Elm in the Highlands: current status and potential management responses to Dutch elm disease

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Executive Summary

1. This study was commissioned by Forestry Commission Scotland to examine the current status of elm trees and Dutch elm disease (DED) in the Scottish Highlands. Drawing upon literature and reports, land manager interviews, surveys and site visits, regionally relevant information was gathered to consolidate data and insights into elm populations.
2. The distribution of elm was analysed from the Native Woodland Survey of Scotland (NWSS) data and from areas of elm trees (and potential DED infection) identified by survey participants. Results of this analysis were mapped onto ArcMap.
3. Elm species composes 0.13% of Scottish and 0.11% of Highland woodlands.
4. The largest areas of elm in the Highlands are in Fort William and Ardnamurchan, Loch Ness, Cromarty and the Black Isle.
5. The greatest densities of elm in the Highlands exist around Loch Ness, Cromarty, Beauly and the Black Isle.
6. Survey respondents identified healthy areas of elm in Skye, Raasay, and locations west of Drumnadrochit, although healthy elm was also found within heavily diseased areas.
7. DED was potentially identified outside of the currently accepted DED boundary, most notably at Invermoriston, Achnasheen and Leckmelm.
8. Further spatial analysis was used to map out DED risk zones and likely vectors of DED, following regionally important transport routes (A9 north and the Great Glen).
9. Two types of vectors dominate the movement of the beetle 1) Transport of timber and firewood 2) Changing climate and potential warmer summers, which increase the range and reproductive capacity of the *Scolytus* beetle.
10. Elm species are subject to high browsing pressure from herbivores in the Highlands.
11. W4, 8, 9, 19, 16 NVC habitats are the main habitats associated with elm species. The main associated species are birch, ash, alder, hazel and oak in that order.
12. Wych elm provides important habitats for a range of lichens, birds and insects, notably the orange fruited elm lichen which has in declined in most areas of the UK, apart from the Highlands.
13. Both seed and planting stock sales of elm have increased significantly in the last three years, possibly as a reaction to the threat of *Chalara* dieback of ash.

14. Elm continues to be considered a valuable timber with multiple uses including furniture, wood turning and firewood; its decorative grain is consistently emphasised by saw millers and craftsmen, but only small amounts are milled and supply is sporadic.
15. Despite a shared landscape memory of DED across all respondents, elm trees are still considered highly desirable, and wych elm (*Ulmus glabra*) is considered suitable for the Highlands, mostly in straths, glens and riparian areas. Planting of the species and further management is also viewed as a benefit for the region's biodiversity, landscape aesthetics and resilience.
16. Elm contributes an estimated £700,000 - £1.2 million to Scotland (discounting urban valuation) and between £250,000 - £345,000 to the Highlands and Islands annually from a range of ecosystem services. Individual trees have been valued between £400 -£1350 and wych elm contributes 35.4 million (NPV) to the City of Edinburgh through combined carbon and structural value. However, the comprehensive value of elm as a species is difficult to monetarise, as the majority of the value contributes to landscape, culture and biodiversity rather than economic markets.
17. Best practice for DED management has shifted from using pesticides and other control methods to one favouring heightened monitoring and targeted removal in priority zones. (Although Dutchtrig® has proved a successful inoculant for healthy elm trees, it costs £12 a tree and has to be repeated on a yearly basis.)
18. In this study a number of "Elm Refuges" (with associated buffer zones for intervention and monitoring of DED) are proposed. The locations of the proposed refuges are based on analysis of elm population density, connectivity and the incidence of DED in the Highlands.
19. Using NVC habitat zones for the main elm woodland habitats (W8, 9, 10, 16), 11,394 hectares has been identified as suitable for elm across the Highlands. 3,144 hectares of this area lie within the proposed Elm Refuges.
20. Twenty one Elm Refuges are proposed, from Arnamurchan (Loch Aline) in the south to Sutherland (Tongue) in the north, covering 17,700 hectares of the Highlands and 123 hectares of elm woodland.
21. Planting and monitoring efforts should feed into increasing citizen science and public outreach programmes, as they offer significant resources for data collection upon which to form management strategies and decisions.

22. Tolerant species for local seed sources should be prioritised above hybrids and other resistant elms from American and Asian origins. However, trials of both, (within and outwith infected areas) are recommended, to evaluate levels of tolerance or resistance.
23. Three possible options future management actions over 20 years were assessed:
    - **No action** – no coordinated management of elm or removal of DED infected trees
    - **Reactive** – increased felling, removal and disposal of DED infected trees in response to reports of spread of the disease
    - **Refuge –** active management including targeted control in and around priority areas (proposed refuges and the DED line), establishing new elm woodland and protecting natural regeneration. This option would involve increased monitoring through landscape and community partnerships, supported by a range of land managers, NGO's, forestry sector and public stakeholders, creating a more comprehensive picture of DED impact.
24. The least expensive management option is the No-action strategy, as no operations are performed (except replacement costs for losses); the Reactive strategy is the most expensive option due to the highest removal costs (responding to reports and extent of DED spread); the Refuge strategy produces the greatest potential gains financially and for the landscape. However costs (ranked second out of three) are likely to be spread over the first five years of management for minimum mitigation impact, whereas the other two strategies operate entirely over a 20 year plan.
25. Linking with current elm partnerships on a national and European level is advised, including raising the profile of the Highlands as an elm refuge area, which could benefit from greater knowledge exchange and best practice.
26. Research assessing DED along with *Chalara* spatially and genetically could increase understanding of the vector movement and improve planning responses (PhD or MRes project). Further research on community stewardship and best practice for strengthening regional resilience – involving citizen science, a range of stakeholders and private sector (including Confor and Scottish Land and Estates etc).
27. Hosting an Elm futures conference in the Highlands to explore multiple approaches to best practice and knowledge on DED and planting trials is proposed (potential to access pan-European funding, e.g. COST Action).

1. Introduction

This study was commissioned by Forestry Commission Scotland to examine the current status of elm trees and Dutch elm disease (DED) with a focus on the Scottish Highlands. Information available in published literature and reports was supplemented by interviews with land managers, surveys and site visits.

This report considers the current extent and distribution of elm, identifying healthy populations and assessing the potential future spread of DED. The economic, environmental and social value of elm in the landscape is also evaluated to assess the cultural importance of elm trees and woodlands in Scotland and the Highlands. As a result of this analysis potential costs and benefits of three future management strategies for elm woodlands are presented, together with recommendations for further research.

2. Background

There are three species of elm native to Great Britain: English elm (*Ulmus procera*), smooth-leaved elm (*Ulmus minor*), and wych elm (*Ulmus glabra*) (Brasier, 1996). In addition, a range of other species, cultivars and varieties has been introduced into the landscape and urban areas. Dutch elm disease (DED), caused by a fungal pathogen (*Ophiostoma. spp*) which is disseminated by bark beetles (*Scolytus. spp*), can be fatal to all British elm species and has spread across Britain since its introduction. English elm suffered the greatest loss due to DED, whereas wych elm, most prominent in Scotland and the Highlands, is more susceptible to the fungus but is less favoured by the beetle, which has contributed to the slower spread northwards (Brasier, 1996).

There have been two distinct incursions of Dutch elm disease in the UK. The first took place during the 1920s-40s when the *Ophiostoma ulmi* fungus caused a European epidemic (Gibbs & Brasier, 1973). The second occurred from 1962 onwards when *Ophiostoma novo-ulmi*, a more aggressive species of the pathogen, caused devastation to the British elm population (Brasier & Kirk, 2001). The spread and impact of DED continues to be a problem and management of the disease has been largely unsuccessful. Pockets of healthy elm survive in the UK and seemingly resistant specimens are being cultivated, monitored and trialled in various locations around Britain (Resistant Elms, 2015; Brookes, 2015). Additionally younger elms and those in hedgerows appear to show tolerance, especially low and managed hedgerows, as they are less attractive to insect vectors of DED (Colin, 2002). Croxton et al., (2004) reported that in restoration of hedgerows, elm trees are the most tolerant to pollarding and coppicing, as well as demonstrating high growth rates and survival in comparison to other native broadleaf species. Elm trees tend to remain uninfected by DED until they have matured, normally between 15-20 years old. This has been highlighted by numerous management authorities, as cycles of renewed infection have been identified after periods of relatively low activity, re-emerging via successional patterns (Harwood, et al., 2011; Brighton & Hove City Council, 2015; Isle of Man Government, 2015).

As the most northerly area of the Britain, Scotland (and especially the Highlands), has been more geographically isolated from the spread of DED than the most affected parts due to less suitable habitat, environmental constraints and low population density, which restricts movement and vectors over the landscape (Connolly, 2015). The fragmented structure of landscape, woodland and infrastructure provides a buffer against the rapid spread of pests and pathogens, which has slowed the advancement of the bark beetle to more northerly parts of Scotland. The borders and central belt of Scotland showed first signs of infection in 1977, taking only a few years to spread from southern England to Scotland (Tomlinson & Potter, 2010). To date the disease has been responsible for over 60 million elm deaths and continues to spread across Scotland to the south-eastern areas of the Highlands (FR, 2015).

The history and plight of elm and DED in Britain serves as a baseline reference for subsequent outbreaks, yet lessons learned from these events and management responses are still developing with great uncertainty (Tomlinson & Potter, 2010). The story of Dutch elm disease highlights the devastating impact of a pest to woodland and the landscape across diverse scales (from local to pan-continental), resulting in the loss of an important and iconic tree species where future planting is viewed as futile (Harwood, et al., 2011). Underestimating the severity of the outbreak and a lack of coordination and management at a national level have been noted as major failures in appropriately responding to the threat of DED (Harwood, et al., 2011). Tomlinson and Potter (2010) explore policy narratives highlighting the scientific assumptions that hindered progress, which were slow to be challenged in the face of overwhelming public observation.

Additionally the failure to deploy meaningful funds for controlling outbreaks at key moments caused significant damage and loss of valuable time in the fight to stem the spread of DED. As a result actions were inadequate and untimely, unable to cope with the enormity of the event.

An assumption persists that elm has passed into landscape history and is absent from present or future planning, as sooner or later they will succumb to Dutch elm disease. However, the Highlands of Scotland has areas of wych elm which are relatively untouched by the disease, and due to its geography and topography it could provide a safe haven for elm species in Britain.

Several examples of successful elm management exist in the UK, most notably Brighton and Hove (Brighton & Hove City Council, 2015) and Isle of Man Councils (Isle of Man Government, 2015). Such areas have succeeded due to active management, monitoring and control programmes, which reinforce the island effect provided by the sea or in Brighton's case the South Downs.

To complement operations on public land, Edinburgh City Council has initiated a procedure to fell and remove any infected elm tree on private land at the cost of the landowner. The aim is to remove infected trees which provide a breeding ground for the beetles that carry the DED fungus, posing a continuing threat to the City's healthy elm population which has been maintained by a programme of monitoring and control (ECC, 2014; McEwan, 2016).

The elm tree is still recognised as an important and desirable tree in the British landscape and most view the continued loss as a significant impact for British woodland diversity and structure. Mixed elm woodlands were once an integral part of the broadleaf woodland mosaic in Scotland, most commonly found in unique but decreasing woodland mixes, such as upland ash woodlands, as well as west coast Atlantic oak and hazel woods (Wilson, 2015). In Aberdeenshire the disease is well-established (Brasier, 1996), however there is little information on the extent and severity of the disease further north. The Highlands has an opportunity to manage its elm population within an isolated area to stem the spread of DED, cultivating healthy and potentially productive woodlands with elm as a significant component.

3. Distribution of elm species

This section presents the known extent of elm in the Highlands and identifies new areas of both healthy and potentially DED-infected elm populations, as well as plotting likely vectors and action/management areas. In the first part of this section context and baseline data are presented using the Native Woodland Survey of Scotland (NWSS) open source data (FC(b), 2015) and the Forestry Commission (FC) supplied boundary of observable DED infected elm in the Highlands, referred to hereafter as the 'DED line' (Figure 1). In the second part of this section, information gathered through surveys (growers and processers) and engagement with land use professionals is presented including observations on the location and extent of healthy and potentially DED infected elm.

3.1 Spatial extent of elm in Scotland

The distribution of native woodland containing elm identified in the NWSS is shown in Figure 1. Elm data were identified by a species summary table within ArcMap using the NWSS dataset, resulting in percentage of canopy cover composed of elm species in native woodland areas. Table 1 summarises areas of elm identified in native woodlands, using Forestry Commission Conservancies as landscape units (Figure 1).

Table 1 – Elm trees and areas broken down for FC Conservancy areas (NWSS, 2014)[1]

Region	NWSS woodland area (Ha)	NWSS broadleaf woodland area (Ha)	NWSS area of elm (Ha)
South Scotland	40,798	31,240	452
Central Scotland	30,010	31,620	445
Perth and Argyll	100,407	68,674	393
Grampian	58,347	24,188	229
Highlands and Islands	161,265	51,479	338
Scotland	390,827	207,202	1,857

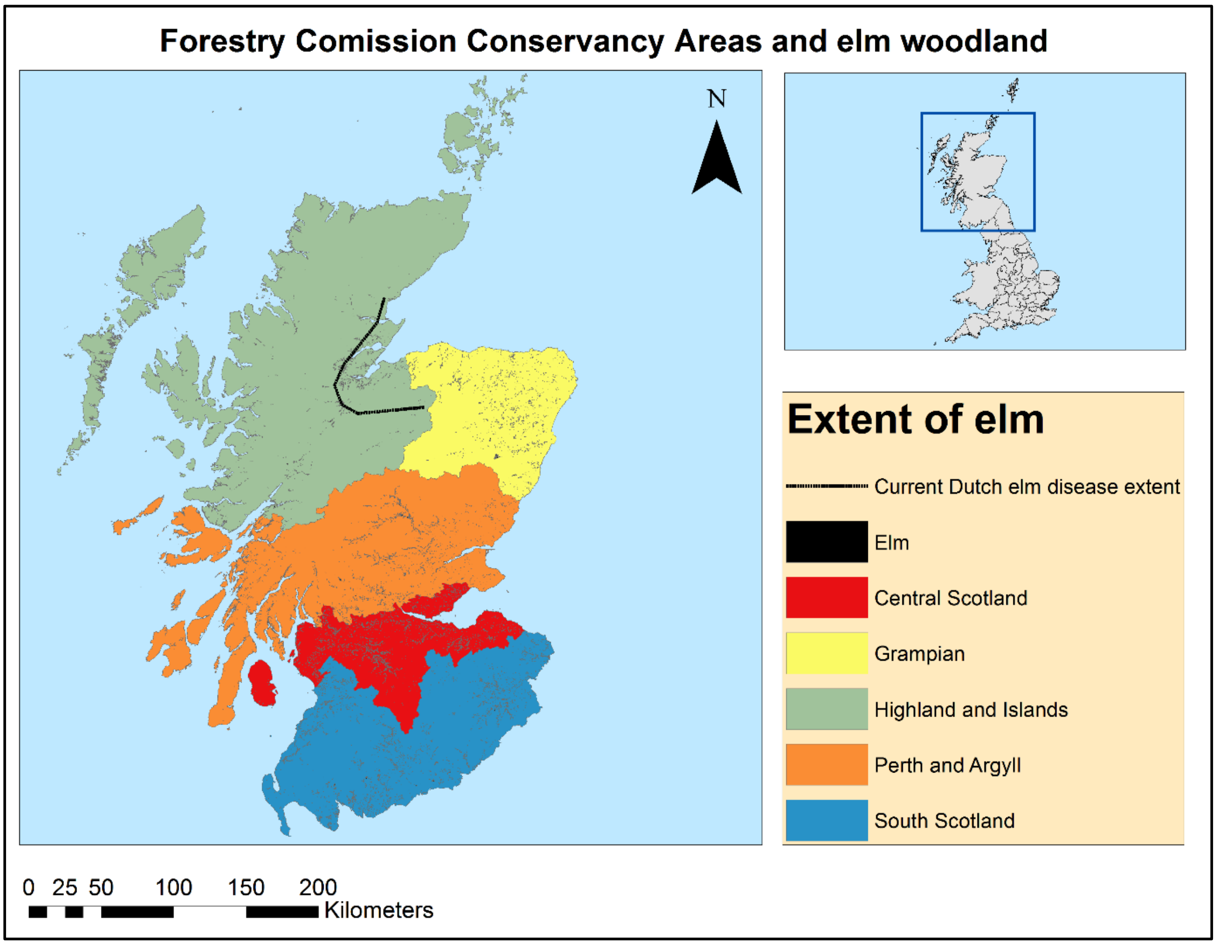

Figure 1 – Map showing the extent of elm over the Forestry Commission Conservancy areas

[1] NWSS area of elm = (Area of native woodland x percentage of woodland cover x percentage of elm canopy cover). Percentage of elm cover=(Area of elm/woodland area*100)

Woodlands currently cover 18% of Scotland, which translates to an area of 1,432,000 hectares (FC(c), 2015). **Elm species constitutes 0.13% of all Scotland's woodlands**, which amounts to 1,856.9 hectares of elm woodland cover in Scotland (Table 1), **and 0.11% of Highland and Islands woodland**.

Elm is currently a very small part of the woodland resource in Scotland and the majority of trees are a minor component in larger, mixed-species stands. This is highlighted by Table 2, which shows that elm constitutes only 0.9% of the total broadleaf woodland resource in Scotland, ranging from 1.4% in South and Central Scotland to 0.57% in Perth and Argyll. As an element of native woodlands, the proportion of elm is lower in the northern parts of Scotland, where native woodlands are dominated by Scots pine (*Pinus sylvestris*), than in South and Central Scotland where there is a greater proportion of broadleaf native woodland.

Elm canopy cover (Table 2) is an estimate of the canopy area of elm (in any woodland containing elm), as a proportion of total canopy area. Across Scotland, elm canopy cover averages 4.35%, with only a little variation between the regions. Considering woodland areas where elm canopy cover is greater than 25% or greater than 50% provides an indication of where concentrations of elm trees can be found. Although the largest total areas of elm are in South and Central Conservancies (Table 1), the Highland Islands Conservancy has the second largest area of woodland with greater than 25% elm canopy cover and the largest area of woodland with greater than 50% elm canopy cover. This suggests that the Highlands and Islands is a region with significant areas of mature elm trees, relative to Scotland as a whole.

Table 2 – Percentage of elm component in various woodland types, based on data from the National Forest Inventory and the Native Woodland Survey of Scotland (FC - NFI, 2011; NWSS, 2014).

Region	Elm in broadleaf woodland (%)	Elm in native woodland (%)	Count of woodland areas with elm	Elm canopy cover* (%)	Area with 25% + elm canopy cover (Ha)	Area with 50%+ elm canopy cover (Ha)
South Scotland	1.4	1.1	3,968	4.2	153.85	21.72
Central Scotland	1.4	1.48	3,393	3.9	108.5	12.99
Perth and Argyll	0.57	0.39	3,220	3.4	62.77	22.79
Grampian	0.95	0.39	1,908	5.4	75.42	24.88
Highlands and Islands	0.66	0.21	1,911	4.9	100.83	45.93
Scotland	0.9	0.48	14,400	4.35	501.37	128.31

* Elm canopy cover is an estimate of the canopy area of elm (in any woodland containing elm), as a proportion of total canopy area

The NWSS is not a completely comprehensive dataset, as many individual trees and small areas were not in the original scope of the survey. Areas were selected for the survey by using digital maps prepared from aerial photos, which identified potential woodland types with native species, as well as Plantations on Ancient Woodland Sites (PAWS) over 0.5 ha (NWSS - H, 2014). One limitation of the NWSS data is a lack of information relating to tree health or stand survival rate or ratio. Such factors would build a more comprehensive regional picture for greater spatial and temporal analysis.

Figure 2 displays the successional structure of the elm population in Scotland[2] (NWSS, 2014). Approximately 75% of the elm trees are composed of pole and mature stage trees. Established regeneration represents 21.5% of the species structure with very few veteran trees (0.3%) and only 2.9% of visible regeneration. During several visits around the Highlands to forests under private ownership, wych elm regeneration was abundant in riparian areas, straths and glens, significantly outnumbering the immature and mature trees. In most areas across the Highlands regeneration is low, as broadleaf species are subject to high browsing pressures from deer.

[2] Elm successional structure = (i.e. Query builder ArcMap: Area of elm>=lowest value AND Visible regen=>=1/total elm area).

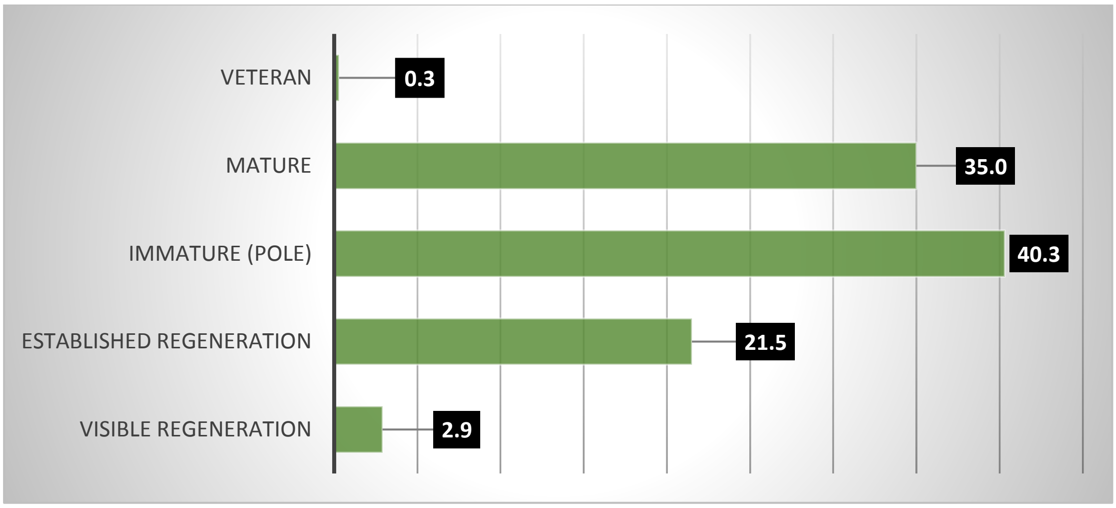

Figure 2 – Structure of elm tree population in Scotland (percentage)

3.2 Spatial extent of Elm species in the Highlands and Islands

The Highlands and Islands area is the largest administrative region in Scotland, with a diverse landscape which includes: significant uplands; sparsely populated, remote rural areas (Highlands average: 7 people/km^2; Sutherland average 2 people/km^2, compared to a Scotland average of 67 people/ km^2); extensive lochs and river systems; and arable farming predominately around the east coast firths (Scottish Government, 2011). Historically the Highlands have been dominated by sporting use and livestock farming, which have suppressed natural regeneration of woodland (Bunce, et al., 2014). In recent years livestock farming has fallen into decline but sporting use for deer stalking (and for grouse shooting on a smaller scale, outside of the Cairngorms) persists and remains an important cultural and economic land use for private landowners (MacMillan, et al., 2010) (covering 43% of the Highlands (Warren, 2009)).

Figure 3 shows the boundaries of electoral wards in the Highlands and Islands[3]; these landscape units were used to spatially analyse areas of woodland with elm species present, based on the NWSS dataset. The Highlands and Islands has an area of 337.7 hectares composed of elm species (mostly wych elm, although English elm are present in the landscape as ornamental and hedgerow trees).

