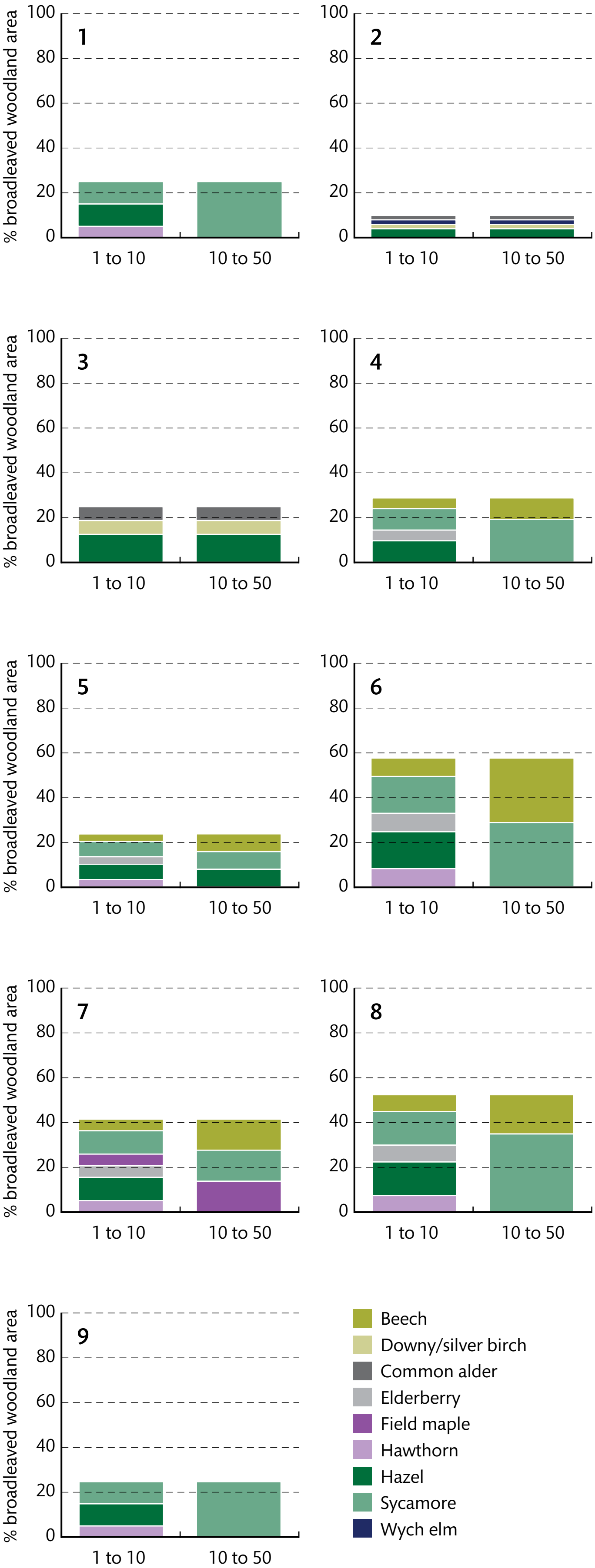
Regeneration and natural succession of broadleaved woodlands

Woodland communities containing ash vary in their distribution across the UK (Box 1) and different tree species may regenerate or be suitable for planting in different parts of the country. If natural succession takes place, other tree species may ultimately fill the parts of the canopy once occupied by ash, replacing shrub species which colonise/expand within gaps immediately following the loss of ash. These predictions are based on woodland community composition, species shade tolerance and competitive ability but assumes regeneration is not limited by browsing.

Figure 4 illustrates the tree and shrub species that are expected to replace ash in the nine UK regions (see Box 1) for map of nine ash regions). In the first 10 years following loss of ash, hazel is estimated to be a component in all regions in about 15% of the broadleaved woodland area, and sometimes mixed with hawthorn and elder. After 10 years, sycamore is expected to be a component filling the gaps in seven of the UK regions and in up to 35% of the broadleaved woodland area in each of those regions. Beech is expected to occur as an important replacement species in five regions and birch with alder in a further two.

Allowing natural succession in broadleaved woodlands may be adequate where management objectives can accommodate some change in the ecology of the 'ash woodland', e.g. changes in the ground flora composition or the species supported by the woodland. In all of the UK regions at least one of the species offering comparable levels of ecosystem function is predicted to replace ash through natural regeneration. Similarly, the majority of the ash-associated species may be provided for in each region by the species likely to regenerate there.

Figure 4 Main tree and shrub species predicted to fill gaps through woodland succession in the 50 years after the loss of ash and the percentage of broadleaved woodland in each of the nine ash regions affected. See Box 1 for map of nine ash regions.



Managing to maximise survival of ash-associated species

Where maximising survival of ash-associated species (biodiversity conservation) is a primary objective, the approach outlined in Box 2 is recommended.

Results of applying this approach at 15 broadleaved woodland sites where nature conservation was a primary objective (i.e. sites were SACs or SSSIs) showed that the majority of ash-associated species could be catered for by minor changes in the management of the sites (Mitchell *et al.*, 2014c).

Maximising replication of ash ecosystem function

This approach is appropriate where continuity in the ecosystem function of woodland, e.g. for maintaining characteristic ground flora, is the objective. Like the approach given in the 'Managing to maximise survival of ash-associated species' section, this requires an assessment of woodland composition, and the management potential (following Steps 4 and 5 (Box 2)), but tree species are selected to most closely match the ecosystem functions of ash (Table 5). It should be noted that this approach has not been tested and relies on information on a limited number (11) of alternative species.

Discussion and conclusions

The ecological value of ash has been explored and compared to tree and shrub species suggested for use as alternatives. For ash and the alternative species, we have considered the ecosystem functions provided, the associated ground flora and the biodiversity which uses the trees as a habitat.

Ash performs the ecosystem functions provided by trees at a higher quality or rate compared to alternative tree species (Mitchell *et al.*, 2014a). Consequently, the ground flora community associated with ash woodland is distinct and diverse. It would therefore appear to be difficult to ensure that the conditions supporting ash woodland ground flora will persist with change in tree species composition.

Various values have been placed on the role played by ash in supporting UK biodiversity. We found a total of 955 species used ash trees as habitat and 11% of these were obligate or highly dependent on ash. Bird species richness was found to be comparable between oak and ash woodlands (Sweeney *et al.*, 2010). Further, Alexander, Butler and Green (2006) list ash as of equal importance to oak for wood-decaying insects and of greater importance than oak for wildlife in terms of its leaf litter.

Box 2 – Maximising the survival of ash-associated biodiversity in broadleaved woodland vulnerable to ash dieback (*Hymenoscyphus fraxineus*)

This table captures the key steps a site manager can follow to identify an appropriate management response which will maximise the survival opportunities for woodland biodiversity.

Description	Explanation
1. Gather information on biodiversity recorded at the site; the aim is to produce as complete a species list as possible.	
• The National Biodiversity Network data repository[1] – extract species records for the site or the 10 km square site lies in. Select all survey dates and all taxa groups. • Site or reserve reports, SSSI citations or similar. • Species lists from taxon-specific surveys conducted at the site. • Local expert knowledge. • Use other survey data available to fill any obvious gaps.	The needs of all shortlisted ash-associated species may be met by a few alternative tree species. If this is not the case, and establishing the full range of alternative tree species at the site is not practical, consider retaining on the shortlist more 'higher conservation priority species which are closely associated with ash' over 'one or two extremely rare and highly (obligate and highly) associated species' if this helps to make management more tractable.
2. Identify ash-associated species present on the site and shortlist those to target for site management.	
• Using the **ash-associated spreadsheet**,[2] identify which species at the site are associated with ash. • Shortlist those that are a priority for management action, i.e. the higher conservation priority species which are also closely associated with ash.	'Closely associated' interpret as species in the 'obligate', 'high' and 'partial' classes. As long-term conservation is the aim, focus on 'high' and 'partial' species, unless 'obligate' species use deadwood.[3] Conservation status is recorded in four columns in the database.[4]
3. Identify tree and shrub species which could act as alternatives to ash in providing habitat for ash-associated species.	
• Using the **assessment of alternative trees**[2] spreadsheet, identify the alternative tree and shrub species that would support the shortlisted ash-associated species.	The needs of all shortlisted ash-associated species may be met by a few alternative tree species. If this is not the case, and establishing the full range of alternative tree species at the site is not practical, consider retaining on the shortlist more 'higher conservation priority species which are closely associated with ash' over 'one or two extremely rare and highly (obligate and highly) associated species' if this helps to make management more tractable.
4. Assess the tree and shrub species composition and management constraints for the site.	
• Determine the amount and distribution of each tree and shrub species present and how they will respond to management. • Assess the factors at the site which are likely to have a significant influence on the choice of methods to manage the site. • Identify the range of tree and shrub species with the potential to grow at the site (e.g. from NVC[5] and the ESC[6] tools) and cross-reference this with the list of alternative tree and shrub species (from step 3 above) to select those which should be encouraged by natural regeneration or by planting.	For assessment of how current trees/shrubs will respond to management, consider, for example: • are the trees/shrubs producing seeds? • are seedlings likely to establish? • will the current saplings/young plants grow on if given more light? • are plants vigorous to re-coppice if cut? Site factors affecting management of the site, e.g. deer browsing/grazing, soil type, current and future climate, ground flora vegetation.

Box 2 – Continued

Description	Explanation
5. Select the most appropriate management method.	
• Considering the constraints identified in step 4, identify the most appropriate method of management (also consider **six generic procedures**[7] according to the management objectives for the site and potential for management and ~aim to maximise the ash-associated biodiversity.	Interventions to encourage natural regeneration might be appropriate where the ash-associated biodiversity is supported by the site native trees/shrubs (not ash) becoming more abundant; clearfell and replanting might be appropriate where ash is dominant in the canopy and the ash-associated biodiversity would be supported by trees/shrubs which need to be introduced as not present.