[3] Shetland was omitted for the area, as no elm was present. Wards in both Orkney and Lewis were merged to create single island groups

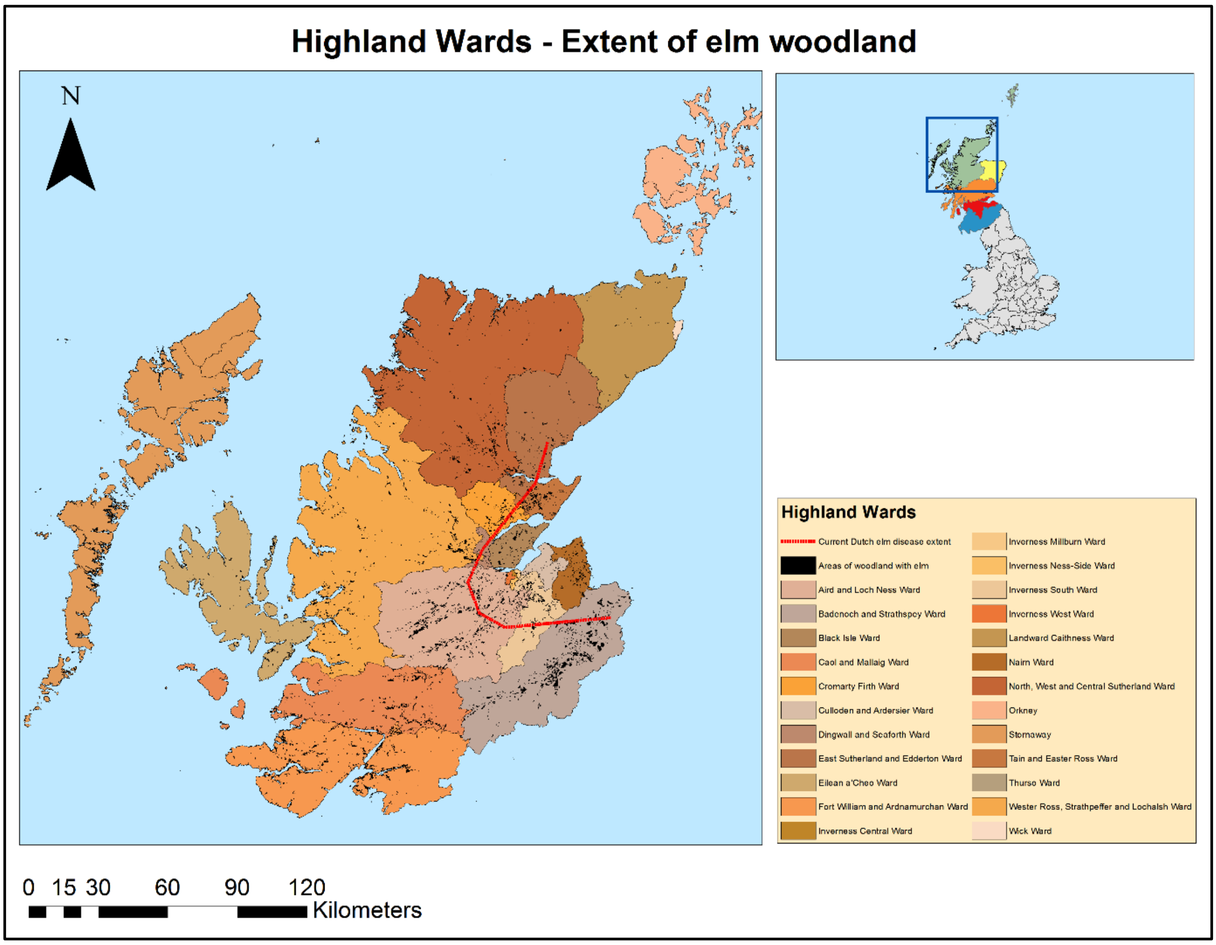

Figure 3 – Map showing the extent of elm woodland areas over the Highland Wards

Figure 4 displays the breakdown of elm area over the Highland wards[4]. Aird and Loch Ness (67.6 Ha) and Fort William and Ardnamurchan (81.1 Ha) have the most significant populations of elm in the Highlands. Other significant areas include the Black Isle, Cromarty and Dingwall, all of which are located around firths and within known DED infected areas. Wester Ross, East Sutherland, and Skye and Raasay also have notable areas of elm. If the data are analysed in terms of average elm canopy cover in woodlands with elm present (as a proportion of total canopy area), Caithness and Dingwall Wards rank highest with 10.1% and 9.3%, with Cromarty, Black Isle, Inverness Milburn and, East Sutherland and Edderton Wards between 6-9% cover[5].

[4] ArcGIS Split analysis tool was used to breakdown and interrogate the elm areas within the Conservancies and the Wards.

[5] ArcMap query builder used to identify larger canopy cover areas: Elm area>=lowest value AND total elm canopy cover>=25/50

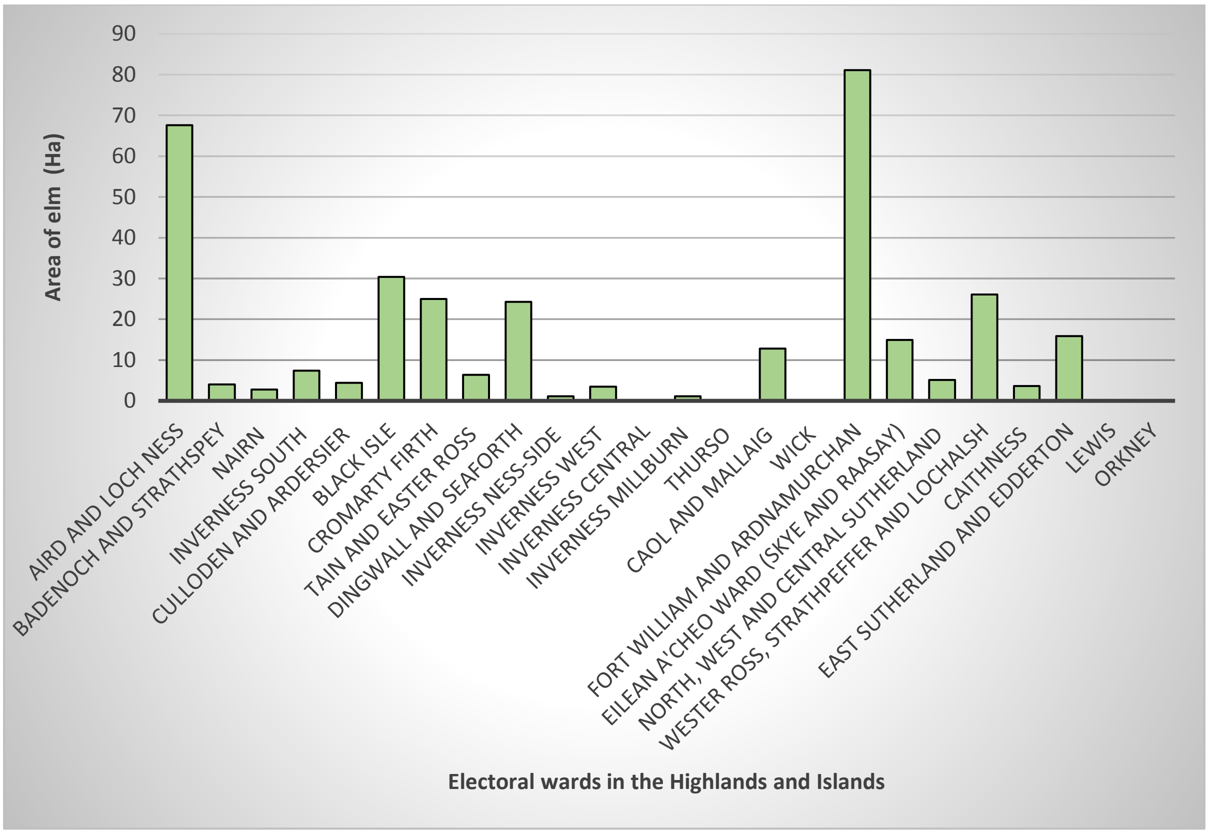

Figure 4 – Area of elm species in Highlands and Islands electoral wards

The areas in each electoral ward with 25%+ and 50%+ elm canopy cover (in woodlands with elm as a component) are shown in Figures 5 and 6 respectively. Focusing the analysis on more significant areas of canopy cover identifies areas with greater elm density and potential connectivity. The Cromarty Firth ward has the largest area of elm density in both the 25%+ (18.6 Ha) and 50%+(14.4 Ha) elm canopy cover categories, with Aird and Loch Ness, Black Isle, and Dingwall wards all with similar areas in the 25% + analysis. In Figure 6 Cromarty Firth Ward is the most significant area of elm species density in Highlands by a large margin, as mentioned previously the Wards with the most significant densities of elm species in woodland are also within the known DED infection area. This emphasises the correlation between species density and connectivity with occurrence of DED.

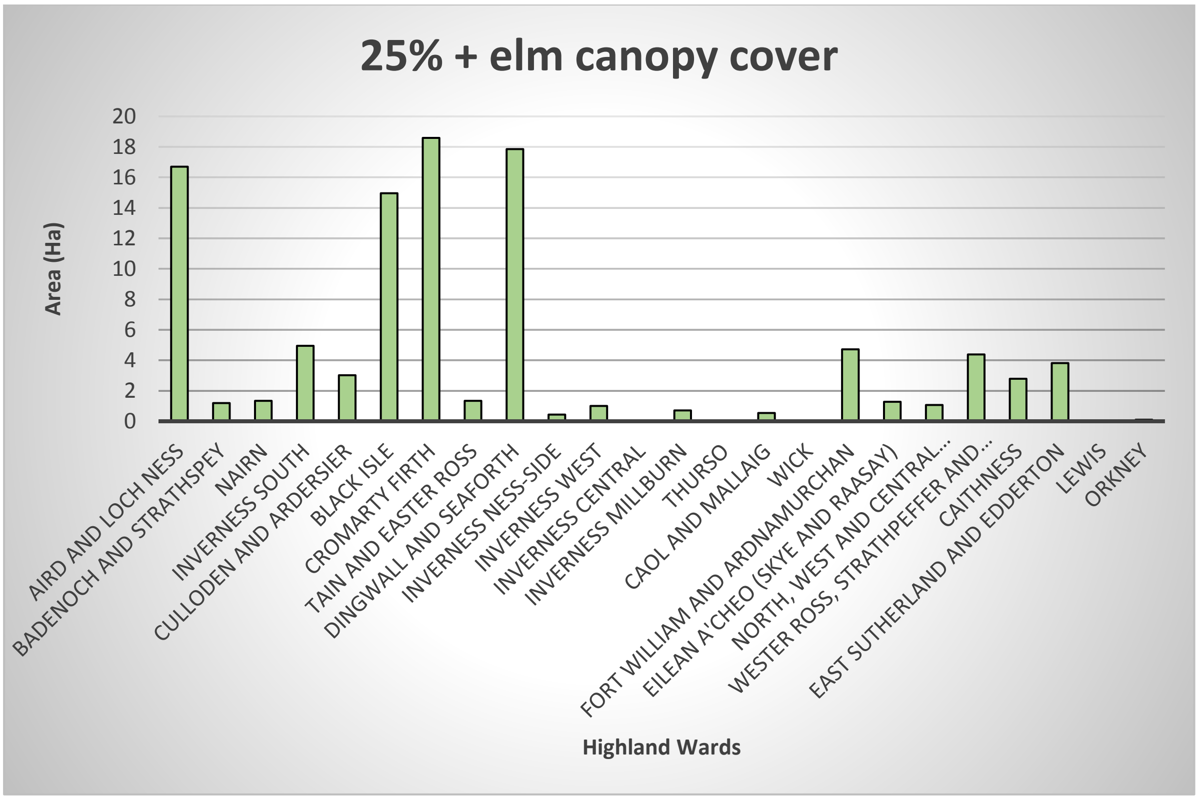

Figure 5 – Areas of woodland in the Highlands and Islands electoral wards with 25%+ elm canopy cover (in areas with elm species as a component)

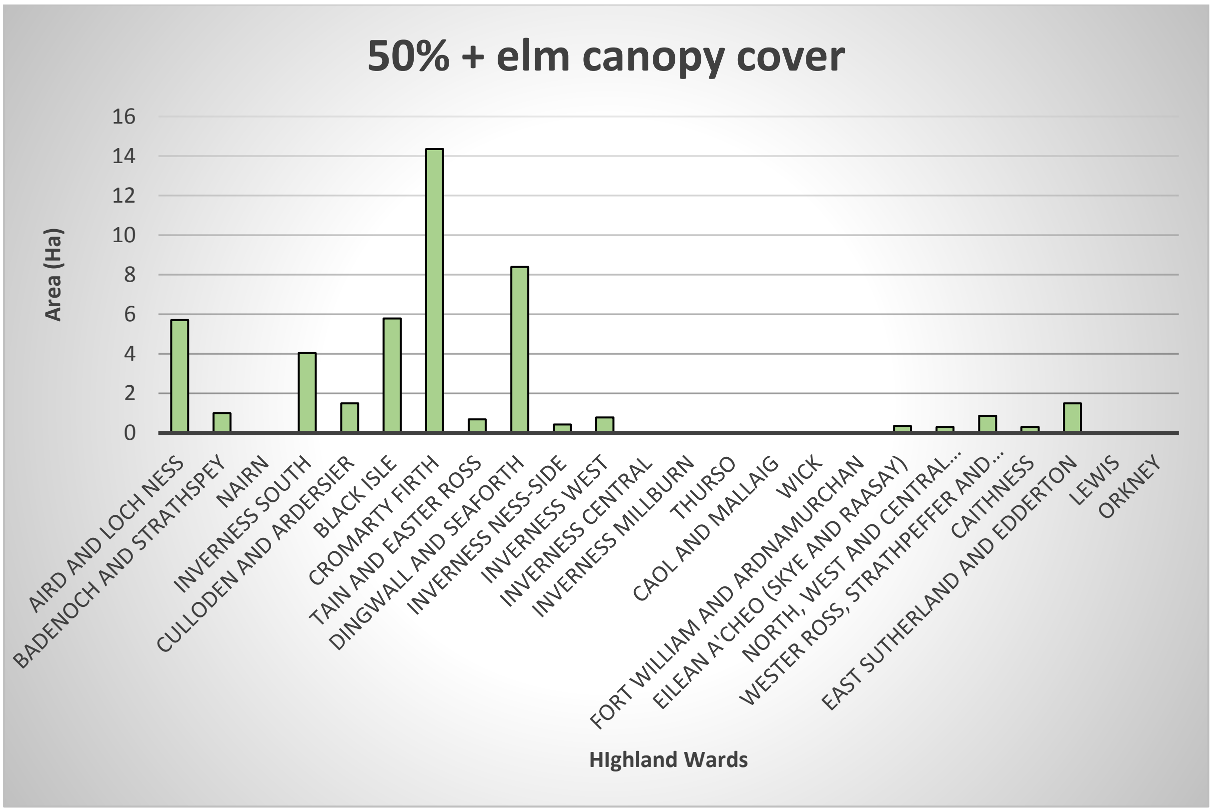

Figure 6 – Areas of woodland in the Highlands and Islands electoral wards with 50%+ elm canopy cover (in areas with elm species as a component)

Figure 7 shows the density of elm canopy cover in woodlands over the Highland and Islands region, highlighting areas with higher levels of elm canopy cover and connectivity over the landscape. The majority of the elm species populations are located around the east coast including Cromarty, Dingwall, Black Isle, Beauly and traces along the banks of Loch Ness following the Caledonian Canal out to the West coast at Fort William. The estimated extent of Dutch elm disease in the Highlands (based on Forestry Commission Scotland information) is represented by the black line that curves around the Firths on the east coast. Drumnadrochit is the furthest west that DED has been identified and Dornoch the furthest north. Figure 7 also identifies fragmented but significant populations of elm in Sutherland, Caithness and a woodland in Orkney, near Finstown.

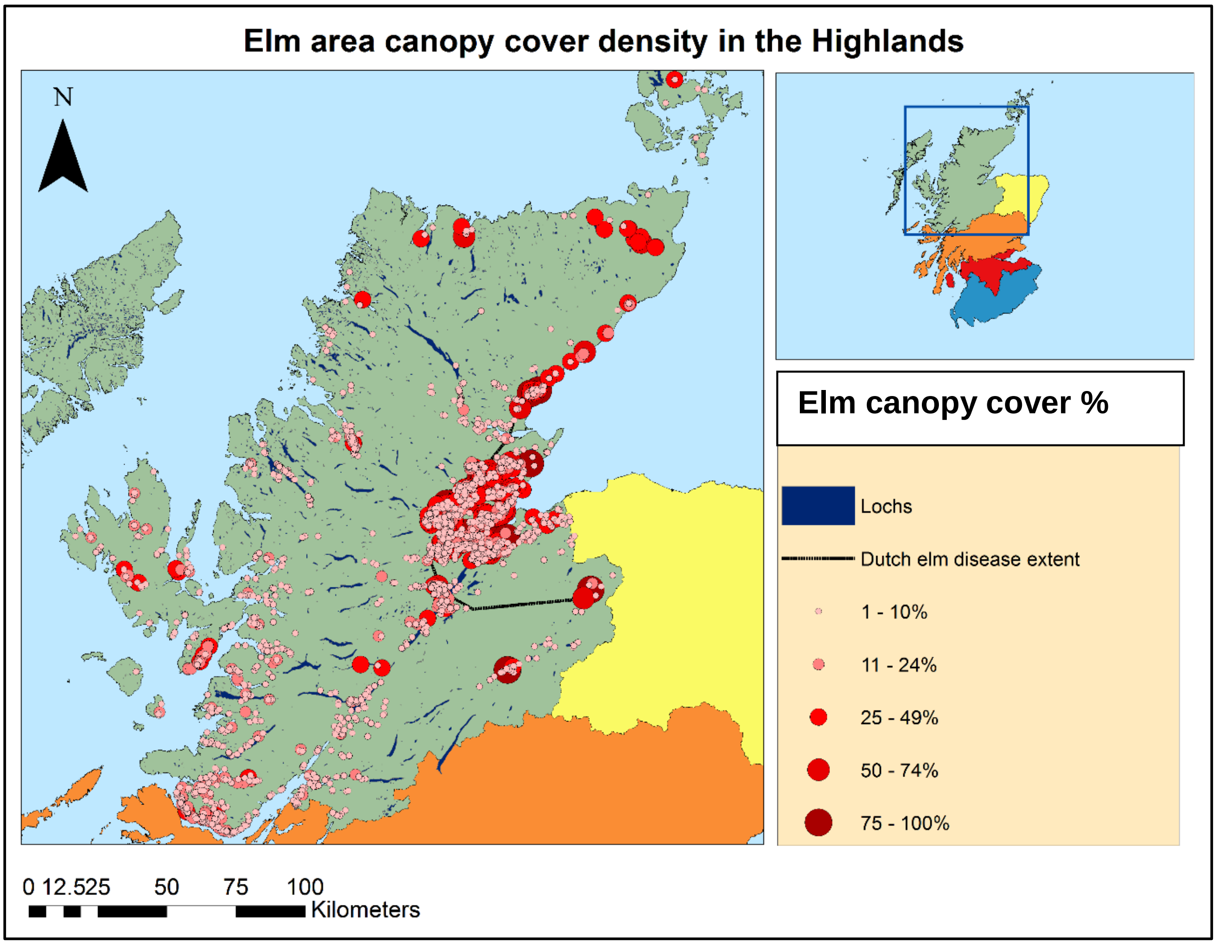

Figure 7 – Map showing the density of elm canopy cover in woodlands containing elm, across the Highlands and Islands area

Figure 8 illustrates the quantity and connectivity of elm species in the Cromarty area, which has the highest density of elm canopy cover in the Highlands and Islands.

Significant areas are present along infrastructure networks, most notably the A9 with dense strips of elm trees on the roadside and around agricultural verges. These areas are lowland fringe arable sites with the largest population of broadleaf species in the area. Figure 8 also shows a large 2.5 kilometre strip of woodland with between 75-100% elm canopy cover, which connects over three individual stands.

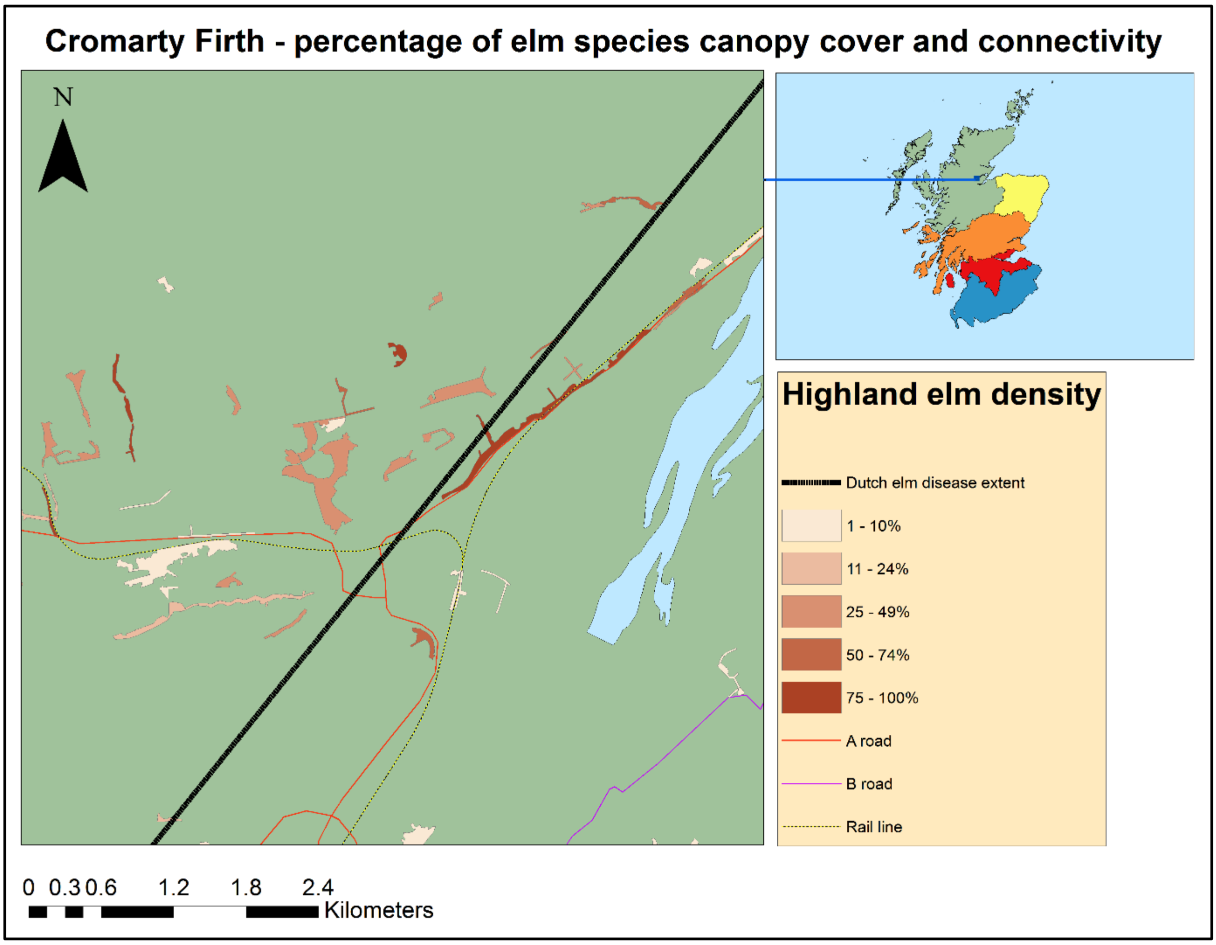

Figure 8 – Map of elm areas and density around the Cromarty Firth

Figure 9 shows the age structure of the elm population in the Highlands and Islands, which has a significantly higher percentage of mature woodland in comparison to Figure 2 (Scotland – 35%). Another clear difference in the structure between Scotland and the Highland Islands is the percentage of established regeneration being significantly lower in the Highlands (8.2%) in comparison to Scotland (21.5%). Percentage of visible regeneration and veteran trees are similar between Scotland and the Highlands. This could be explained in part by Figure 10, which shows that elm areas of woodland in the Highlands are under significant herbivore browsing pressure. According to the NWSS (2014) approximately 43% of woodlands with elm areas are subject to either high or very high browsing pressure and a further 51.9% is under medium browsing pressure. This results in over 94% of woodland with elm heavily impacted by browsing, which supresses natural regeneration associated with the levels in Figure 9.