1. https://data.nbn.org.uk/
2. See list of resources at: http://publications.naturalengland.org.uk/publication/5273931279761408
3. Definitions of the five classes of association between ash and ash-associated species:

Value	Definition
Obligate	Unknown from other tree species
High	Rarely uses other tree species
Partial	Uses ash more frequently than its availability
Cosmopolitan	Uses ash as frequently as, or less than, its availability
Uses	Uses ash but the importance of ash for this species is unknown

4. Conservation status is recorded in four columns in the database in the **Ash associated sp** spreadsheet. Columns are labelled 'BAP', 'Red Data Book', 'IUCN' and 'Birds of Conservation Concern'.
5. NVC = National Vegetation Classification (Rodwell *et al*., 1991).
6. ESC = Ecological Site Classification (Pyatt *et al*., 2001).
7. **The six generic methods of management:**
(1) **Non-intervention** – stands are allowed to develop naturally with no interventions.
(2) **No felling with natural regeneration promoted** – no felling but otherwise stands initially managed for natural regeneration (e.g. fencing and vegetation management).
(3) **Felling** – all ash trees and coppice removed in one operation with, if necessary, additional trees of other species cut to make the operation at least break-even economically. No subsequent interventions carried out.
(4) **Felling and replanting** – all ash trees and coppice removed in one operation with, if necessary, additional trees of other species cut to make the operation at least break-even economically. Then active management to replant with alternative tree and shrub species focused on the felled areas of the stand, with subsequent management to develop overstorey species.
(5) **Thinning** – regular operations to thin stands by removing significantly diseased and dead trees or coppicing ash, with, if necessary, additional trees of other species cut to make the operation at least break-even economically.
(6) **Felling with natural regeneration promoted** – all ash trees and coppice removed in one operation with, if necessary, additional trees of other species cut to make the operation at least break-even economically. Then active management initially to achieve natural regeneration in the stand (e.g. fencing and vegetation management), with subsequent management to develop overstorey species.

However, considering species richness of foliage-eating insects on UK trees, ash ranked 12th out of 18 trees or 12th out of 15 if only native species are considered (Southwood, 1961).

We have shown that the majority of ash-associated species in ash woodlands of high conservation value can be supported by providing a mix of broadleaved species (Broome *et al*., 2014). The replacement of ash by naturally regenerating mixtures of tree species is an attractive option for replicating the ecological value of ash lost from woodland. However, regenerating a range of broadleaved woodland species in gaps created by dying ash may be difficult. Ash produces large quantities of seed with good dispersal (up to 1.4 km), and readily creates a 'seedling bank' as seedlings can regenerate in light or heavy shade, requiring only a small depth of well-drained but moist soil to establish (Thomas, 2016). The presence of the ash 'seedling bank' gives this species a strong advantage in filling gaps in the woodland canopy, as compared to species such as birch or alder which do not show these traits (e.g. Tapper, 1993). Given that beech and sycamore are the only other alternative species with similar gap colonisation properties (Schütz, 2004; Herault, Thoen and Honnay, 2004; Thomas 2016), it is unlikely that the litter and soil conditions suiting the ash woodland ground flora will be maintained, although ash-associated species may still be supported.

We have described here a number of approaches to mitigate against the ecological impact of loss of ash based on the use of alternative tree species. While the approach of using alternative tree species to host ash-associated biodiversity is well supported by data, knowledge is limited on the ecosystem functions provided by alternative species. This is particularly so with non-native ash species such as Manchurian ash, manna ash, American ash and green ash. These species have been suggested as plausible alternatives to native ash, which may support many of the obligate and highly associated ash-associated species most at risk of extinction and may perform similar ecosystem functions. Experimental work has shown that Manchurian ash is also susceptible to ash dieback, but results so far indicate that manna ash, American ash and green ash may be more tolerant to the disease (Loesing, 2013). It may be worth testing these species as planting options to complement the list of alternative tree species identified by this research, provided no tree health implications of such an introduction were indicated. Recommendations of replacing ash with broadleaved trees already common in UK woodlands needs to be weighed against constraints posed by existing pests and pathogens (e.g. grey squirrels and *Phytophthora ramorum*).

Studies continue to examine the existence of tolerance within native ash trees, and the basis and durability of such tolerance. Some of these studies have suggested that common ash selected for tolerance could become available in a reasonable timescale (Harper *et al*., 2016). The use of such material may present the best approach in due course. However, until such work provides greater confidence in continued survival of the species, the advice in this Research Note provides guidance for those wishing to begin mitigation measures now.

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FCRN029/PURE/WWW/JUL17

ISBN: 978-0-85538-959-8