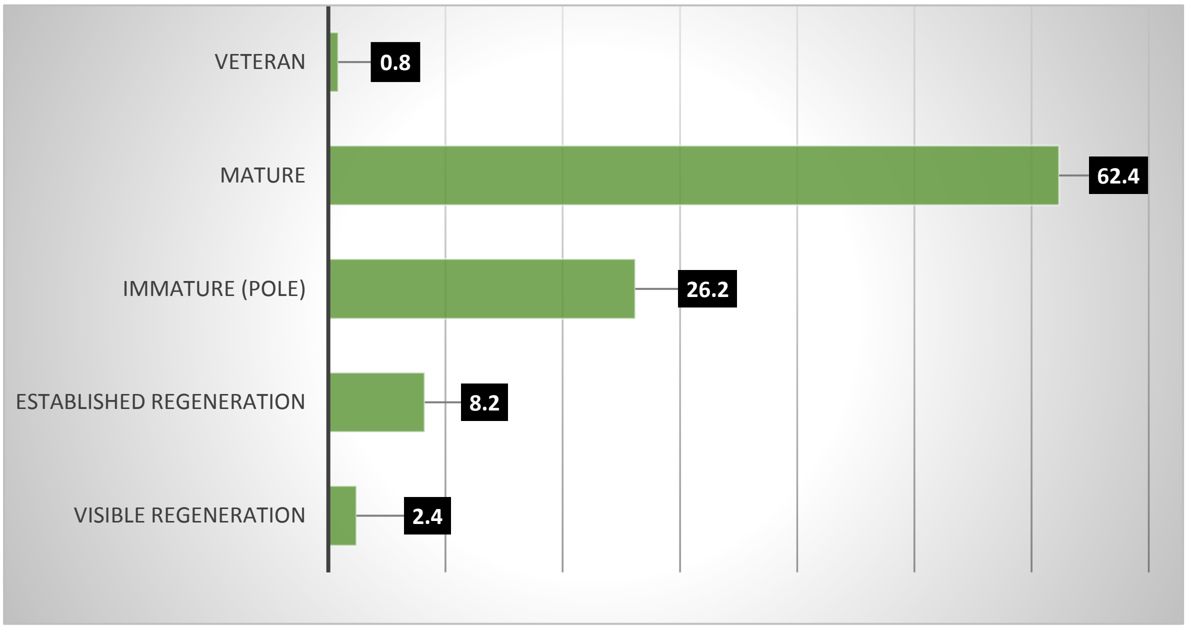

Figure 9 – Successional structure of elm species in the Highlands and Islands (percentage) (NWSS, 2014)

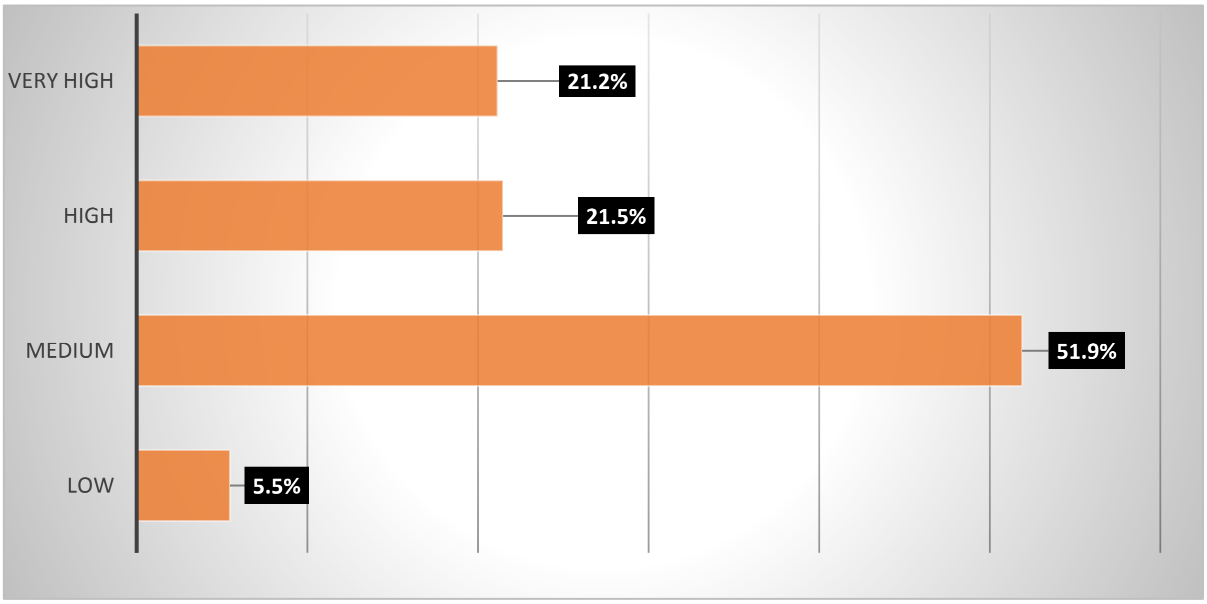

Figure 10 – Levels of herbivore browsing pressure in elm woodlands in the Highlands and Islands (percentage) (NWSS, 2014)

Elm is historically associated with certain woodland types in the Highlands including upland ash mixed woodland, oak woodland and hazel woods (Wilson, 2015). The NWSS (2014) identified five dominant habitat types associated with elm species (Figure 11):

- Upland mixed ashwood (W9)
- Upland birchwood (W4)
- Lowland deciduous wood (W8, 10 and 16)
- Upland oakwood (W11 and 17)
- Wet wood (W1-7)

This aligns with main primary or secondary species in mixed woodland areas with elm (Figure 12), as both ash and birch (*Fraxinus exlcelsior; Betula pendula and B. pubescens*) have the highest share of species mix followed by alder (*Alnus glutinosa, A. incana*), hazel (*Corylus avellana*), sycamore (*Acer pseudoplatanus*) and oak (*Quercus patrea, Q. robur and Q.rubra*). Beech (*Fagus sylvatica*) is the lowest associated species, which is congruent with beech's growth strategy, resulting in canopy dominance over other primary canopy trees.

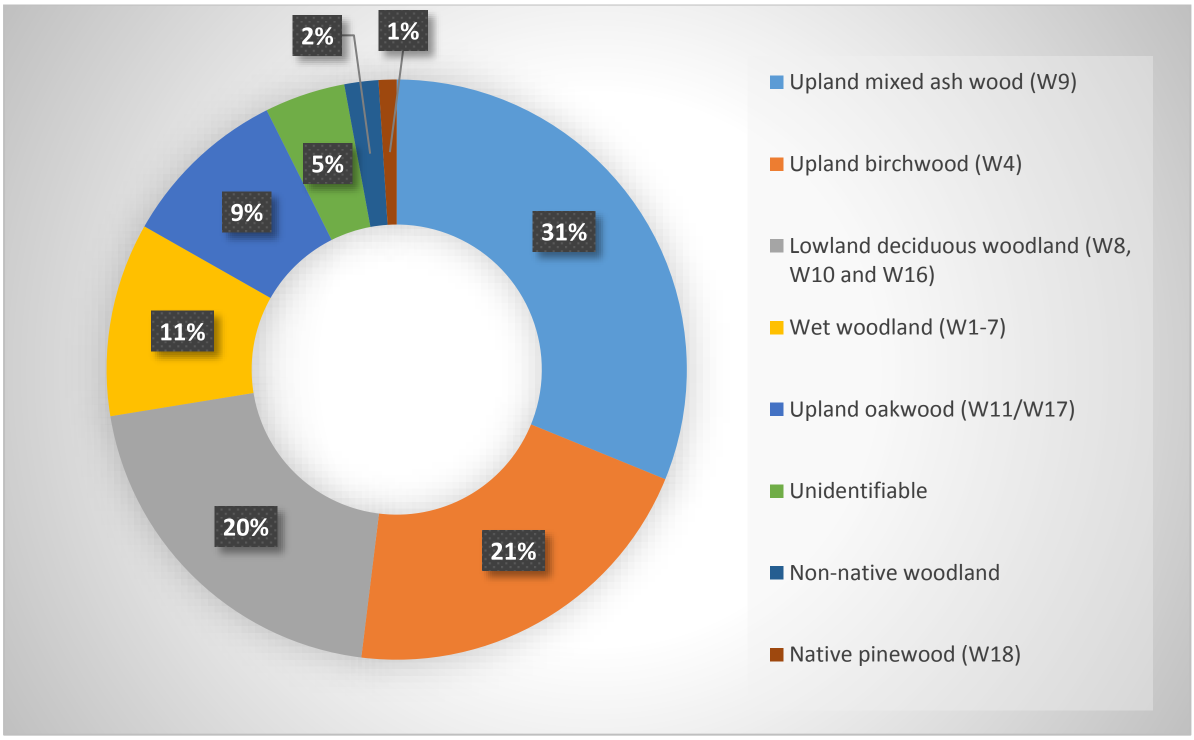

Figure 11 – Range of habitat types associated with elm species (NWSS, 2014)

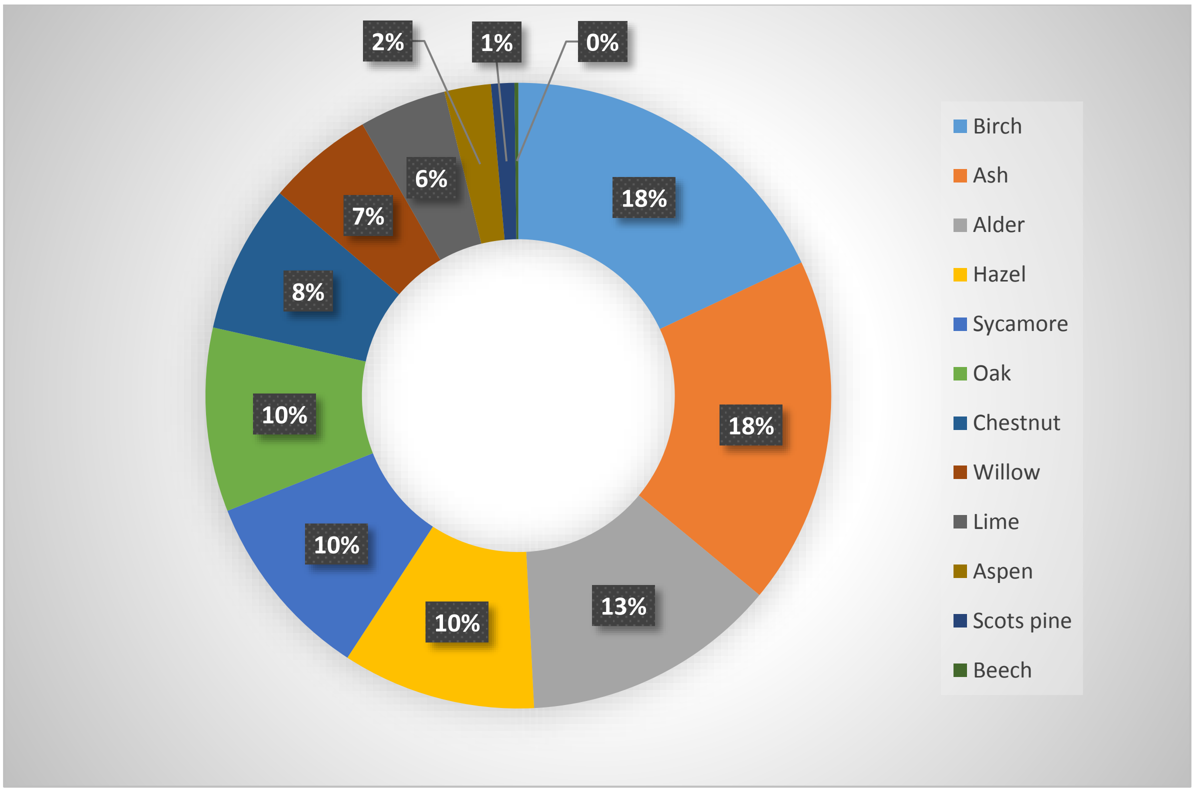

Figure 12 – Main primary or secondary species of mixed elm woodland in the Highlands (NWSS)

3.3 Elm survey results and analysis

A group of land use professionals and landowners was engaged to gain greater insight into the extent of elm species and DED over the Highlands, and in the first instance asked to identify known areas of elm (healthy, unhealthy or dead). Subsequently, an e-mail and online survey (Appendix A) was distributed to a wider group of stakeholders, requesting locations of elm in the Highlands and Scotland, as well as information on the landscape and social significance of the species to the region. The survey and hyperlink link to the online version was sent out by email to regional offices of Forestry Commission Scotland, Scottish National Heritage, RSPB, John Muir Trust, National Trust for Scotland, Community Woodland Association, Scottish Land and Estates, Confor, and Trees for Life: each was asked to distribute the survey to members and colleagues. Over 60 completed surveys were returned from a variety of organisations (Appendix C).

During interviews and site visits with landowners and forestry companies, areas identified as having significant components of elm mostly ocurred along river banks, on fringe and edge habitat areas surrounding lowland infrastructure routes, as well as agricultural fields. Closer to urban areas these often took the form of small amenity woodlands containing a mix of six or seven different broadleaf species, normally a mixture of the species identified in Figure12.

Figure 13 shows all species associated with wych elm by survey respondents in the Highlands; the results are generally consistent with results of the NWSS presented in Figures 11 and 12. Ash was the species most associated with elm, which is consistent with historical woodland structures (Wilson 2015). Oak, birch and hazel also ranked highly and also support the historical range and mixture of species. Sycamore was highly associated with elm despite its non-native status, thought to be a neophyte introduced as early as the 10th century but only recorded as far back as the 15th century (Milner, 2011). In the Beauly area and around the Cromarty Firth regions, lime (*Tilia x europaea*) was the dominant species identified by survey respondents in woodland mixtures with elm.

The majority of other species were native broadleaves with the exception of plane (*Platanus spp.)*, and prominent Scottish landscape associated conifers (Scots pine (*Pinus sylvestris*), spruce (*Picea stitchensis* and *P. abies*) and Douglas fir (*Pseudotsuga menziesii*)). Giant sequoia (*Sequoiadendron giganteum*) was the most obvious outlier in this group of species, likely to be an ornamental tree planted sometime in the 19th century. Damson (*Prunus domestica* subsp. *insititia*) and dog's mercury (*Mercurialis perennis*) were also mentioned, both common woodland plants throughout the majority of Britain, although more common in England. Often found on lime rich soils with a long history of woodland establishment dog's mercury can thrive in dense woodland cover, for example oak and beech woods (Mabey, 1996). Damsons are tolerant to many soil types and altitude, favouring wetter climates found in the western areas of Scotland (which matches the respondent's location); despite favouring damp conditions their roots do not thrive in swampy condition and pollination needs dry periods to be effective (Mabey, 1996).

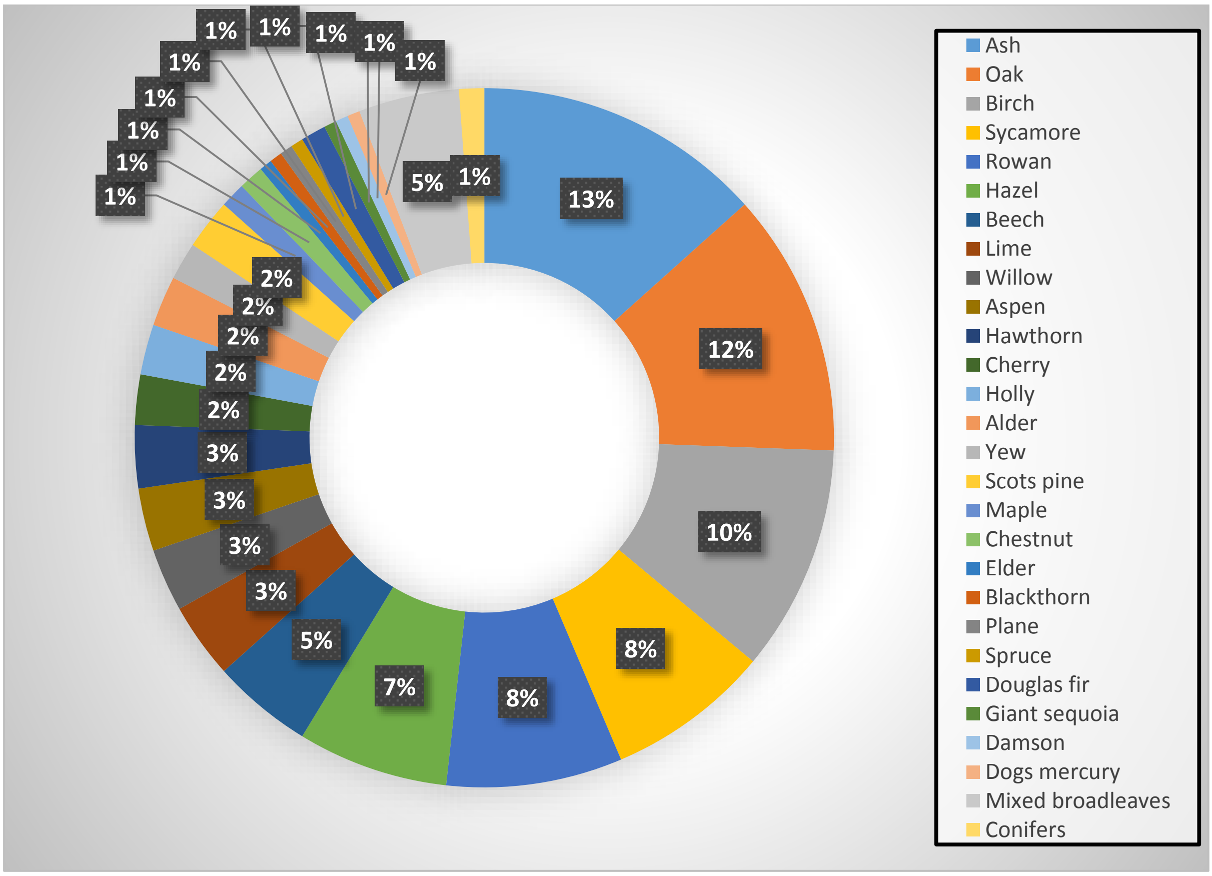

Figure 13 – Species that the survey respondents most commonly associated with wych elm in the Highlands

These species form a general list of native and non-native species mixes occurring in the Highlands. A more comprehensive list could be assembled as a decision-making matrix for adjusting mixtures in response to perceived or heightened tree health threats.

Biodiversity and regionally specific environmental factors would have to be taken into account to create the most robust and appropriate mix.

3.3.1 Dutch elm disease areas

Figure 14 shows locations identified by survey respondents as having elm present, categorised as healthy, unhealthy or a mixture of both. Areas with a high density of possible infection were identified in Moray, as well as around the east coast firths (Moray, Beauly, Cromarty and Dornoch). The most northerly confirmed DED tree death is on Skebo estate near Dornoch. However, a number of unhealthy elm trees have been removed from Argyle Square in Wick over the last few years – this could potentially point to infection by DED, but this has not been confirmed. There have been reports of fallen elm trees and potential infection in Achnasheen (no recorded elm in the NWSS) and Ardcharnich, just south of Ullapool. These represent (potentially) the most westerly extent of DED, which if verified would move the current line 40 miles west, signifying the rapid and unnoticed spread of the disease. DED can be found along the River Ness within the city of Inverness. Dochfour estate (to the west of Inverness) noted DED in 2013; many trees were infected, however pockets of healthy elms also survive. Drumnadrochit has recorded DED and represents the furthest extent down the Loch Ness vector. Participants of the survey identified potential cases of DED further along the Loch Ness vector at Invermoriston and close to West Drummond on the west side of the Loch.

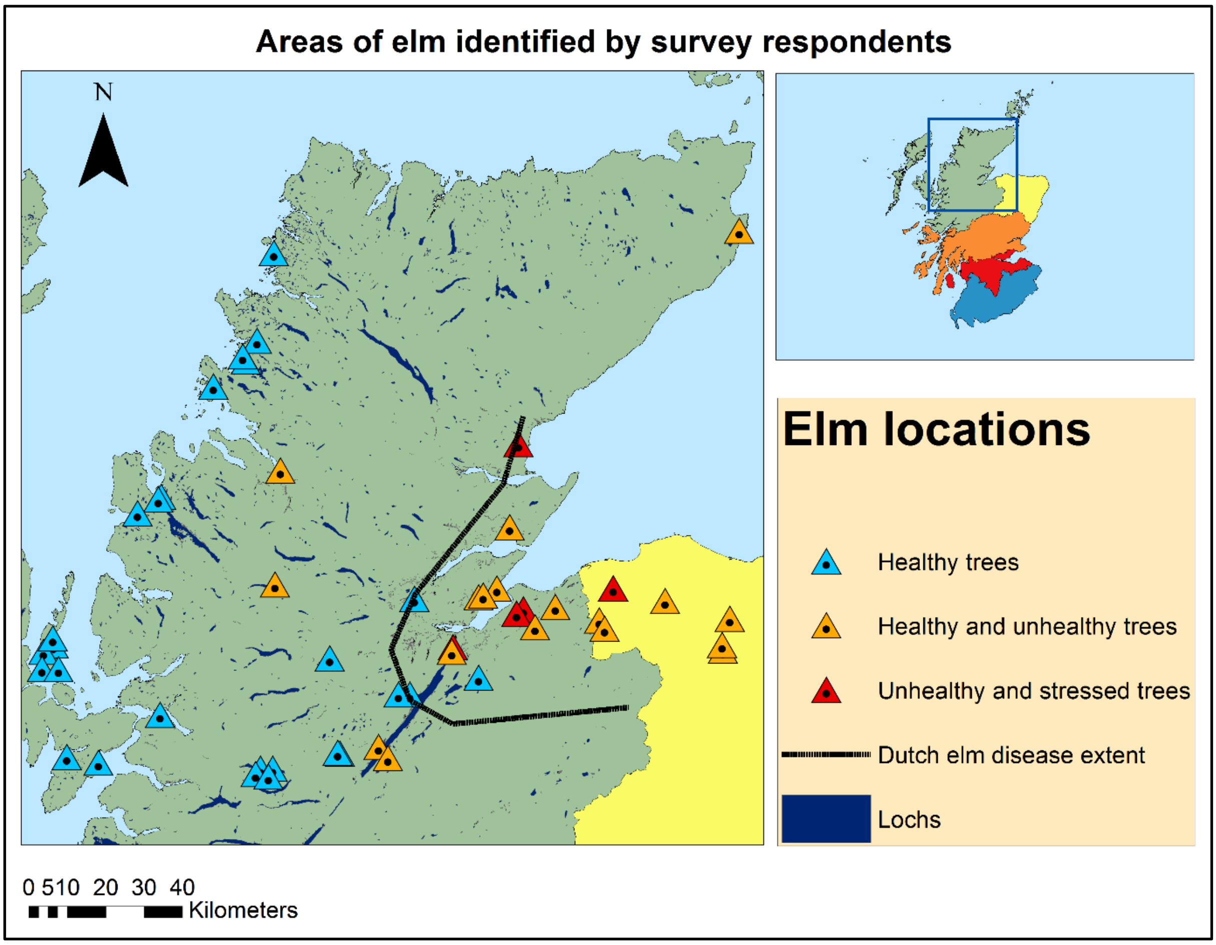

Figure 14 – Areas of elm trees identified by survey respondents

Many areas identified by the survey respondents and visited during interviews have a mixture of healthy, infected and dead elm trees with infection intermittently re-emerging in the area and infecting vigorous trees. Normally these trees succumb to infection within the year. Notable areas which demonstrated this trend are the Beauly/Cromarty Firth and Kinvinnie estate, north of Dufftown. Kinvinnie estate has an abundant elm population, especially along the rivers Spey and Fiddich where there are hundreds of healthy mature wych elm, natural regeneration, as well as sporadically dispersed DED infected trees

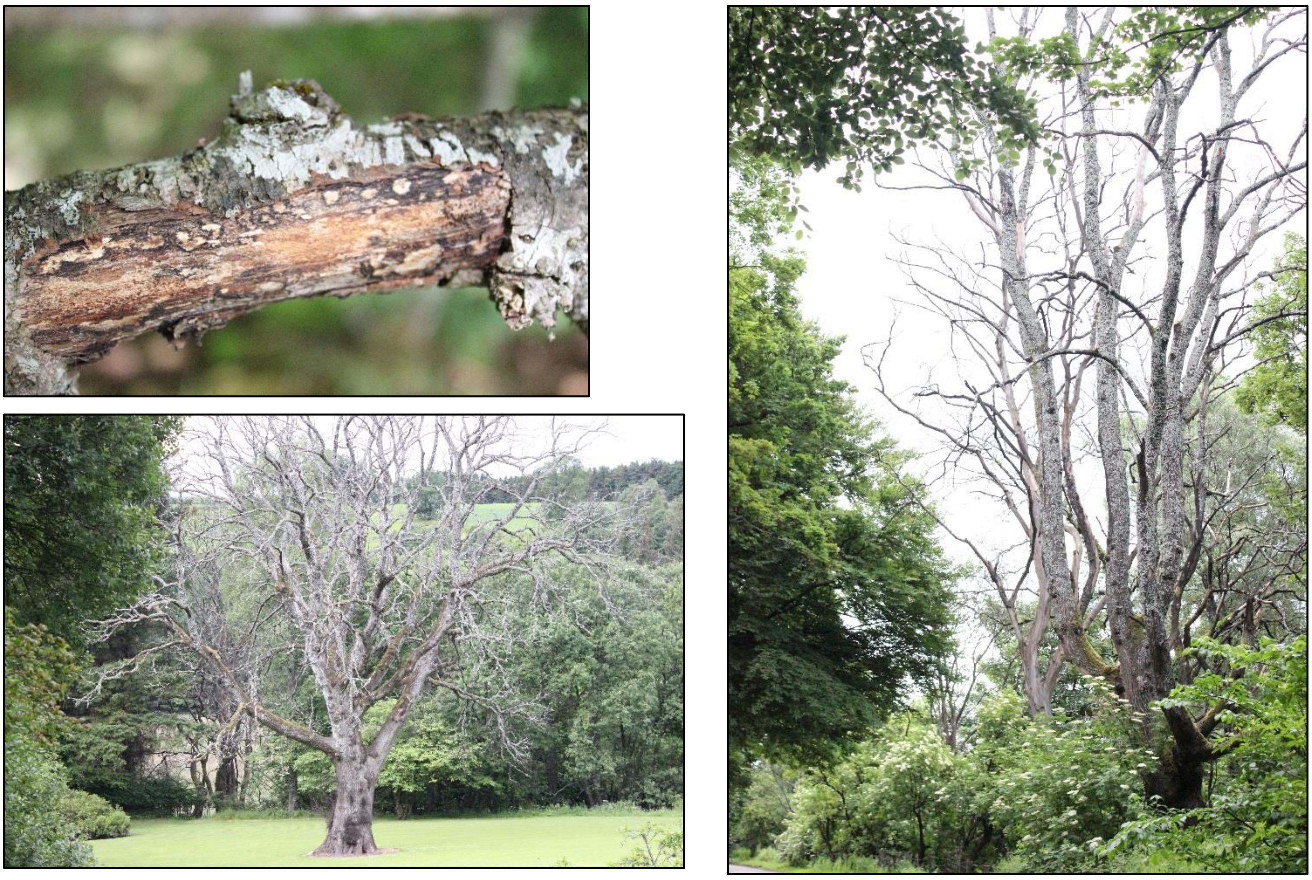

Figure 15 – Examples of elm trees in the Highland region that have recently been infected by DED

3.3.2 Healthy areas of elm

Healthy areas of elm trees and woodland have been identified by survey respondents and accurately mapped in Figure 14. These areas occurred mostly outside of the current DED line but some areas within the line held an abundance of healthy wych elm, usually in mixed broadleaf woodland. Such examples can be found along the A9 travelling from Inverness to Dornoch and fringe woodlands on the edge of agricultural fields and stands of plantation conifers (e.g. at Milton, close to Alness). Reports of healthy areas begin around Invermoriston with the unconfirmed DED infection, which could be a tree under stress. The disease has not been observed at Dundreggan and abundant areas of elm have been reported along the A87, especially around Loch Cluanie. Other areas with significant populations of elm are Ardintoul, Loch Alsh and Loch Duich (See Figure 16). This pattern continues as healthy populations have been reported on the southern end of Skye, close to Ord and Duisdale Beag. Additionally, abundant areas of wych elm have been reported on Raasay, survey respondents saying, "*there are too many to count*".

The west coast has small areas of elm growing in sheltered areas around the firths and small peninsulas. Gairloch and Poolewe are areas identified by the survey participants, as well as Polbain and Achiltibuie. Further north, south of Inverkirkaig and Lochinver elm trees have been identified in Polly More and around Cnoc Èisg Brachaidh forests. An area was also identified on the north side of Loch Druim Suard'alain, close to Glencanisp Lodge; this area is close to several areas identified with elm in the NWSS. The Assynt Foundation identified several areas of elm close to their offices and abundant populations along river banks. Scourie was the most northerly extent of elm identified on the west coast, however, this area is one of the most remote in the Highlands and may have several areas of wych elm that are not easily accessible or identifiable.

Figure 16 – Healthy elm around Loch Alsh

3.3.3 Possible vectors and routes for the spread of DED

Figure 17 shows the spread of DED over the Highland landscape identifying a general trend of the disease travelling from the east in Aberdeenshire along the Moray Firth area into Inverness through Beauly, Black Isle, Cromarty and Dornoch Firths. This spread appears to be paralleled by the road network, following the A96 and joining up with the A9 northwards. According to many of the land management professionals who responded to the survey, this pattern of spread of DED is probably caused by the transport of elm wood products, especially firewood, and compounded by storage of infected timber in areas without DED.

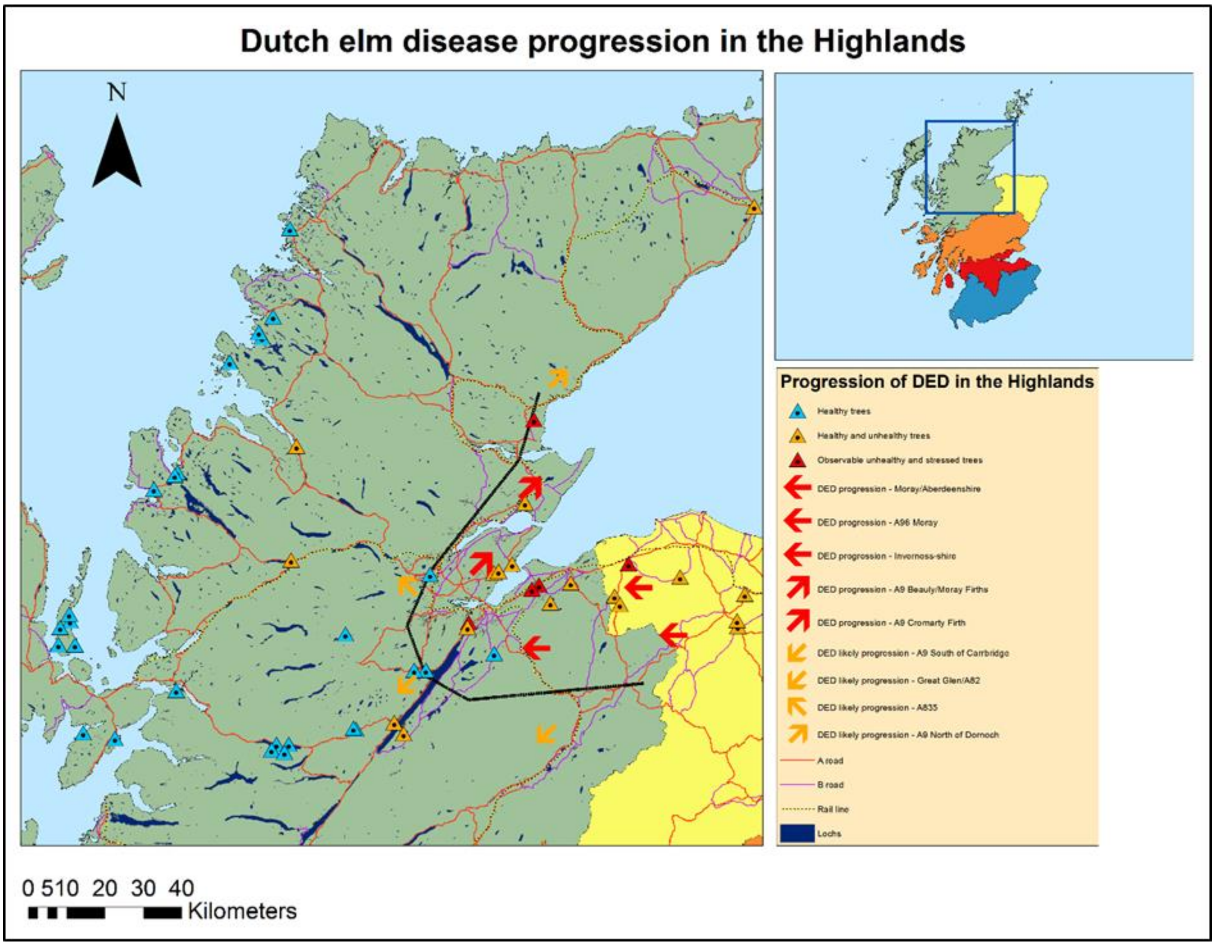

Figure 17 – Known and potential vectors of DED through the landscape

Another corridor for DED emerging in the Highlands is along the A82, which travels south west of Inverness, running along Loch Ness down to Fort August and eventually to Fort William (Caledonian Canal network – Great Glen). So far DED has only been confirmed at

Drumnadrochit. This study confirms that finding but also identifies potential DED further south west at Invermoriston and Knockie (based upon reports of land management professionals in the survey). A report of DED at Achnasheen, which has no identified elm in the NWSS, would indicate a corridor along the A835 and A832. The DED progression along the A835 corridor might extend as far as Leckmelm, as a wych elm tree in poor health fell recently, however the reason and cause are unknown. It appears that three high risk corridors that are implicated in the spread of DED in the Highlands are (in order of potential severity and connectivity) A9 northwards, A82 south-westerly, and A835 spreading west.

3.4 Factors affecting the spread of Dutch elm disease

A warmer climate has been linked to increased movement of the *Scolytus* beetle and warmer summers could mean two or three more generations due to increased reproductive rates (voltinism) (La Porta, et al., 2008). If this occurs over large geographical ranges, such as the Highlands, this could aid the spread of the disease (Lonsdale & Gibbs, 2002). Field trials conducted by Sutherland et al., (1997) showed that damage caused by DED increased when the mean temperature increased above 17°C; this is supported by a study in England, which correlated increased damage over 14 years with warmer years (Harvell, et al., 2002; ESCC, 2012). The temperature in Scotland is predicted to rise by 3.5C on average by 2080 (Wainhouse & Inward, 2016), which would increase the potential seasonal range for *Scolytus* beetles into spring and autumnal months in Scotland and the Highlands. Predictions for the Highlands region show an increase in average temperatures, which may result in warmer mean summer temperatures that exceed 17 °C and increase woodland vulnerability to disease damage (Ray, 2008).

The overall increase in abundance of insects due to longer breeding seasons, greater generational turnover, and warmer winter temperatures could intensify the damage to many tree species. Insects such as the *Scolytus* beetle where dormancy is influenced by local temperatures and which feed upon wood or bark could develop throughout the year, benefitting from an increase in longer and more favourable seasonal periods (Wainhouse & Inward, 2016). While increases in precipitation and floods may wash out and destroy some tree pathogens, the stresses placed on the tree will make it more vulnerable to colonisation and infection, as will drought (Wainhouse & Inward, 2016), which has been increasingly common in recent years on the west coast of Scotland.

Despite this, the condition and state of the wych elm in some Highland areas may be partially protected from DED infection due to cooler temperatures which are associated with lower level vector pressure, as observed in mountain areas with wych elm in the Alps and northern Europe (Hansen, 1994). Higher temperatures in the Moray region have most likely aided the vector progression into the Highlands but less favourable climatic conditions along with woodland fragmentation in central areas of the Highlands may have created barriers for vector pressure (Figure 18).

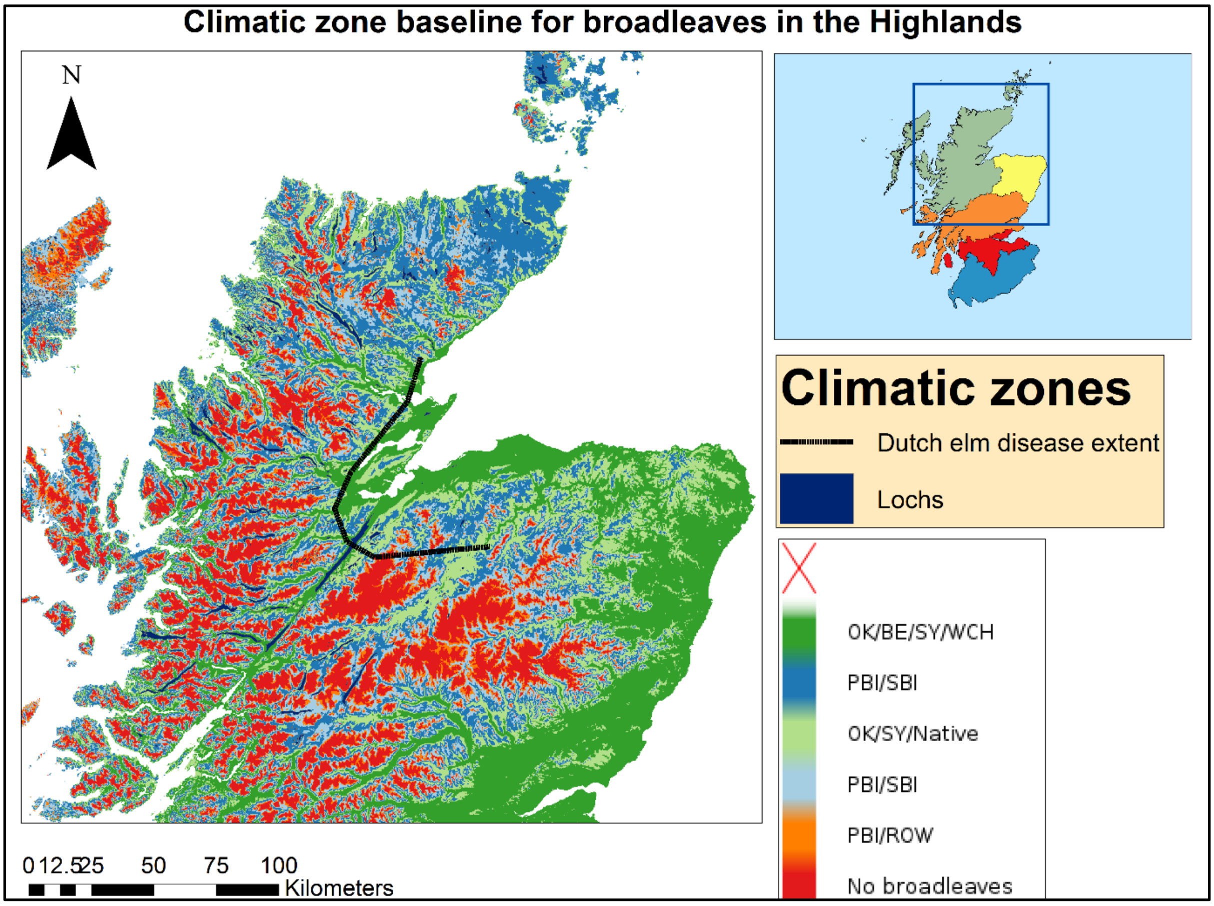

Figure 18 – Climatic zone baseline for broadleaves

Climate and soil suitability for W8 lowland deciduous woods were evaluated using the Ecological Site Classification (ESC, 2016) (Figure 19). It can be seen that the west coast of the Highlands has favourable areas for elm growth which are connected along the Great Glen, which forms a fully connected corridor of areas suitable for elm from the east to the west. The River Oykel forms another potential corridor, although this is not fully connected. Focusing management actions upon the likely DED vectors identified in Figure 17 should be a priority to prevent the spread of DED to the west coast of the Highlands.

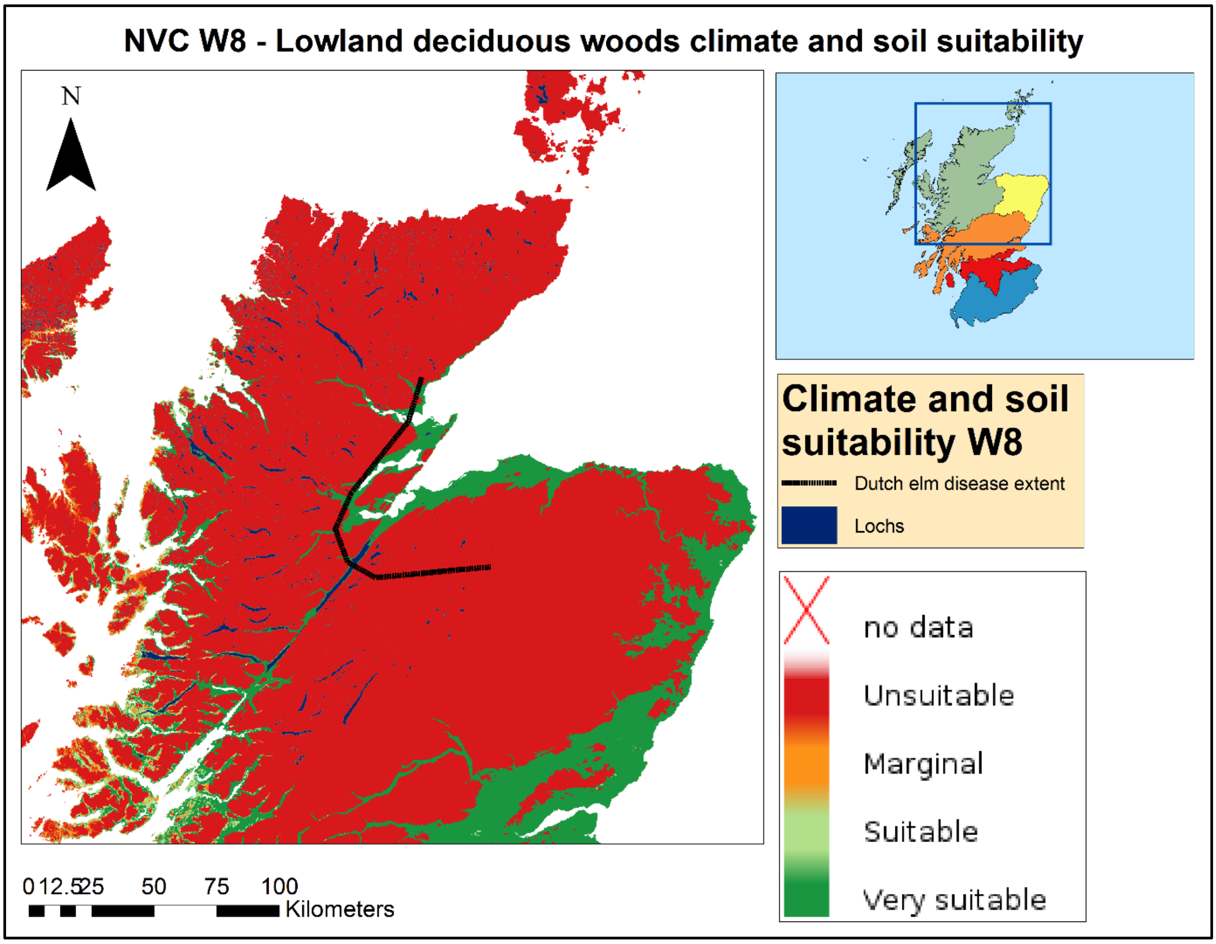

Figure 19 – W8 suitability climate map for the Highlands[6] (ESC, 2016)

Other factors that are likely to be favourable for insect pests include an increased numbers of mature and windblown trees, resulting from longer rotations associated with changing silviculture practice (Wainhouse & Inward, 2016). However, the smaller diversified broadleaf woodlands in which elm is found are less exposed and prone to

[6] W9 and W7 suitability maps also available W9 very similar to W8. ESC based upon V.S. = Top 33% of yield class rank.

windblow (unlike large conifer plantations), especially if management intervention and regimes exist.

Although the recent spread of DED northwards in southern Sweden and climbing elevation in the Appenines of Italy has been associated with climate change (warming) (Pecori, et al., 2013) significant knowledge gaps exist regarding the factors of insect aggressiveness and fungus pathogenicity (Santini, 2015). Greater consideration has been given to the effectiveness of vectors spreading DED throughout the landscape. Moser et al., suggest that two phoretic mites *Proctolaelaps scolyti* (Evans) and *Tarsonemus crassus* (Schaarschmidt), which occur principally on *Scolytus scolytus* may increase the chances of successful infection, as they carry additional inoculum of *O. novo-ulmi* (Moser, et al., 2010). The flight range and dispersal of *Scolytus spp* have been estimated at between 400 and900 metres, with greater distances covered with stronger winds (Wollerman, 1979; Barak, et al., 2000). Recent studies, however, have traced the spread of insects such as *Scolytus* and estimated an annual advance of 4 km and between 14-16 km, the latter estimates taking into account the impact of facilitated human movement (Evans, 2016).

A major challenge relates to trade and transport, which pervades all scales of tree health from international trade to local transport of timber goods, and firewood storage and movement (Gadgil, et al., 2000; Potter, et al., 2011; Harwood, et al., 2011; Santini, 2015; Wainhouse & Inward, 2016). This network of infrastructure and commerce are the arteries by which pests and pathogens spread, and was thought to be the original route for DED introduction (timber from the USA) (Brasier, 2008). The introduction of new provenances and species may create opportunities for non-native pests arriving through international trade and transport to become established: the recent case of Morfeo elm and Elm yellows is a relevant example (Forestry Commission, 2016). Biosecurity is a major concern for disease spread, the recent explosion of international nursery trade, which has more than doubled in the UK since 1992 (31% rooted plants) has introduced an effective dispersal mechanism for unknown diseases (Brasier, 2008). Within the nursery and plant health sectors the danger of infested nursery stock with exotic and endemic pathogens is widely acknowledged. Another practice that presents a significant risk to tree health issues and increasing the import of new pathogens is ex-importing, which involves exporting stock from the UK to southern Europe to winter or increase growth in early stages, and then re-importation to the UK (Brasier, 2008). Rebadging is another risk where stock is imported from outside of Europe or another EU member state and then relabelled as the exporting nursery's country (Brasier, 2008). This practice purposely hides the true origin of the stock, which could have serious implications for the importing country's woodland resource. This may not directly increase the spread of DED but could be a vector of another pest or pathogen that could further undermine the resilience of elm, broadleaf species or wider woodland structures.

4. Habitat value of wych elm

A full evaluation of the ecological value of wych elm is outwith the scope of this report, but here we give an overview of its importance for a number of species. With the anticipated loss of much of the ash population due to *Chalara* ash dieback, wych elm trees in Scotland could be increasingly significant for some of these species, particularly the elm-specialist lichens.

4.1 Birds

Wych elm seeds can be a valuable source of food for finch species in spring. Bryant (2011) reported mixed groups of finches (chaffinch, goldfinch, greenfinch, siskin, linnet and bullfinch) feeding on wych elm seeds in trees near Bridge of Allan, in late April and May in each of 3 consecutive years (2009-2011). He noted that mixed species feeding groups, such as those observed, are generally uncommon in spring when birds are establishing territory. From his observations it appeared that finches feed preferentially on elm seeds rather than on available seed from nearby feeders and he proposed that this may be related to specific nutrients or the palatability/digestibility of elm seeds. He suggested that the importance of wych elm for finches may have previously been under-recorded.

4.2 Lichens, and bryophytes

Mature broadleaved trees growing in open habitats, such as elm, oak, ash and field maple, can provide a valuable habitat for well-developed communities of lichens and bryophytes, including rare and endangered species (Douglass, et al., 2010).

The decline of elm trees in the Britain has resulted in a loss of habitat for a number of lichen species, as reported by Edwards (2005). The rough, water-retentive and relatively alkaline bark (pH 4.7 – 7.1, compared to 3.8-5.7 for oak, 5.2 – 6.6 for ash and 3.2- 5 for birch) of mature elm trees offers a favourable habitat for many species of lichen and more than 200 species of lichen species have been recorded on elms in Britain. A small number are classed as "elm specialists" which are now threatened due to the decline in elm populations, including several which are classed as nationally scarce and are priority species under the UK Biodiversity Action Plan : eagle's claws (*Anaptychia ciliaris*); sap-groove lichen (*Bacidia incompta*); orange-fruited elm-lichen (*Caloplaca luteoalba*); clustered mini-jelly lichen (*Collema fragrans*); shy cross-your-heart lichen (*Cryptolechia carneolutea*). Figure 20 illustrates the reduction in recorded occurrences of orange fruited elm-lichen over the last sixty years.

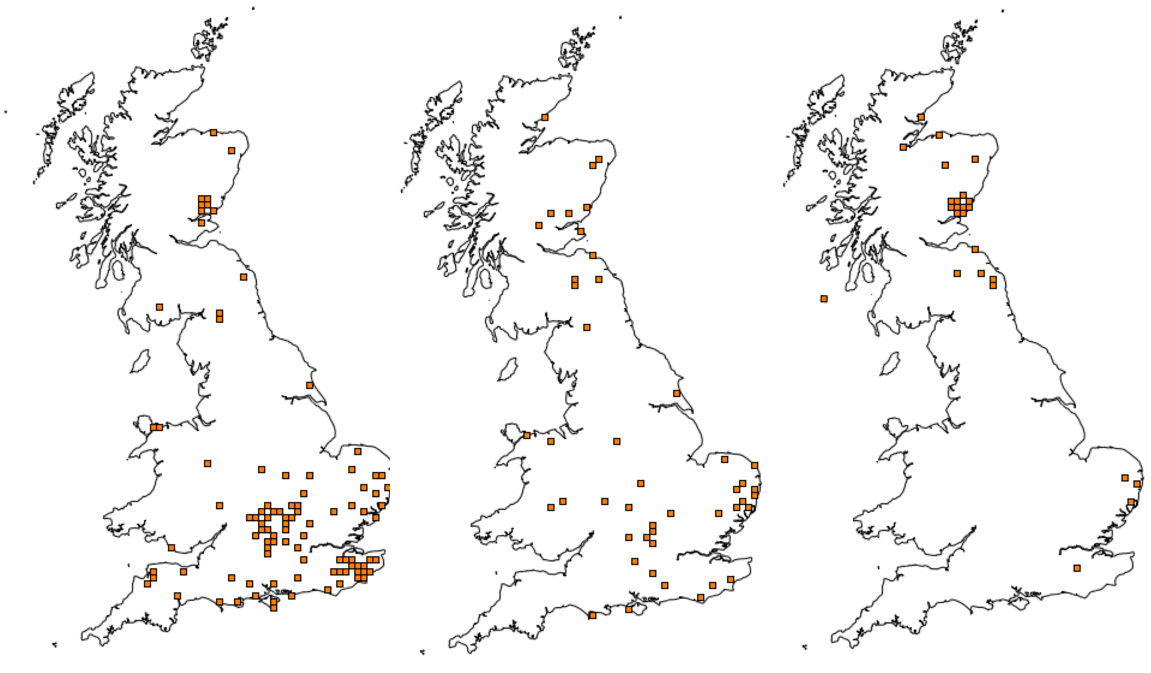

Figure 20 – Recorded occurrences of orange-fruited elm-lichen (*Calopplaca luteoalba)* over the last 60 years, illustrating the decline in elm specialist lichens (Data courtesy of the NBN Gateway with thanks to all the data contributors. https://data.nbn.org.uk/Taxa/NBNSYS0000020545/Grid_Map The NBN and its data contributors bear no responsibility for the further analysis or interpretation of this material, data and/or information.)

Tree species with relatively alkaline bark, such as elm, ash and oak, are known to support more diverse communities of bryophytes than those with more acidic bark, particularly in the drier conditions found in the east of Scotland (Douglass, et al., 2010). Species such as pendulous wing-moss (*Antitrichia curtipen*dula) and squirrel-tail moss (*Leucodon sciuroides*) may be found covering the trunk and branches of mature open-grown trees. A number of rare species, including blunt-leaved bristle-moss (*Orthotrichum obtusifolium*), pale bristle-moss (*Orthotrichum pallens*), dwarf bristle-moss (*Orthotrichum pumilum*) and lesser squirrel-tail moss (Habrodon perpusillus) have also been recorded on open-grown broadleaved trees. These mosses are all UKBAP priority species and considered to be of conservation concern "*particularly since habitat loss, especially the demise of elms, has removed so many host trees*" (Douglass, et al., 2010).

4.3 Insects

The value of Wych elm as a habitat for insects, and the complexity of relationships between some of these, have been summarised by Watson-Featherstone (2016), derived from Coleman (Coleman, 2009) and Richens (Richens, 2012):

Elm is a good all round tree for moths, supporting a range of common species that feed on various broadleaved trees. These include the Hebrew character (*Orthosia gothica*), common Quaker (*Orthosia cerasi*) and species with twig-mimicking caterpillars, such as the scalloped hazel (*Odontopera bidentata*) and the peppered moth (*Biston betularia*). Two moths that specialise in feeding on wych elm are the dusky-lemon sallow (*Xanthia gilvago*), whose larvae feed on the ripening seeds in late spring, and the clouded magpie (*Abraxas sylvata*), but in Scotland that is confined to the southwest of the country. Caterpillars of the brick moth (*Agrochola circellaris*) also feed on wych elm seeds, but it is a polyphagous species, meaning that it feeds on more than one species of tree. The white-letter hairstreak butterfly (*Satyrium w-album*) feeds exclusively on elms, including wych elm, but in the UK it is confined to England and Wales, and does not occur in Scotland.

Other species recorded feeding on wych elm include the common leaf weevil (*Phyllobius pyri*) and the elm tree leafhopper (*Ribautiana ulmi*). The larvae of several micro-moths in the genera *Coleophora*, *Phyllonorycter* and *Stigmella* make mines in the leaves of wych elm, as do the larvae of a sawfly (*Fenusa ulmi*). A number of different species induce galls in the leaves of wych elm, including a midge (*Physemococecis ulmi*) that causes blister galls, an aphid (*Tetraneura ulmi*) which causes fig-like galls to develop on the upper surface of the leaves and a fungus (*Taphrina ulmi*).

Another aphid (*Schizoneura ulmi*) is responsible for leaf curl galls, which develop on the leaves of the adventitious shoots that grow at the base of the trunk - the galls apparently do not occur on leaves higher up on the tree. This aphid is preyed upon by the elm gall bug (*Anthocoris gallarum-ulmi*) and a rare hoverfly (*Pipiza luteitarsis*). The hoverfly in turn is parasitised by an ichneumon wasp (*Campocraspedon caudatus*), which is rarer still.

5. Production and commercial aspects

5.1 Nurseries and stock

In order to gain an overview of the availability and use of wych elm planting stock, direct enquiries were made to a major supplier of forest tree seeds and to commercial nurseries advertising elm for sale (three nurseries contacted, two replies received). In addition, Forestry Commission Scotland's nursery manager at Newton near Elgin, who co-ordinates the supply of planting stock to all FC forest districts in Scotland, provided details of elm planting stock obtained for FC Scotland.

5.1.1 Seeds

According to the Forestry Commission's National Register of Approved Basic Material there are no registered seed stands for any elm species in Great Britain.

Information about seed collected and supplied to the nursery trade was provided by Forestart, a company based in Shropshire which supplies tree, shrub and wild flower seeds. Wych elm seed is either collected locally to the company (UK native seed zone[7] 403) or in Scotland (mainly UK native seed zone 201 – See Figure 21 (FC(a), 2016)). Seed can be stored so collections for at least 2 years' demand are made at the one time. Forestart do not have difficulty in obtaining the quantity of seed they require, but did mention a number of challenges associated with elm seed collection (seed blows off soon

[7] See http://www.forestry.gov.uk/pdf/FRMguidelinesRoPmap.pdf for details on native seed zones

after ripening so easy to miss; seeds may be attacked by beetles or weevils; seed viability can be very low).

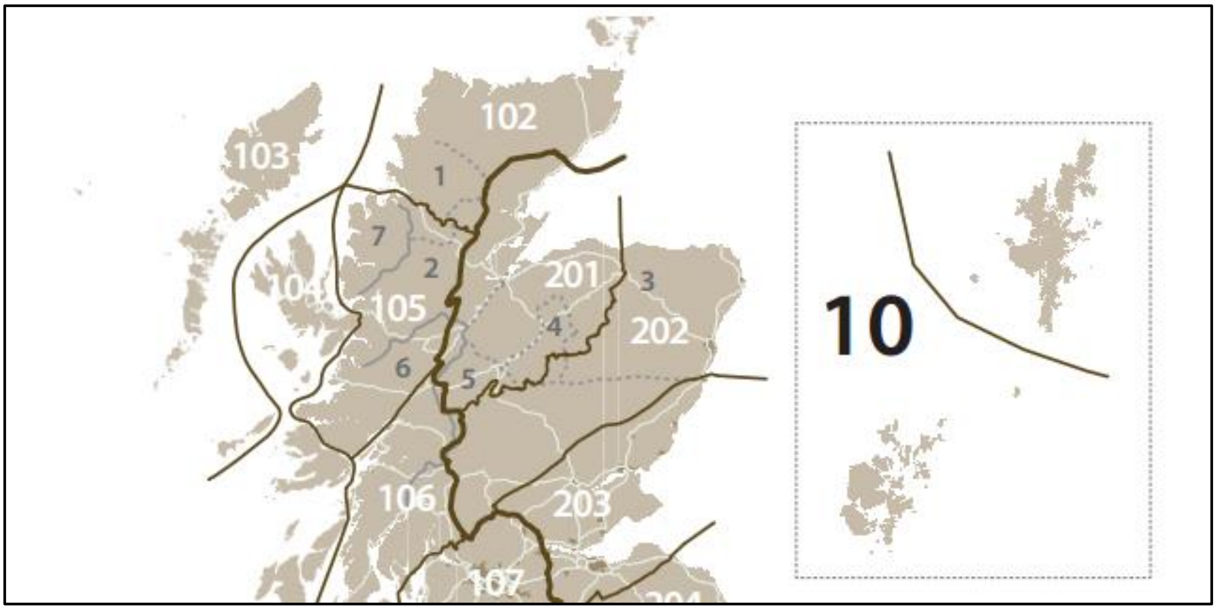

Figure 21 – Forestry Commission native seed zones for Scotland

The amount of seed sold each year varies – 1.5kg was sold in 2014, 4kg in 2015: this was an increase on previous years' demand, but they are uncertain whether or not this will be sustained. Forestart estimates that 17,750 plants will be produced from each kg of seed (therefore potential plant production from seeds sold was 26,625 in 2014 and 71,000 in 2015).

5.1.2 Nursery production

Only three of the commercial nurseries that are members of the Confor Nursery Producers' Group advertise wych elm planting stock for sale, and of these only two replied to a request for information (one in north-east Scotland, the other in north-east England). To meet customer requests both nurseries sourced seed largely from Scotland (mainly native seed zone 201), with some collected by the nursery and the remainder bought from Forestart. Between these two nurseries annual production of wych elm plants was 15,000 – 25,000 trees per year. Both reported a slight rise in demand in recent years, but not dramatically so.

Forestry Commission Scotland's nursery manager confirmed that no elm is currently produced in any of the Forestry Commission's nurseries, so all requirements are bought in from commercial nurseries. The demand for wych elm for planting in Scottish forest districts was relatively low during the five years between 2008/9 and 2012/13, averaging just over 2,500 trees per year. In the last two years there has been an increase, with 12,000 trees planted in 2013/14 and 35,500 in 2014/15. The increased planting was predominantly in Moray Forest District (11,500 trees in 2013/14 and 7700 trees in 2014/15) and West Argyll Forest District (23,250 trees in 2014/15).

5.2 Timber and milling

Historically elm was an important timber species in Britain, as a strong, flexible, water-resistant timber used for ship building during the expansion of the British Empire and colonies (Albion, 1952; Bass, 1992; Burton, 2013). The density of elm timber is around 560 kg/m^3 at 15% moisture content, and its strength is about 30% below the strength of oak (TRADA, 2015). Elm is considered a valuable timber species and is used frequently for furniture-making and bespoke crafts.

As part of this study a survey focused on milling and production of elm was sent out to the Association of Scottish Hardwood Sawmills (ASHS) and Highland sawmills (Potentially reaching over 30 sawmillers with 9 responses – See Appendix B). Approximately 70% of the respondents stated that they did not mill any elm and would be cautious about considering the timber as a milling prospect due to DED impact. These cautious attitudes were motivated by the sporadic, unpredictable and dwindling supply of the timber rather than safeguarding the potential spread of DED. "*99% of mature elm trees died in this area between 20 and 30 years ago. Trees that were standing dead were available for milling until about 5 years ago and now that resource has gone. But there are plenty of healthy saplings (all wych elm I think) and I am hopeful that they will survive and my successors will be milling them in years to come*". There is a clear demand for elm timber and most millers are eager to secure supplies whenever possible. In 2013 a single tree extracted from the Black Isle area was sold for approximately £13,000[8], this is an exceptional case but highlights the potential value of the timber, as well as limited supply created by the spread of

[8] Personal communication with foresters from Cawdor Forestry. However it is unclear whether this included burr wood, which would have a bearing on the overall value (FCS(a), 2011).

DED. "*Elm can be a highly decorative timber, and quite sought after as the Dutch elm disease spreads…there is an element of rarity value of course*".

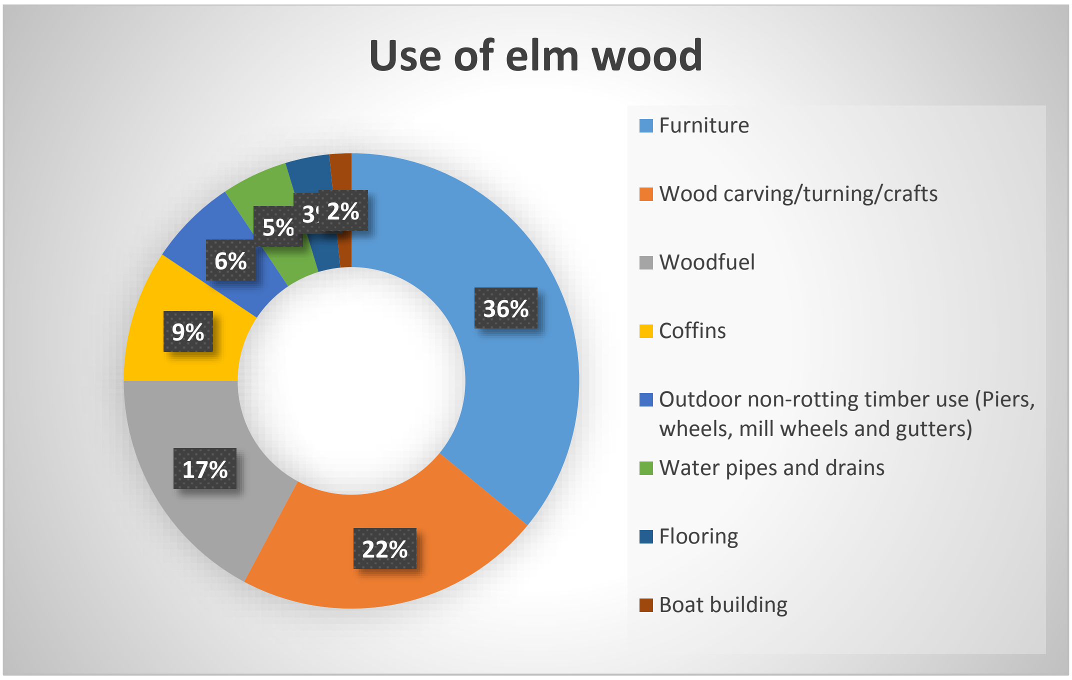

Figure 22 – Perceived use of elm timber

An estate in Moray, an area abundant with diseased, healthy and regenerating elm, recently sold 150 elm trees to a sawmill in Northumbria for £10,000. Whereas another Moray estate owner fells, extracts and mills the elm. However, many of the dying or healthy trees offering potentially valuable timber are located on river banks with steep inclines, which significantly impacts the end value. Successfully extracted timber is stored in a small lumber yard (Figure 24), some of which is milled into boards and parts are kept for local craftsmen and firewood (Figure 24 (right photo)).

Figure 22 shows that the main use of elm timber by survey respondents is for furniture-making and wood turning, as well as being a good source of woodfuel. Many respondents associated elm with water resistant, non-rotting uses, such as guttering and pipes, as well as coffins. This highlights the diverse utility of elm, as well as potential or resurgent markets for the timber, if supplies were to increase. There is potential for wych elm to be used for external cladding purposes, as a possible replacement for imported Canadian cedar and Siberian larch, although the quantities available of a suitable quality are likely to be limited. Additionally, unlike ash and sycamore species, elm can be of mixed quality (straightness and branches) and still retain significant value (FCS(a), 2011).

The sawmillers that responded to the survey have generally positive experiences with elm as a product and commercial species, but uncertainties in sustainable supply, DED spread and future plantings to maintain the resource over time limited any active investment in sourcing elm timber.

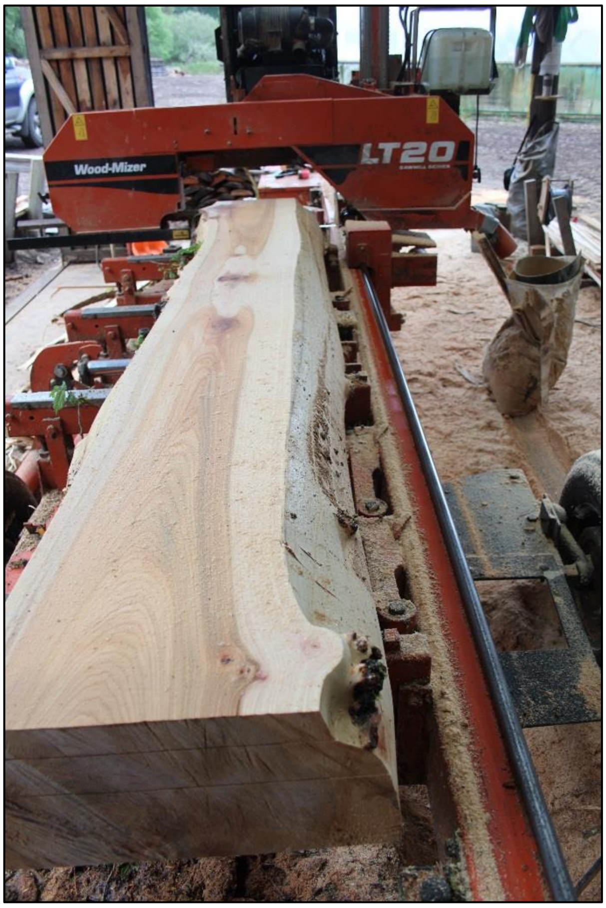

Figure 23 – Milling of elm (Left) and elm storage on a private estate in Moray (Right)

Sources of elm timber mostly come from windblown trees, as well as arboricultural arising with some sawmillers seeing a consistent supply of 20-25m³ and others milling less than 5m³ annually or whenever they receive a workable timber. Other sawmillers come across large mature elm trees (8m³) preserved by rivers and lochs. Most of the timber is milled into quarter sawn boards and 1.5"/2" waney edged planking (Figure 24 (left photo)), which is converted into furniture, lintels and mantles, worktops, as well as decorative internal pieces, such as shelves, windowsills and internal trimming. Burrs are mainly supplied to wood turners. The price of elm is variable, dependent upon the size and quality of the timber, normally the millers pay around £120-140/m^3 with high graded material reaching over £200/m^3. However, the majority of millers believe that elm is a relatively undiscovered product and Highland sources of wych elm could potentially provide a significant niche market, "*Still difficult to convince people that all furniture is not oak… Demand above will improve as customers discover the figure and appearance, particularly amongst the English market for cabinet-makers. These are being targeted, and in particular for large/long/thick boards*".

Figure 24 – Decorative grain of elm timber prized by furniture makers and craftsmen

Overall sawmillers identified a lack of understanding and knowledge about the spread of elm species in Scotland and the Highlands for targeting appropriate sources of mature timber. A potential sustainable supply map was suggested to assess wych elm's future role in productive forestry sector, "*We seem to have a good and regular supply but I don't have a spread/growth map of Scotland so can't predict the sustainability and future supply*". Additional constraints included the movement of DED westwards from Inverness, climate change, and accidental movement of timber. However, all sawmillers were in agreement that, "*Ulmus glabra produces beautiful straight trunks… yielding excellent stable timber….and its colour, figure, grain, strength, stability once kiln-dried, in short provides desirable and beautiful appearance*".

6. Landscape and social aspects

Increasingly, woodland diversity, structure and management are considered through landscape and social aims. Individual species can play a crucial role over multiple scales (spatial, temporal, and cultural) influencing landscape aesthetics, social perception, public demand and resilience. This section is based upon the collated data from the elm surveys (Section 2.3) and provides insight into the value placed upon elm and perceptions of the species on a regional level (Scotland and Highlands).

6.1 Landscape value

As presented in Figure 25 the majority of respondents considered the ecological role of elm in the landscape as the most vital. This includes the biodiversity provided by the species in a region relatively sparse of broadleaf woodlands. Many cite elm as, "*vital component for mixed habitats*", also as, "*an important species, which is leaving a gap that cannot be filled by other species in its place*".

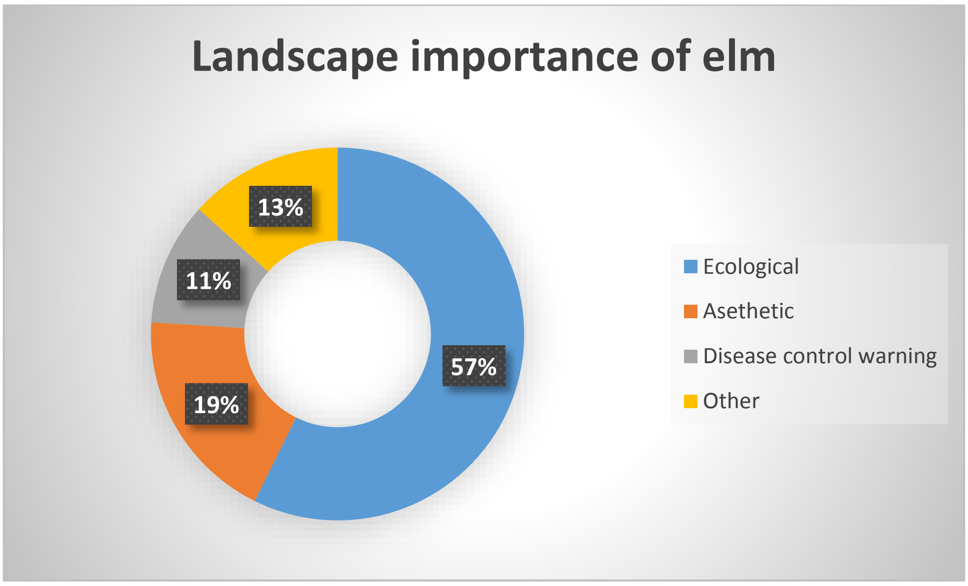

Figure 25 – Elm species importance for the landscape

Highlighted by many of the respondents was the unique factor of healthy uninfected mature elms existing in the Highlands, which should be safeguarded, enhanced (more planting) and celebrated. "*The northern parts of Scotland are a refuge for elm. Elm along with ash provides a unique habitat, especially for some lichens. Both species are threatened by disease. It would be good to see elm planting and management encouraged in the areas where it can still grow to maturity*"…. "*So I think we should celebrate the fact that there are a good number of elm in the Highlands*". Another facet of elm is the importance to the wider landscape ecology, as well as the rare elm-ash, elm-hazel woodlands in Scotland, and the potential devastating ecological impact, if both species were to succumb to looming threats of disease. "*Its loss has become more important with the arrival of ash dieback, because ash is often substituted for elm. Lowland W8/9 woodland used to be called ash-elm woodland and now both principle species are liable to be lost, which is ecologically devastating…. It can be locally important as a landscape tree*".

Secondary to ecological importance is elm's aesthetic value, as highlighted in both Figures 26 and 27, over two thirds of respondents considered elm's aesthetic appeal to be either 'Very high' or 'High'. This becomes evident in the 'Other' section of Figure 25

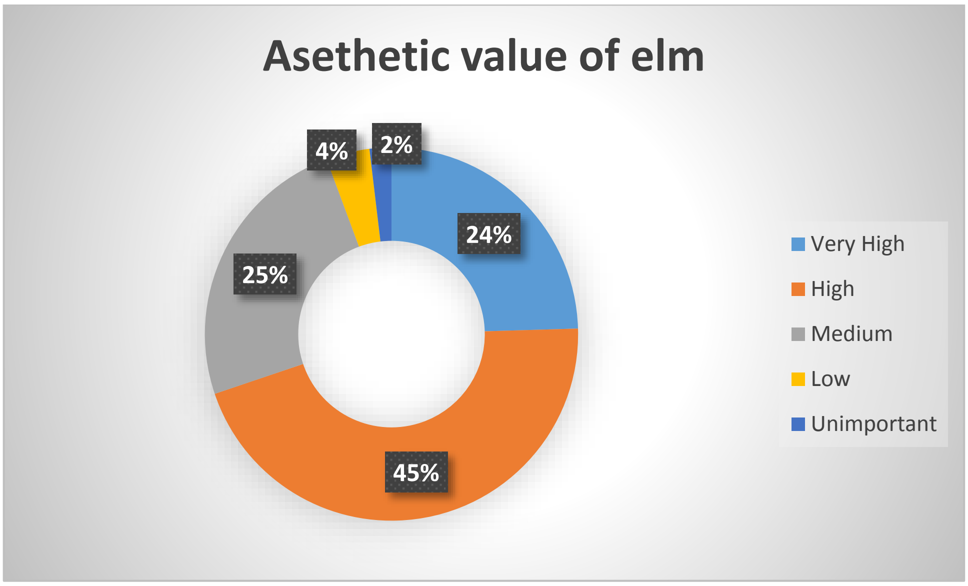

Figure 26 – Aesthetic value of elm

and attached comments, which describe elm as, "*Magnificent… Beautiful… Rare… Majestic… Precious and Iconic*". Related to both the 'Ecological' and 'Disease control warning' categories in Figure 17 are the concepts of robustness, integrity and resilience, which were all mentioned frequently in the section for expanded responses. "*Where present, it adds to the complexity and robustness of woodlands - hopefully more so in future if elm recovers from disease over time*". As shown in Figure 27, 92% of the survey participants indicated that having more elm in the landscape through either natural regeneration or planting would be considered favourable for the landscape.

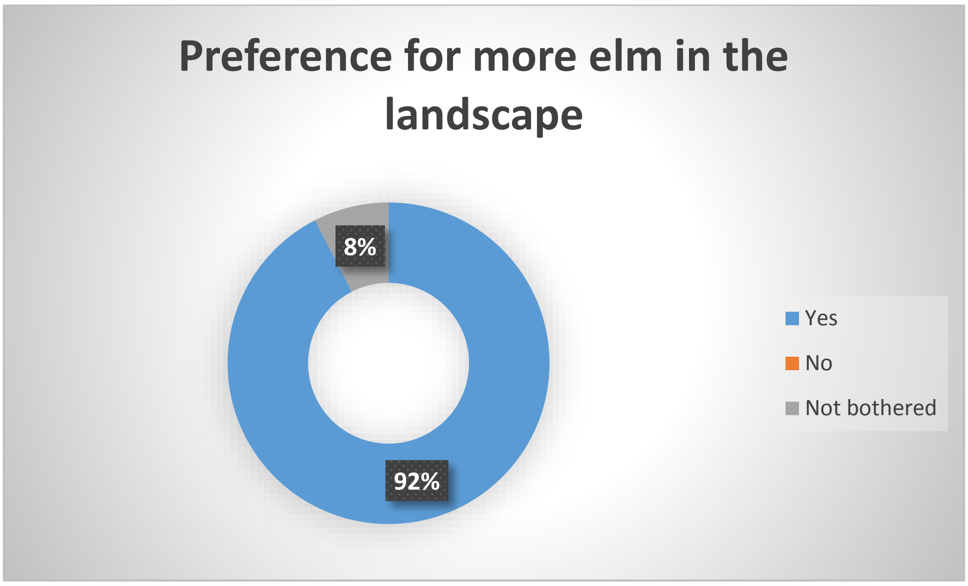

Figure 27 – Preference for increased elm in the landscape

Not one participant stated that more elm would not be beneficial for the landscape, however, 8% indicated that having elm in the landscape was unimportant (Figure 27).

6.2 Perception of elm in the landscape

Closely connected to landscape values are the filters through which these values are perceived and the subsequent influence upon management actions and decision-making. Figure 28 indicates the most preferable sites for elm trees in the landscape, in the opinion of the survey respondents. Woodland is considered the most appropriate site for elm, followed by farmland (associated with hedgerows and mature trees that delineate boundaries between arable fields). Parks and street trees are considered relatively low priority, as many trees have been removed and many diseased trees continue to be visible by the general public in urban areas, creating an undesirable aesthetic. Riparian areas were highlighted by many respondents as highly suitable areas despite the apparent low priority (5%), along with straths and glens. "*It's an important farmland and hedgerow species but also important as riparian species particularly in west ravine woodlands*".

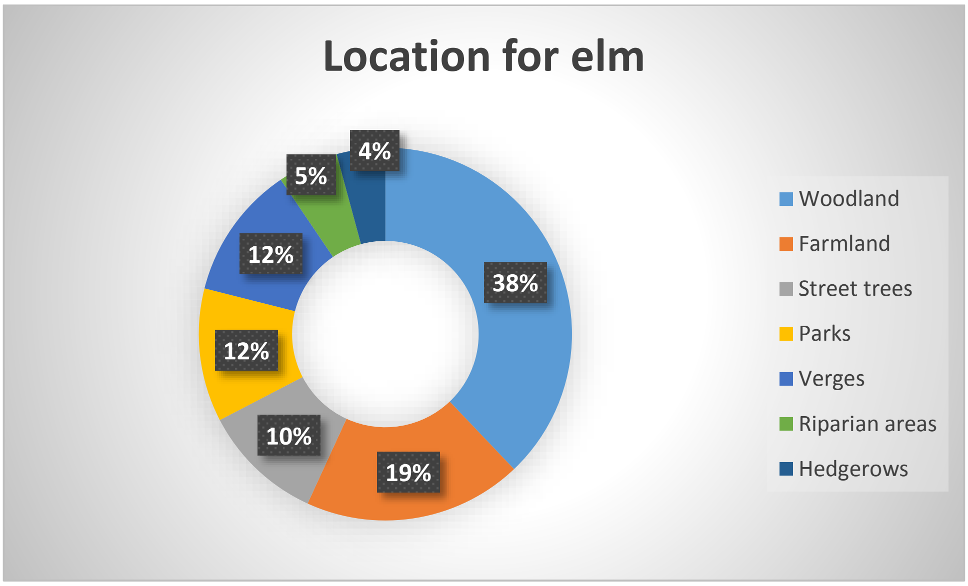

Figure 28 – Preferred location of elm in the landscape

Respondents emphasised the strong association of wych elm with Scotland, and is therefore, "*a part of Scotland's natural heritage and should be safeguarded against threats and seen all over the landscape*".

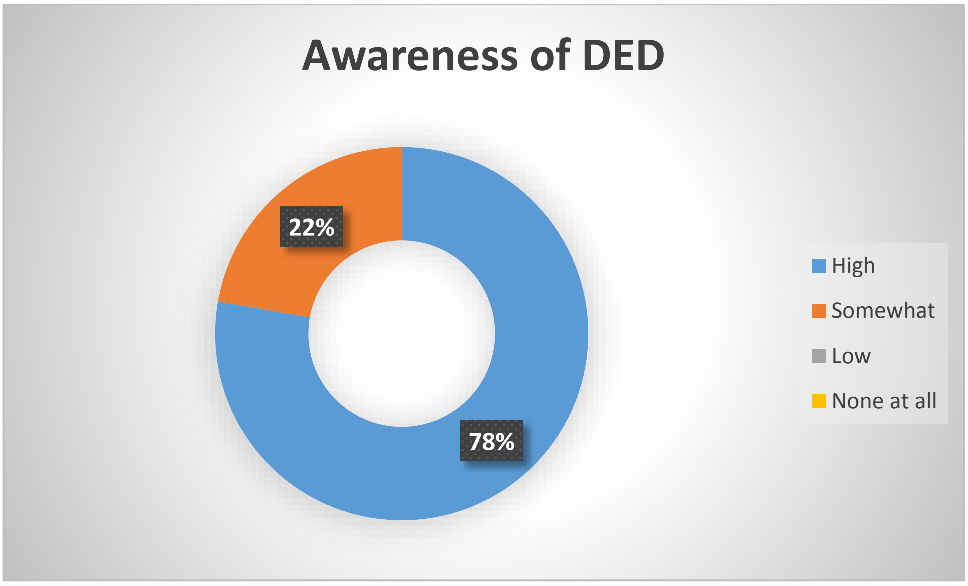

Figure 29 – Awareness of DED and the impact on the landscape

Figure 29 shows that awareness of DED and the impact on elm is high, emphasising the long lasting effect of DED on the landscape and in the memory of respondents. This is further highlighted by Figure 30, which demonstrates that almost 30% of all participants' (land management professionals) knowledge of elm is highly influenced by DED, and a further 39% are partially influenced. As a result almost 70% of participants associate elm with an aggressive disease or as a highly vulnerable species.

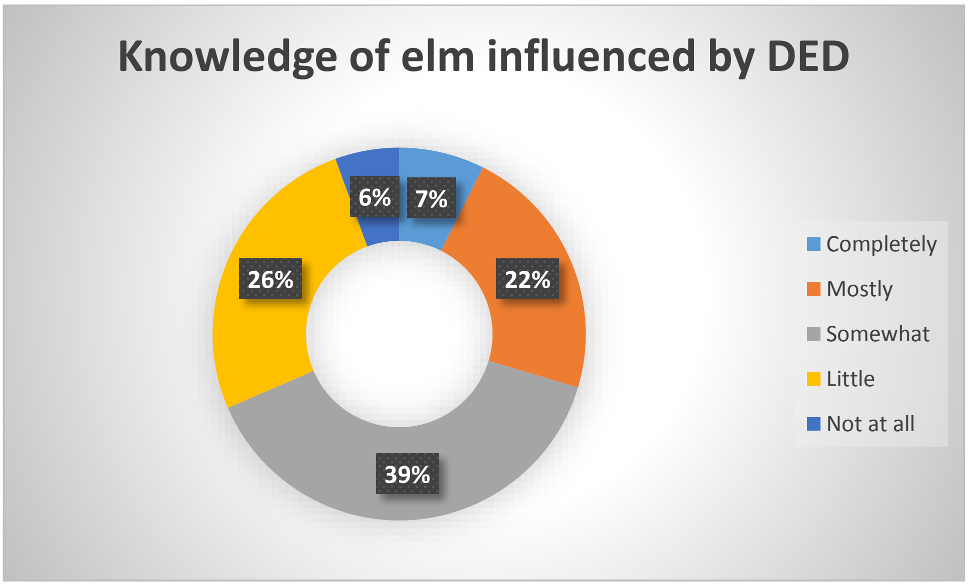

Figure 30 – Knowledge of elm as a species primarily influenced by DED

There is a strong possibility or danger that Scottish woodlands will be viewed through potential threats rather than for the species, biodiversity or productivity. This perception and subsequent effects could have dramatic impacts upon forest planning and design, core policies and individual land manager response to the validity of forest management and expansion. In spite of these factors over 80% of participants unequivocally regard wych elm as a suitable species for the Highlands (Figure 31), which should be protected, restored and expanded in the landscape. However, emphasis was placed on both the need to secure sites where the *Scolytus* beetle is unlikely to spread and for targeted research on disease resistance trees. Using or hybridising with elm species from North America and Asia is also suggested by several respondents; this is viewed as a viable strategy in boosting elm plantings and populations in the future.

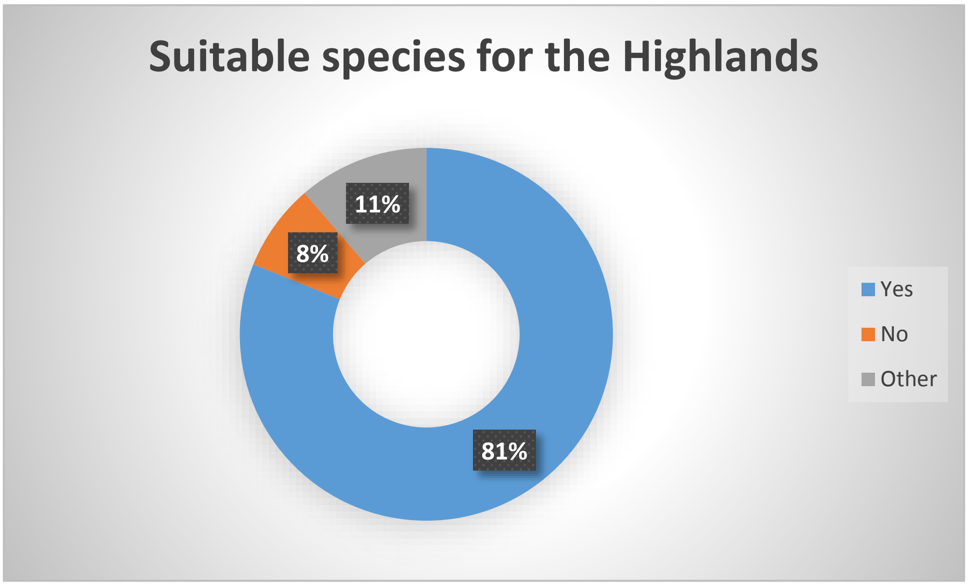

Figure 31 – Suitability of elm species (wych) in the Highland landscape

6.3 Economic value of elm as a species

Valuing a resource is becoming increasingly important for planning and management in regard to ecosystem services and climate change mitigation policies (Daily, et al., 2009; Bateman, et al., 2013; Baral, et al., 2014). There are multiple tools, models and methods for assessing the value of different ecosystem services, which link a monetary value to intangible services that lack economic markets, for example InVEST and i-tree (Bagstad, et al., 2013; Rumble, et al., 2015). In this report we have used figures generated by DEFRA for the socio-economic value of UK forests and extrapolated figures for Scotland, and the Highlands and Islands from the comparative percentage of the elm species (i.e. Scotland elm species = 0.06%; Highland and Islands elm species = 0.01% of UK woodlands).

In Table 3 the value of elm species are separated into five categories, as derived from the DEFRA assessment. Social carbon value has been added to the table, as this connects the wider landscape value of carbon and not just upon current economic market value. The figure of £276/ha was taken from Valatin (2010) using the mean value over the period between 2001-2009. However, prices will vary depending upon the age and structure of woodland with woodlands planted after 1921 possessing a significantly higher value per hectare (i.e. Woodlands planted in 1945 have a social carbon value of £500/Ha in 2010 prices) (Valatin & Starling, 2010).

Table 3 – Estimate of elm species socio-economic value in Scotland and the Highlands[9]

Value attribute	Scotland (£ per year)	Highlands and Islands (£ per year)
Landscape	112, 850	37,000
Recreation	296,240	96,800
Biodiversity	292,800	96,000
Carbon sequestration (economic – current trading floor price)	70,150	23,000
Air pollution and absorption	244	80
Total	**702,090**	**252,880**
Social carbon sequestration (comprehensive value)	512,256	93,012
Total with social carbon	**1,214,346**	**345,892**

Elm has been viewed as an important landscape tree, especially in southern England as the 'elmscapes' became culturally synonymous with an idyllic quintessential lowland

[9] Sourced from DEFRA and report by Worrel (2013).

English landscape through the paintings of John Constable-Dedham (Brasier, 2008). In Scotland and the Highlands the elm tree has not been portrayed as such an iconic landscape species due to sparser populations, remoteness and less emphasis on lowland broadleaf woodland. Despite this elm is still recognised as an important species in Scotland and the Highlands, with a clear desire to conserve and expand the species presence and range.

Individually the value of a single elm tree has been valued using formulae based on landscape loss with amenity value being the main component, in the 1980's elms were valued at $2000 per annum (Scott & Betters, 2000). More recently a small disease-resistant elm tree (6.4 cm diameter) with a life expectancy of 50 years has been valued at £23,000 or £460 per annum (Brasier, 2008). Taking an approach that draws from the willingly undertaken costs to protect elm trees from DED suggest that individual trees are valued at £1350 and above (Price, 2007). In Newcastle upon Tyne a group of weeping elm trees in a churchyard were valued at £149,000, if the trees were to die and not be replaced (Cobham Resource Consultants & Price, 1991). These values are derived from urban house price differentials, which are dependent upon the different views unique to each property (Price, 2010). The figures presented in Table 3 of £702,090 for Scotland and £252,880 for the Highlands per annum represent markers by which management costs and species expansion can be based, these figures can even be reduced to local and ward level to aid multiple levels of decision-making. Unique to elm, American chestnut and increasingly ash is the perspective that contrasts the cost of loss and emphasises the investment, research, volunteer work and public advocacy to reintroduce and re-establish the species or a tolerant variation into the landscape, and if successful the money saved through the reduction of control and sanitisation programmes, as well as further research and investment.

The broad valuation in Table 3 provides a landscape scale value but may not account for the inflated values of elm trees in urban and city areas. For example Edinburgh has approximately 15,000 elm trees (Edinburgh City Council, 2014), which are under active management and make up some of the most appealing areas of parks, green infrastructure and gardens, as well as holding some rare species, varieties and cultivars, as well as disease resistant elms that are continually being surveyed and monitored (Naughton, 2014). Each area of trees or even individuals might be subject to different valuation criteria dependent upon, location, maturity and visibility. Using the £1350 value per tree Edinburgh's elms would be valued at roughly £20 million. In 2012 a survey of Edinburgh tree population using i-tree was performed to assess the value of the city's trees (Hutchings, et al., 2012). This assessment identified that wych elm compromised 4.5% of the city's tree population, 4.4% of the city's tree canopy leaf area and is the city's 8th most important tree species, scoring 8.9% in importance value (Hutchings, et al., 2012). Using this value wych elms' economic contribution to the city can be estimated through the total carbon sequestration and structural value of the city's tree population generated by i-tree assessment. Wych elm is worth £1,394,833 (low scenario) through carbon sequestration and £3,998,000 through the structural value to the city[10], this equates to £38,915 annually (NPV).

DED remains Edinburgh's most significant tree disease with around 1000 trees felled every year. This is consistent with the i-tree assessment, which found approximately 9% of the wych elm population in poor or critical condition, which is higher than that for any of the other top ten species. The continual efforts of the city's DED management programme limits further losses to the city's tree canopy (Hutchings, et al., 2012).

Individual trees may be linked to the history of a place or represent a unique specimen. One such tree is the Brahan estate's wych elm near Dingwall, which is an example of a monumental and ancient champion tree (Monutmental Trees, 2013; Ancient Tree Forum, 2015) attracting visitors and generating public interest. As emphasised by Brasier (2008) models, formulae and valuation tools often gut the true value and leave only the price, which simply cannot account for the cumulative and fluctuating value of evolutionary history and cultural heritage.

7. Future prospects and recommendations

This report shows that the extent of both healthy and diseased areas of elm in the Highlands is still relatively unknown, as many populations are in remote and rural areas, inaccessible and unseen. Diseased elm trees may remain unreported, as many people will

[10] Total carbon sequestration value for Edinburgh City in 2016: £15.67 million (Low scenario), 44 million (High scenario); and structural value £382 million (Hutchings, et al., 2012).

be unable to identify either healthy or DED infected elm trees, and often such landscape features go unnoticed. In this section the main findings of the study are summarised along with management options, planting strategies, further research, and overall recommendations.

7.1 Main findings

The main findings of this report into the status, extent, value and feasibility of elm and impact of DED in the Highlands are divided into five categories:

Area, extent and habitat of elm

- Scotland has 1,856.9 Ha of elm species in woodland (Mostly wych elm – *Ulmus glabra*), representing 0.13% of Scottish woodland.
- The Highlands and Islands Conservancy area has 337.7 Ha elm species in woodland, representing 0.02% of Scottish woodland estate and 0.82% of Highland woodland estate
- Highlands and Islands Conservancy area has the fourth highest area of elm but the second highest average elm canopy cover
- The largest areas of elm are present in Fort William and Ardnamurchan, and Aird and Loch Ness electoral wards, followed by wards around the Beauly and Cromarty Firths.
- The largest areas with 25%+ elm canopy cover are Aird and Loch Ness, as well as the Beauly and Cromarty Firth wards.
- The largest areas with 50%+ elm canopy cover are Cromarty, Black Isle, Dingwall, then Aird and Loch Ness wards
- Significant browsing occurs on elm species in the Highlands and Islands
- Upland ash woods, upland birch woods and lowland deciduous woods are the three habitats with greatest areas of elm species
- The main species associated with elm are birch, ash, alder, hazel and oak, according to the NWSS.

Extent and vectors of DED

- Dutch elm disease might be present in Invermoriston, Achnasheen and Ardcharnich, further west than the current known extent (Drummnadrochit).
- Furthest northerly extent is Skebo estate around Dornoch. However, potential infection of street trees in Wick has been reported, as unhealthy elm trees have been removed recently.
- Main vectors of the disease are the A9 northwards, A82, A835 westward and potentially A9 southwards
- Healthy areas of elm are spread throughout the Highlands, including populations within heavily infected areas (Beauly, Black Isle and Kinvinnie).
- Main healthy areas identified by the survey include Skye, Raasay, Loch Alsh, Loch Maree, Assynt, Loch Inver, Clunes (near Loch Arkaig) and A87 around Loch Cluanie
- Small healthy pockets of fragmented elm populations exist up the west coast as far north as Scourie, Tongue and Caithness around Loch Watten (verification required) as well as a single island population near Finstown, Orkney.
- Highest population density of elm is around the Cromarty and Beauly Firths

Commercial production of elm

- Elm timber is considered very valuable due to its decorative grain and rarity due to DED (£220/m^3 on average), potentially thousands of pounds for a single mature tree and even more for burr wood.
- Use of wood associated with furniture, small crafts, water tolerant timber products and firewood
- Elm is not highly utilised by most saw millers but they would buy more elm, as it is highly sought after for its strength, beauty and flexibility
- Current nursery seed sales have seen a 130% increase from 2014-15
- A significant rise in plantings 12,000 in 2013/14 to 35,000 in 2014/15 has been recorded in a few FC Scotland districts (could be the result of ash dieback threat)

Perceptions of elm

- Wych elm is viewed as important for biodiversity of region and landscape composition
- Viewed as iconic species important to Scottish and regional heritage
- Viewed as a versatile species suited to multiple locations but mostly in woodland, farmland, straths, glens and riparian areas
- Perception of the species has been highly influenced by the impact of DED
- Viewed as extremely suitable and desirable species for the Highlands, despite the threat of DED

Landscape value of elm

- Economic value of elm based on socio-economic assessment is £702,090 for Scotland and £252,880 for the Highlands and Islands per annum.
- Including the social value of carbon significantly increase the value of elm.
- Individually elm trees are valued between £460-1350 per annum, depending on age, size and location. However individual or groups of trees with significant amenity and cultural value can be valued much higher.

7.2 Recommendations

From analysis of the information presented in Sections 3 -6, several potential actions and strategies have emerged, which could both aid the development of healthy elm populations, and take advantage of the Highlands' unique geographical and topographical characteristics. The Highlands region, as well as areas within the region, can benefit from using the island effect (due to its northerly extent, climatic conditions and fragmented broadleaf woodland) to support management of elm species more securely than any other mainland region. Enhancing these natural barriers and recognising the significant population of mature and healthy elm in the Highlands through the creation of '*Elm Refuges'* is a logical step, if management of DED and restoration of wych elm is considered a priority. However, such refuges would have to be supported by targeted intervention to buffer the spread of DED, as well as greater surveying and research, which could be enhanced by community involvement and citizen science frameworks and mechanisms.

7.2.1 Planting and restoration strategies

In order to protect and develop the health and expansion of elm species in the Highlands greater planting efforts, including of an increased variety of elm species, should be implemented. As demonstrated in Figure 10 elm species in the Highlands are vulnerable and subject to high rates of browsing from herbivores, which will suppress areas of natural regeneration. Figure 2 and 9 show that the amount of regeneration areas in the Highlands and Islands is lower than other regions in Scotland, suggesting that to maintain a sustainable and growing population of elm species a mixture of natural regeneration enhancement and planting is required.

Table 4 – Summary of planting areas for Highland Wards and Highland refuges combined under two NVC sets (Tables of individual Wards and Refuges are in Appendix D)

	NVC – Hectares (W7,8,9,10,11,16,17)	NVC - Hectares (W8,9,10,16)
Highland Wards	97,777.7	11,393.8
Refuges	14,947.3	3,144.1

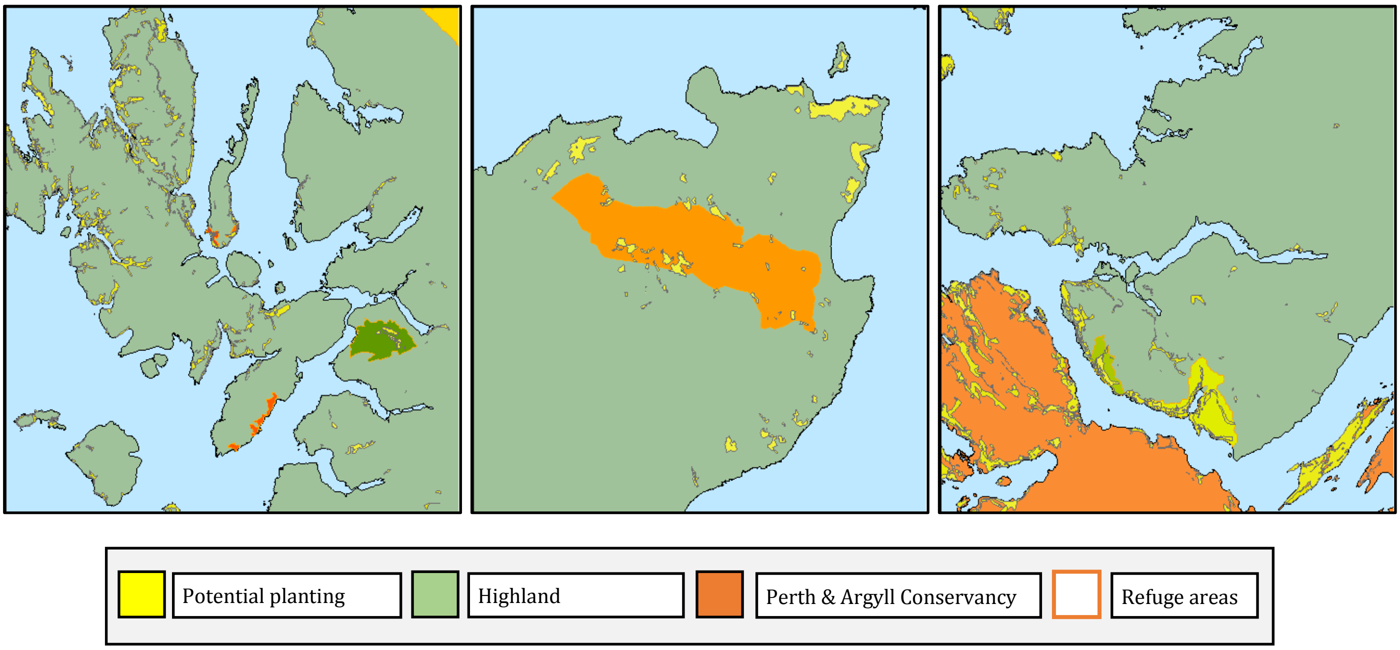

Figure 32 – Potential planting areas based upon NVC W8, 9, 10, 16 for Skye/Raasay, Caithness and Ardnamurchan (out with current woodland estates)

Table 4 presents a summary of potentially suitable areas for planting, based on NVC most commonly associated habitat types with elm species in the NWSS (2014). In ArcMap overlaps of these NVC areas and current woodland estate were discounted[11] to show only non-wooded areas. In the Caithness Ward, W7 (Wet woodlands) habitat area accounted for over 87% of the potential area, and in other areas such as Aird and Loch Ness, Badenoch and Strathspey Wards W7, as well W11 and 17 (Upland oak woods) accounted for over 90% of the open NVC areas. In Figure 32 snapshots have been taken of potential areas for planting against the backdrop of suggested refuge areas, including upland birch and ash woods, as well as lowland mixed deciduous woods (W8, 9, 10 and 16), identifying planting areas to explore within and without the refuges. These areas will be subject to a mixture of land uses, designations and social and political pressures, which will most likely significantly reduce land availability and cultural suitability (WEAG, 2012).

In recent reports and guidance from the Forestry Commission, wych elm has been omitted from recommended planting lists due to the threat and impact of DED, therefore policy in the recent past has actively discouraged the expansion and planting of native elm species (FCS(b), 2011). This is despite an acknowledgement that wych elm is extremely important for lichens and other epiphytes, fungi and invertebrates associated with deadwood (FC, 2003). Elm is also noted as being an important species in past wood pastures systems, which now remain as landscape relics populated by a few ancient specimens of broadleaf species (FC, 2003). Areas with good soils in sheltered valleys that were not cleared for farming cultivate mixes of ash, oak and elm species, which have been retained for amenity, shelterbelts or parklands areas (FCS(a), 2011). Expansion and conservation of such areas may enhance current area coverage. Planting strategies of local authorities generally advocate the use of native species, but encourage planting of non-native hybrids where native species are susceptible or vulnerable to disease. In the case of elm, therefore, resistant elm hybrids are deemed appropriate (Moray Council, 2008).

Development of healthy elm populations in the Highlands and Scotland in general will require the trialling and use of new more tolerant species or varieties. The use of social media, community driven initiatives, NGOs, extension work and citizen science will play an increasingly important role with issues such as tree health, as the resources of agencies such as the FC and SNH, and their ability to cover the woodland estate for

[11] This was done using the Clip tool and exporting a new shapefile based upon the dataset.

detailed surveys is diminishing. Observatree and Tree Alert are steps forward in this process or partnership between the general public and agencies as co-stewards of the environment helping to monitor tree health on a national scale, which can also build a locally relevant picture (FC(a), 2015). However, DED is not considered a priority pest and disease out of the twenty listed, but resources and materials exist on the Observatree website for education and identification (http://www.observatree.org.uk) including a recent webinar series (FC(a), 2015; Webber, 2016).

The Great British Elm Experiment (2016) represents the current trends in engagement and education as an Environmental No-Governmental Organisation (ENGO) initiating projects by tapping into the will, self-motivation and interest of the general public including community groups, schools, landowners, local authorities and individuals. This project is operated under the larger Conservation Foundation organisation (2016) and aims to distribute thousands of native saplings that have been cultivated from cuttings of mature elms that have seemingly resisted DED to secure a new generation of elm in the British landscape and aid the work investigating tolerant specimens. Currently two locations in the Highlands have planted smooth-leaved elms (*Ulmus minor*), a school in Garve and Strathnairn community woodland close to Farr. These trees are bought at the cost of the participant and subsequent guardian of the elm tree (£34-45), which may be a barrier for wide adoption of this planting strategy.

Potentially larger organisations and local authorities could intervene on behalf of a community and region to plant greater quantities of these trees. Another UK based website 'Resistant Elms' (2016) aims to educate, provide advice and guidance on planting the right elm species/variety in the right place. This site includes information on twenty two most promising hybrids (Appendix E), as well as information on adaptation, timber and inoculation trials. Its sister site Immemorial Elms (2016) (in reference to an Alfred Tennyson poem – Come Down, O'Maid) pays homage to the lost landscape of elm and emphasises it's cultural value through pictures, art and language.

Recently some nurseries have stopped selling Morfeo elm despite commitment to significant distribution and planting initiatives, although resistant to DED the Morfeo elm is susceptible to Elm Yellows disease (*Candidatus phytoplamasa ulmi*) and it is thought prudent not to add to spread (Ashbridge Nurseries, 2016). Although Elm Yellows is not believed to be present in the wider UK environment, several infected elm trees sold from nurseries in England have been traced and destroyed (FC(b), 2016). Trials of elm species in England established under 'DEFRA Biodiversity Action Plan for priority species' (White Hairstreak butterfly [*Satyrium w-album*]) have been substantially revised in the past few years due to the 'Princeton fiasco' (BC, 2014). This American elm cultivar was widely sold and promoted in the UK without any testing for resistance to DED in Europe; this occurrence has forced many organisations to rethink planting strategies involving American species, varieties and cultivars (BC, 2014).

However, all of these trials thus far focus on southern England and could be beneficial to efforts on a landscape scale, if such projects were deployed more widely with willing participants. Combining the outputs of both Observatree and the Great British Elm Experiment could build a more comprehensive and valuable tree health network, which would track links between DED, elm inventory and new hybrid planting on a spatial scale and recognise the Highlands and perhaps other areas of Scotland as equally important refuge areas. Table 5 shows the payment rates offered by the SRDP for planting and maintenance of new broadleaf woodlands in Scotland (RPS, 2016), which could potentially be used for planting new woodlands with elm species as a component.

Table 5 – SRDP planting and maintenance payment rates for native and broadleaf woodland creation

Woodland creation options	**Payment rates standard areas**			**Payment rates target areas**		
	Initial planting payment rate (£/ha)	Annual maintenance payment rate (£/ha/year)[12]	Total payment rate (£/ha)	Initial planting payment rate (£/ha)	Annual maintenance payment rate (£/ha/year)[13]	Total payment rate (£/ha)
Broadleaves	2,880	528	5,520	3,240	594	6,210
Native upland birch	1,840	128	2,480	2,070	144	2,790
Native broadleaves	1,840	272	3,200	2,070	306	3,600
Native low-density broadleaves	560	96	1040	630	108	1,170

[12] Public bodies are not eligible for 'Maintenance payments'.

Native broadleaves in northern and western isles	3,600	624	6,720	n/a	n/a	n/a

Target areas are identified as, "Areas identified as being preferred or potential in the relevant Local Authority Woodland Strategy (or equivalent)". These areas will release higher payment rates for the following types of woodland creation (RPS, 2016):

- Conifer
- Diverse conifer
- Broadleaves

Broadleaved woodland creation aims to grow trees that are suitable for sawn and prime timber and close to transport networks for ease of accessibility.Elm is included in the species selection list and there are minimum stocking densities and species must be planted on land that is either very suitable or suitable to achieve yield class 6 across the mix. However, the Native Broadleaves scheme aims to create native priority woodland habitats based on NVC habitat types W6, 7, 8, 9, 10, 11, 16 and 17 all of which are compatible with elm species (RPS, 2016). Whereas the Native Low-density Broadleaves woodland aims to create specific woodland habitats including scrub, treeline and wood pasture (RPS, 2016). The following bullet points indicates possible next steps and recommendations for developing and restoring the elm resource.

→ Encourage the increase of elm species percentage and variety in mixed native woodland planting and regeneration schemes, therefore strengthening policy advocacy and response to tree health issues and future species/woodland resilience

→ Map and timeline the progression of DED across the Highlands and in surrounding areas – employ community stewardship and citizen science to develop this resource

→ Identify abundant regeneration sites that could become mature mixed elm woodlands

- → Target suitable areas for expansion of elm woodland in the Highlands (straths, glens, riparian areas and historic elm sites). These could be within or connected to the proposed refuges and NVC areas although climate suitability analysis should be integrated
- → Align and coordinate strategies with ENGO groups for increased species and DED awareness, advocacy and smart planting action plans.
- → Free elm trees could be offered through local authorities for people to plant in gardens and local areas (based upon tolerant and resistant seed sources), possibly sourced from nurseries and sites such as 'Resistant Elms' and 'Conservation Foundation'.
- → Create greater awareness of the elm species resources and potential refuges in Scotland and especially the Highlands. Current focus is on southern England and Isle of Man.
- → Identify potentially tolerant local seed sources from uninfected areas, as well as within the DED infected areas.
- → Focus a comparative planting trial on proposed refuge areas with a mixture of local and hybrid species. Including refuge, infected and control sites.

7.3 DED practice and control

Ongoing programmes for the control of Dutch elm disease exist in Edinburgh (ECC, 2014), East Sussex (Bruin, et al., 2013) and the Isle of Man (Isle of Man Government, 2015). These programmes aim to limit or slow the spread of Dutch elm disease by regular monitoring of elm trees to identify occurrences of the disease, then implementing prompt sanitation felling and burning of infected trees before a new generation of beetles is able to emerge in the spring.

In Edinburgh, the 37-year control programme has resulted in the survival of around 15000 elm trees, from an initial estimated population of around 45000, with between 500 and 1000 newly infected trees being identified and removed each year. The costs of the programme (annual survey, tree removal and destruction), which are covered from within Edinburgh City Council's operational budget, are not available. A recent study in New Zealand estimated that removal of diseased elms in a control programme would cost in the region of £500-£600 (€1000-€1200 New Zealand Dollars) per tree (Ganley & Bulman, 2016).

A recent report examined East Sussex's DED control programme (similar to that implemented in Edinburgh) and considered options for future control (Bruin, et al., 2013). A new "priority" method of control is recommended: rather than felling and destroying all disease-infected trees within 4-6 weeks of symptoms being identified, some infected trees should be retained for longer to act as a preferential site for beetle feeding and breeding, and to minimise beetles moving on to uninfected trees. The retained trees are then felled just before the new generation of adult beetles emerge, thus reducing the beetle population and limiting spread of the disease. The study showed that this approach could be a more cost-effective method of reducing the beetle population and minimising the need for tree felling, but that it is dependent on reliable ongoing monitoring and co-ordinated, timely felling and destruction of the retained trees. In addition to council-led survey and monitoring activities, a citizen science approach has been adopted in East Sussex to involve interested members of the public in the 'Ulmus Martime' project, to protect and expand the elm population in this area (UM, 2016).

DED was first observed in the Isle of Man in 1992. A programme of monitoring and sanitation felling is in place, and to date less than 1% of the estimated 250000 elm trees on the Isle of Man have been infected and removed. The Isle of Man Government has sought to involve the public in mapping elm tree locations and identifying incidences of DED through the crowd-funded Open Elm project (OEP, 2016), which includes an App for use on mobile devices. The Open Elm project is also now being used to by the East Sussex 'Ulmus Maritime' project for recording elm trees in their area.

In addition to sanitation felling, the use of pheromone traps has also been investigated as a means of reducing beetle populations. It appears that this method has not been effective in controlling the disease (Ganley & Bulman, 2016), and that suitable pheromone traps are not easily available (Naughton, 2016).

A number of chemical and biological approaches to DED control have been trialled over the last few decades. The most successful of these appears to be the treatment of individual trees by injecting with DutchTrig®, a biological control product containing the fungus *Verticillium albo-atrum,* which acts by enhancing the natural defence mechanisms of elms (Postma, 2016). This treatment is only effective in protecting uninfected trees, and has to be repeated every year. Using this treatment, only 0.1% of injected elm trees have become infected with DED through beetle transmission, with an additional 0.4% infected through root contact. In the Netherlands this treatment is used to protect 25000-30000 mature urban trees that have been identified as having particular value. The cost of treatment for each tree has been reported as ranging from 16 – 25 Euro (£12 - £20).

Recent research has also investigated the use of a virus-based biological control, but as yet this does not appear to have yielded a commercially viable treatment (Ganley, 2010).

7.3.1 Management and control methods in the Highlands and Islands

In 2009 Highland Council's Land, Environment and Sustainability Strategy Group produced a report on the spread of Dutch elm disease (Patton, 2009). It noted that since an outbreak had been identified in Auldearn in 1997, annual monitoring for the disease had been undertaken. The report also stated that Highland Council had agreed not to pursue control methods for DED, on the advice of the Forestry Commission and Forest Research. The reasons for this decision included:

- Past experience of control in a rural area suggested that measures would only, at best, slow down the advance and spread of the disease;
- The financial considerations of implementing control measures would be considerable, for both the Council and private landowners;
- A number of outbreaks lay outwith the geographic area within which the Council had powers to remove trees under the Dutch Elm Disease (Local Authorities) Order (as amended 1988) – which was restricted to Nairn, Badenoch, Strathspey and parts of Inverness and Lochaber to the south east of the Great Glen.

To date we have not been able to confirm with Highland Council if this approach is still current policy or whether survey and monitoring for infected trees are continuing.

7.4 Management options and action plans

In order to strengthen elm species and wider woodland resilience in Scotland and the Highlands, as well as safeguarding and developing important woodland habitats and dependent biodiversity, practical actions and management options are needed for practitioners, policy-makers and interested stakeholders.

A) Strategic Objectives

1) Help conserve the services and benefits provided by elm as a species and as a component of mixed native woodlands.
2) Aid the development of a communicative and reciprocal network for elm conservation, research and monitoring including encouraging citizen science, and engagement of the private sector. Advocate and raise awareness of central principles common to all, such as landscape stewardship and guardianship, and practical responses to DED.
3) Strengthen economic, ecological and social resilience of woodland species to threats in parallel with climate change

B) Key Priorities

- → Landscape maps for spatial and landscape analysis of healthy elm species distribution and rate/extent of DED spread
- → Monitoring and surveillance
- → Research
- → Communication and education
- → Preventive management
- → Pragmatic management
- → Define and map refuge areas

7.4.1 Proposed elm refuges

The future resilience of elm populations in the Highlands will be heavily dependent upon the spread and severity of DED. Therefore management responses will be critical in conserving, diversifying and proliferating elm as a significant species component in Highland woodland. Figures 7, 14 and 17 could be used to inform potential intervention points and set buffer zones between DED infected and healthy areas of elm. These points and zones could indicate primary areas of preventative and remedial action, as well as greater monitoring and mapping efforts to track DED and robust populations. The highest risk areas are around the Beauly and Cromarty Firths, and the connected woodland that runs from Inverness southerly along the Great Glen.

The most northerly zone around Dornoch is a medium risk in spite of high levels of DED, as the connectivity and density diminish along the A9 route. The lowest risk area is from Fort Augustus to Fort William: there is no reported DED but it is notable as a significant area of elm and suitable broadleaf woodland linked to the A82, which seems to be directing the trajectory of the DED progression south-westerly. Ground truthing of reported unhealthy elms from the survey and evaluating the health of elm populations along the DED line at points with particular connectivity could help monitor the spread and severity of the disease impact. Such steps would help inform targeted interventions and focused areas of monitoring.

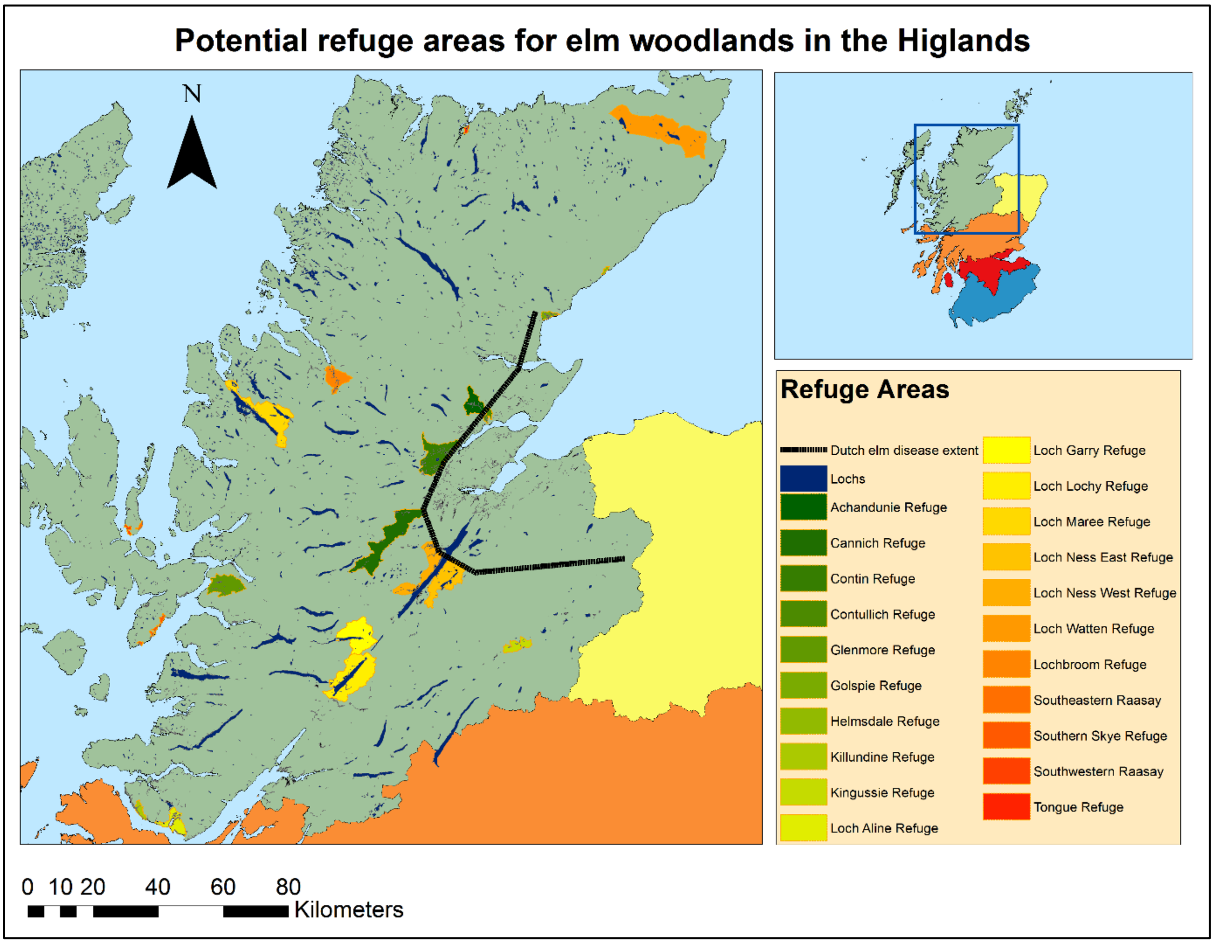

Figure 33 – Proposed Elm Refuges in the Highlands

Through consolidation of data collected from the surveys, the NWSS, and subsequent spatial analysis[13] twenty one elm reserve areas are proposed (Figure 33). The refuges range from Loch Aline in Ardnamurchan (southerly extent) to Raasay (westerly extent), Kingussie/Helmsdale (easterly extent) and Loch Watten, Caithness (northerly extent). Achandunie, Contin, Cannich, Loch Ness and Golspie refuges border the current DED line, thus their integrity as a refuge will be more difficult to maintain, however these areas represent the highest density of elm in the Highlands, in regard to both canopy cover and connectivity. In order to maintain their status as refuges greater surveying and monitoring strategies will be required to design and create an intervention buffer around and inside the current DED line.

[13] Spatial analysis: Density of elm populations and density of individual stands. Cluster and Hotspot analyse were also performed to identify any areas of significant connectivity. However this did not produce any significant results.

Table 6 – Area information for proposed elm refuges

Name	Area (Ha)	NWSS (Ha)	Elm area (Ha)	% elm in area	% elm of NWSS	Potential planting area (Ha)
Achnadunie	3,362	613.2	3.1	0.09	0.5	10.6
Cannich	11,638.4	4,129.1	1.6	0.01	0.04	779.9
Contin	7,577.1	1,737.5	24.5	0.32	1.4	45.7
Contullich	632.9	88.6	3.6	0.57	4.06	0
Glenmore	5,245.6	329.8	4.5	0.09	1.38	779.9
Golspie	838.5	431.7	10.4	1.24	2.41	0
Helmsdale	240	3	0.4	0.16	12.96	0
Killundine	938.5	143.4	7.8	0.83	5.45	303.8
Kingussie	2,200.4	502.8	1.3	0.06	0.25	367.9
Loch Aline	3,056.5	316.7	26.3	0.86	8.30	674.5
Loch Garry	7,979	1,780.9	0.6	0.01	0.03	124.6
Loch Lochy	12,670.8	1,249.5	2.7	0.02	0.21	280
Loch Maree	9,625.3	444.6	1.3	0.01	0.3	260.2
Loch Ness – East	7,712.2	2,017.2	2.7	0.03	0.13	558
Loch Ness – West	6,237.9	3,419.4	24.9	0.4	0.73	69.8
Loch Watten	19,271.3	56.9	2.6	0.01	4.5	10,042.4
Lochbroom	3,640.5	286.6	1.95	0.05	0.68	201
South-eastern Raasay	233.7	52.9	0.44	0.19	0.83	118.2
South-western Raasay	235.6	4.5	0.15	0.06	3.33	112.4
Southern Skye	773.2	53.6	2.6	0.34	4.85	0
Tongue	240.7	38	0.6	0.24	1.5	2
TOTAL	104,350	17,699.9	123.9	0.3	2.7	14,730.9

Table 6 presents more information on the potential refuges including area, elm area, percentage of native woodland and potential planting suitability[14]. Skye and Raasay have the water (Lochs and Sounds) to buffer and protect against the DED progression.

[14] These areas are based upon NVC W4, 7, 8, 9 AND 10 identified through the National Vegetation Model minus current woodland estate. Further analysis could be performed in regard to climate suitability when appropriate format of maps become available through ESC.

However, Skye is likely to be more vulnerable than Raasay as the road bridge at Kyle of Lochalsh is connected to the A87, which stems from the A82, a current vector route of DED. Reports of both *Phytophthora ramorum* and *Chalara* on Skye, Raasay and around Loch Carron have been confirmed recently, demonstrating the persistent spread of pathogens to more remote western areas of the Highlands (Brockman, 2015). Depending upon the tree health strategy for the Highlands, a greater amount of survey work in the west could identify more areas of elm and suitable land for mixed broadleaf woodlands. This could lead to further elm refuge areas (i.e. Assynt – Figure 34), including historically prominent mixtures with ash, oak and hazel. Natural regeneration could be supported by planting of diverse seed stock from potentially tolerant/resistant trees and then monitored. Such actions could be implemented with ash, as an anticipatory action in regard to *Chalara* ash dieback (*Hymenoscyphus fraxineus*).

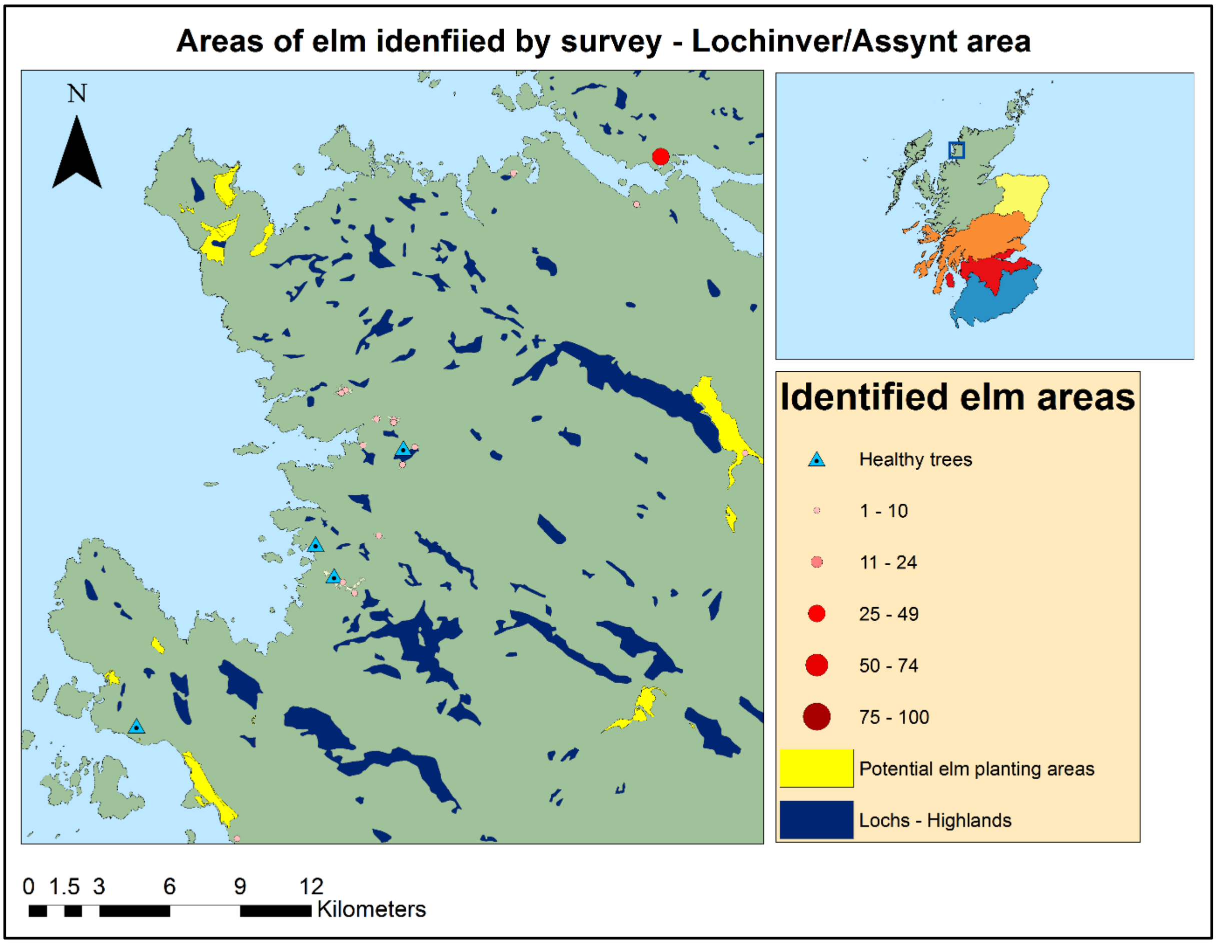

Figure 34 – Area for potential elm expansion and increased surveying

Smaller refuges that may not be visible in Figure 32 are Golspie, Helsmdale, and Tongue (Sutherland). Helmsdale refuge has almost 13% of elm cover of native woodlands, other refuges with significant percentage of elm cover include Loch Watten (4.5%), Contullich (4%), Killundine (5.5%), and Southern Skye (4.9%). Refuges with greatest area of elm (over 10 Ha) are Loch Aline (26.5), Loch Ness West (24.9), Contin (24.5) and Golspie (10.4). The refuges boundaries were designed around local integrated hydrological units (catchments)[15] (Kral, et al., 2015) to enable ease of management and match refuge areas with the growing approach of using river catchments as integrated management units for multiple landscape benefits (Gilvear, et al., 2013; Rouillard, et al., 2015; Natural Scotland, 2015). The Cannich refuge has very few areas of elm but presents an opportunity for expansion in an area with limited infrastructure connectivity and significant areas suitable for planting along the river Eskadale, which includes Aigas reserve. Loch Aline and Killudine refuges are on the southern area of the Ardnamurchan peninsula, which offers protection and geographical buffering for greater ease of management and expansion of an elm resource isolated from areas more at risk. Loch Watten refuge is based around a chain of woodland with elm as a significant component, following the A882 between Bilbster and Thurso, Loch Watten name represents the highest density of elm in the area. These areas appear to border farmland or open areas, close to properties and potential pasture areas. Areas around Lochs resent another significant area for elms and potential expansion, including Loch Ness East and West, Lochy, Maree, Broom and Garry.

Planting suitability in the refuges demonstrate that significant areas are available for native deciduous woodland expansion of which elm could be a component. The most notable outlier is around the Loch Watten refuge in Caithness, which has a very large figure of over 10,000 hectares suitable for planting. This is due to the W7 wet woodlands category, which climatically would be unsuitable (See Figure 18), additionally this area has a high percentage of soils with peat depth exceeding 0.5 metres, which restricts tree planting. If the Loch Watten refuge planting area is discounted that leaves around 4,500 hectares of suitable planting areas in the refuges. Currently the Forestry Commission recommends including 5% elm in a mixed native woodland creation scheme, in that case

[15] Integrated hydrological units shapefile downloaded from: Centre of Ecology and Hydrology. https://catalogue.ceh.ac.uk/documents/3a4e94fc-4c68-47eb-a217-adee2a6b02b3

225 hectares of elm woodland expansion would mean a 12% increase in the elm population in Scotland and 67% increase of the Highland population. However, it is unlikely that all this woodland would be planted with new native woodland, therefore areas of new planting, restoration or beating up in the refuges could include a higher percentage of elm to increase the populations and resilience of the species.

7.4.2 Management Actions

Implementing applied and integrated DED management has the potential to arrest the development of the disease in geographically isolated areas (Menkis, et al., 2015), and in turn increase the presence of elm in the landscape whilst strengthening woodland resilience (Cavers & Cottrell, 2015). The following section presents three management alternatives based upon insights of this report and current literature.

No Action
Inaction appears to be a moderately costly option according to many local authorities due to the spread of DED and the subsequent removal, disposal, restocking required, and some infrastructure damage. Although the elm population in the Highlands is distributed over the landscape, the greatest density of elm is close to clusters of urban population (Inverness, Beauly and Dingwall) all within the DED infection line. The greatest cost of taking no action would be the unnoticed deterioration of the elm population in many places, especially in remote and rural areas, as well as private estates. Additionally, and most importantly, DED would continue to spread unchecked and may have unforeseen ecological, biodiversity and landscape consequences. DED would most likely spread further west and north in the Highlands, reaching the western Isles and Caithness. Mature resource of the species would diminish from current numbers due to low levels of natural regeneration and browsing pressure. Mixed broadleaf woodland structure could change dramatically with the impact on elm from DED and the ash from *Chalara*, beside the presence of oak broadleaf woodland would be dominated by sycamore, chestnut and lime species. Lichens,

mosses, some fungi and invertebrates may decrease or disappear from the Highlands. This management option would weaken the region's resilience and undermine the wider management efforts of the tree health community, as well as reducing ecosystem services benefits on a landscape scale. There would be a risk of squandering an important and potentially significant area of healthy elm.

Cost	Moderate
DED Impact (Reduction)	Low - negative
Elm population impact (Enhancement)	Low - negative

Table 7 – Summary of 'No Action strategy' financial implications[16]

No Action (over 20 years)	Notional timber value[17]	Ecosystem services	Financial cost (Restocking loss)
Annual cost	675,200	86,473	17,231
Annual benefit	0	0	0

Reactive – Increased felling, removal and disposal (expanding current operations)	
This option would be the most costly to those bearing the expense of management and typically such a broad brush approach tends to be ineffective cost/benefit wise, as well as generating inordinate amounts of administration. Although a rotating targeted approach has been successful in contained areas (Isle of Man Government, 2015) it would be difficult to coordinate on a landscape scale in remote regions with poor infrastructure.	
Cost	High
DED Impact (Reduction)	Medium

[16] Cost estimates were based on recent average operational prices (kindly provided by Bartlett Tree Experts), data from published Forestry Commission output guides and and SRDP pricing for maintenance costs.

[17]Estimates the costs of timber loss through potential timber value going to waste using £120/m^3, as a conservative price, 4 m^3 per mature tree and 500 trees/ha.

Elm population impact (Enhancement)	Low – positive

Table 8 – Summary of 'Reactive strategy' financial implications

Reactive (over 20 years)	Notional timber value	Ecosystem services	Financial/operational cost (Restocking loss and removals)
Annual cost	486,400	62,261	114,493
Annual benefit	0	0	0

Refuge - Targeted buffer zone and refuge management
This approach would be focused upon designating DED and elm refuge management zones (Figure 18 and zones that address vector areas in Figure 16). A recommended shift in emphasis from infected and dead elm trees to the management of beetle populations follows increasing best practice (ESCC, 2012; ECC, 2014). Trees that are identified as hosts or potential hosts of beetles and grubs (indicative of breeding beetles) would be removed, which leads to a reduction in breeding beetles in that year and therefore prevents infection the following year (ESCC, 2012). Such activities should slow the spread and impact of DED on elm populations and reduce costs over time. Also treating stumps and areas of healthy trees connected through root systems with herbicide (Glyphosate) has be shown to be an effective measure against the spread of DED in isolated areas (Menkis, et al., 2016). Due to the likelihood of limited resources (funds and labour), such an approach should coordinate with volunteer, community-led and citizen science initiatives. DED identification has been heavily reliant on the valuable work of citizen scientists in some local authorities, enabling local tree officers to react (ESCC, 2012). The combination of these management responses would be more effective and cost efficient, addressing the need to reduce the beetle vector population (Brasier, 1996). Refuges management would involve a combination of monitoring tree health in the area, identifying any host trees, keeping track of any movement of elm wood through the refuge (Firewood/felled trees for milling – which may require securing information on the wood's journey to end product), protecting natural regeneration

and establishing new planting including hybrid elms. Establishing focused centres of "Elmwatch" activity will ease the burden on management and administration and set-up a manageable landscape wide experiment in which multiple levels of management are implemented, including a control site/refuge.	
Cost	Low-moderate
DED Impact (Reduction)	Medium
Elm population impact (Enhancement)	Medium – High (positive)

Table 9 – Summary of 'Refuge strategy' financial implications

Refuge (over 20 years: 5 operational)	Notional timber value	Ecosystem services	Financial/operational cost[18]
Annual cost	190,000	24,212	79,087
Annual benefit	176,000 (assuming maturity in the future)	22,528	0

The estimated financial implications given in Tables 7-9 demonstrate that the greatest costs incurred would be intangible (Notional timber value and ecosystem services – for complete cost/benefit break-down see Appendix - F) and that the core financial burdens would be the removal and disposal of elm timber. Feeding the timber into local woodfuel markets could potentially cut removal costs, adding value to the local energy budgets and supply chains. In this instance these variables have not been included in the potential management actions due to the sensitive nature of elm timber transport and storage, however, municipalities in North America are currently considering turning DED infected waste wood into woodfuel (Tank, 2016). The 'No Action' strategy has the smallest financial burden with costs significantly lower than the other two options, additionally removing the restocking action would reduce the costs to zero. However, this could be potentially catastrophic to not only the elm species population but also the several types

[18] Restocking loss – 20 years replacement schedule, whereas removals, elm expansion planting and establishment costs are performed over a 5 years schedule to minimise loss and DED spread

of diminishing mixed broadleaf woodland, and subsequent biodiversity reliant on such habitats.

The Reactive strategy incurs the greatest financial commitment in which teams respond to outbreaks and known disease areas in an effort to remove as much DED infection from the landscape as possible. In all likelihood priority would be given to urban and peri-urban areas, as well as trees in danger of compromising infrastructure and roads, which would minimise the threat of hazardous trees to people but would have less impact upon the potential landscape and ecological threat of DED. However, this strategy will reduce further losses and interrupt connectivity between infected areas. In spite of reduced DED spread from this strategy the Highland Council in recent years has chosen to forego this strategy, citing the potential impact against the costs being of little value to slowing the spread of DED.

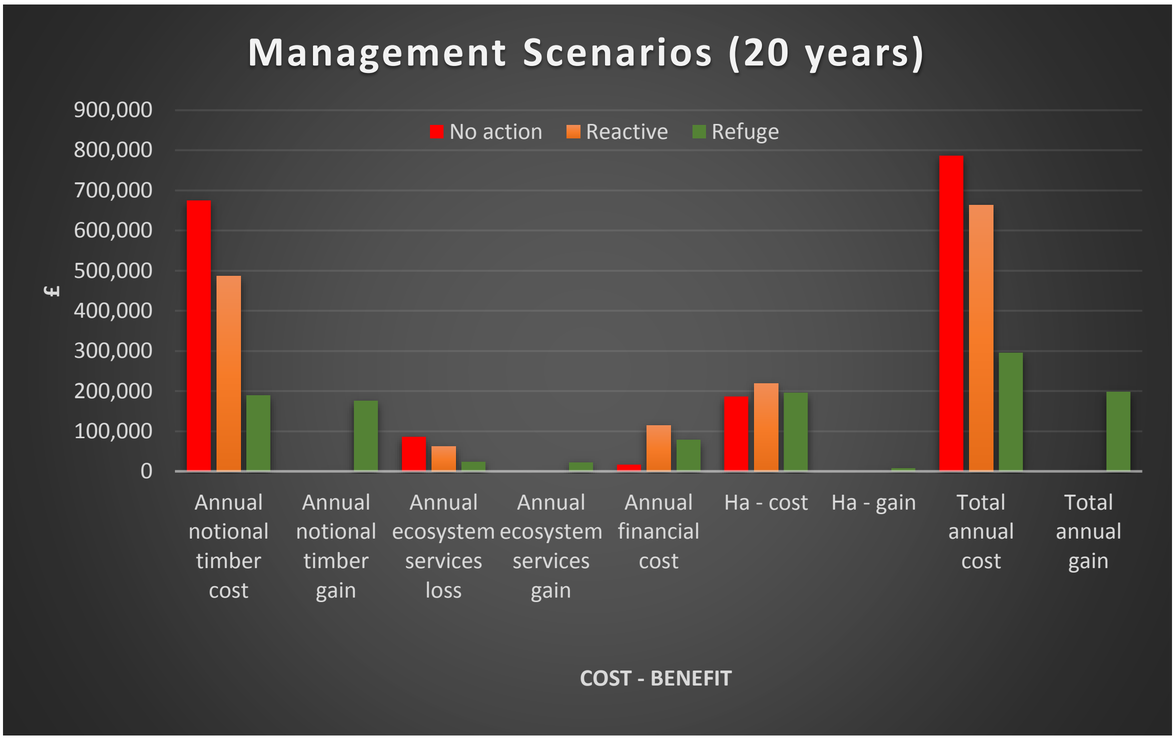

Figure 35 – Cost/benefit analysis of management options

The Refuge strategy has less financial costs than the Reactive strategy, even when incorporating the 22 hectares of elm woodland expansion, due to targeted management actions in and around the refuges. Figure 35 shows the comparative costs and benefits between the three management strategies highlighting the potential gains across the board for the Refuge strategy and despite the lowest financial costs the No Action strategy has extremely high hidden costs and no gains apart from the initial financial savings. These figures can only be estimates and there is still uncertainty regarding the interactions of DED with the regional environment, movement of elm wood around the Highland road network and subsequent actions of landowners. This uncertainty emphasises the need for action to work in partnership with awareness raising and education.

Table 10 – Potential costs of mixed elm species planting trials

Planting trials (6 sites – 3 within DED zone and 3 without the DED zone)	**5 hectare sites (£)**	**2 hectare sites (£)**
Cost of local elm trees (1600/ha) – 15%	18,424	1,354
Cost of hybrid/resistant species (1600/ha) – 15%	144,000	57,600
Cost of other local broadleaf species (1600/ha) – 70%	15,792	6,317
Cost of fencing (6000/2400 metres - £8/m)	48,000	19,200
Cost of planting and labour	26,880	10,752
Cost of tubs and stakes	76,800	30,720
Cost of establishment/maintenance	37,500	15,000
Cost of monitoring (over 30 years every 3 years combination of citizen science and professional oversight)	50,000	20,000
Total	417,396	160,942

Planting trials of local, potentially resistant and hybrid elm has been separated out from the main costings of management actions. The time and costs required to conduct research would represent commitment to a holistic management strategy, dedicated to future conservation and proliferation of elm species, recognising their importance to Highland landscape. Such an approach may even establish the Highlands as an important refuge and centre for elm species not only within Britain but in Europe. Figure 36 identifies potential locations of the planting trials around the Highlands which focuses on dense populations of elm in the DED infected area in refuges around the DED line and populations of elm further west and north. These plantings would be mixed with common Highland broadleaf species associated with elm (Figure 12), a 30:70 mix ratio of elm species to other broadleaf species would be suggested.

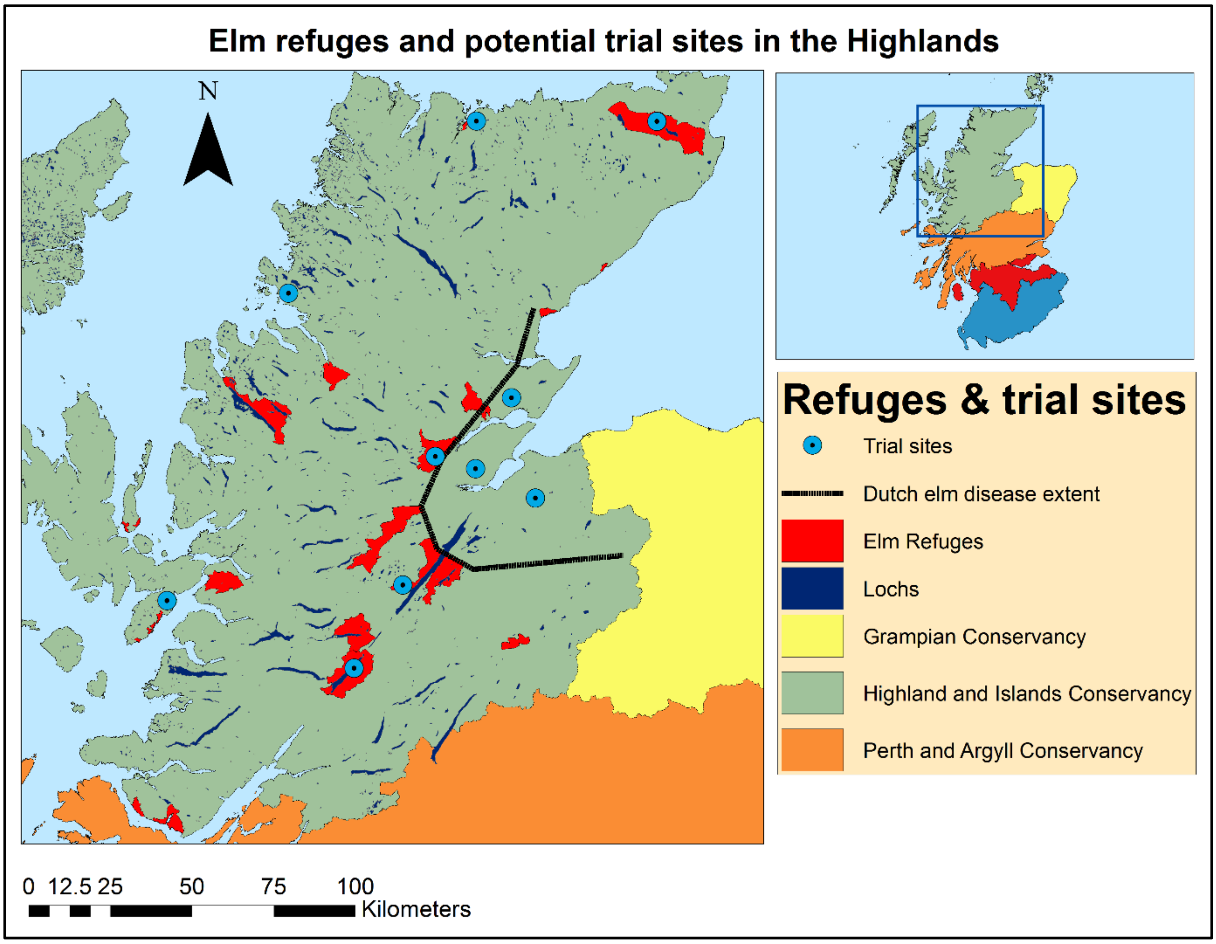

Figure 36 – Suggested locations for mixed elm species trials

Varying the levels of the associated broadleaf species to the trials would add a potentially informative species interaction element, especially in the DED infected area, providing insights into more resilient woodland structures rather than focusing on a sole genus.

7.5 Further research

- Encourage greater surveying capacity in parallel with *Chalara* surveys
- Implement a specific DED monitoring system. Online (ElmWatch – with educational videos and identification tips) could be tied into Observatree and the Great British Elm project. A network of landowners, managers, community groups

and interested parties could be set up to form a regional Elm Watch network. Build the DED landscape map and timeline mentioned in section 6.2.1.

- Pheromone traps (mark and capture) to track the extent of *Scolytus* beetle, potential range from one tree to another and identify other species possibly used as bridging vectors, which could inform effective buffer zone design (Pines & Westwood, 2008). This could come in the form of an MRes or PhD project with a Highland region focus, possibly focused around DED boundary line and refuge areas.
- Further monitoring of tolerant specimens including seed collection and planting of these seed sources in both infected and uninfected areas
- Planting trials of other elm species to test regional suitability and tolerance to DED including *Ulmus laevis*, potentially tolerant species of English elm cultivated in southern England, now being trialled in various locations and institutions including Kew Gardens, but priority should be placed on producing highly tolerant genetic seed sources of wych elm from the Highlands.
- Planting trials with Hybrid Asian elms (Accolade, Cathedral, Discovery, Triumph, Commendation and Danada Charm) (UM, 2015).
- Develop a selection, establishment and maintenance guide for elm areas
- Raise the profile of Highland elms: Potential to form a landscape/UK partnership with other high profile elm areas (i.e. Brighton and Hove, Isle of Man, Edinburgh city Council, Kent trials, Butterfly conservation), which could help strengthen management, best practice, knowledge exchange, as well as landscape and species resilience. This partnership could target greater EU funding to support further work and knowledge exchange. Linking up with other European partners could dramatically enhance the scope of these efforts.
- Research project on networks and stewardship to address and combat tree health issues with a focus of DED and *Chalara* – generating meaningful data for management, awareness, best practice and innovative resilience strategies.
- Host an Elm Conference in the Highlands to draw attention to the population of elm in the region, highlighting that the challenges and issues facing management and moving forward are similar to those faced by other regions decades ago.

8. Summary – Elm futures

The elm (mostly *Ulmus glabra*) population the Highlands and Islands of Scotland represents a unique opportunity to apply best practice and experience of practitioners and researchers over the globe to manage a landscape with healthy elm untouched by DED. However, comprehensive data on the extent and spread of DED in the Highland landscape is lacking, which complicates considered management responses to DED control. In spite of this DED appears to be travelling both northwards and westwards in the Highlands putting further healthy populations at risk. The continued spread of DED is mainly associated with two types of vectors: firstly, climate suitability (warming) becoming more favourable to an increase in beetle populations, and secondly, transport of timber that hosts larvae and beetles, following infrastructure networks (e.g. A9, A82 and A96). This creates a leap-frog effect that transports the beetle and larvae populations to areas that would normally be unreachable through natural ecological vectors, thus creating new landscape nodes for DED distribution.

Elm species contribute significantly to biodiversity of the region as a component of several unique woodland habitats, such as upland ash woods, Atlantic oak and hazel woods, as well as lowland deciduous woods. Several rare lichens are associated with elm species and appear to be thriving in the Highlands, whereas in other parts of the UK populations have dramatically decreased. The elm tree also provides habitats and hosts numerous bird species and insects. Elm's importance as a species is heightened by the threat of *Chalara* to the ash tree population and the combined loss of both these species would severely diminish native broadleaf woodlands, and subsequently have a cascade effect directly and indirectly on dependent biodiversity.

As a productive species elm has a small presence, nursery production and sales have risen in the past two years but they also provide a vector for introduction of new species or stronger strains of woodland pests and pathogens that undermine the integrity of the woodland resource. More careful management and best practice is advised to limit biosecurity risks. Despite being a versatile timber in demand and historically used for diverse products from ships to cladding little elm timber is milled or used in the Highlands, which has increased its value but in general more timber supply is desired by millers and growers as it provides a strong and decorative product highly prized and value (especially in burr form) (Informed by processors survey).

The elm landscape survey emphasised the aesthetic importance of elm as a species in a rural, urban and garden environment to the majority of respondents with most advocating expansion of their population in the region and greater management for conservation. However, most respondents are sceptical about further planting and landscape use due to the impact of DED, assuming that all elms will eventually succumb to the disease. Elm provides significant economic value through ecosystem services, as well as ecological, cultural and heritage value in both the rural and urban environment.

Formulating management responses to counter DED and enhance conservation of elm populations has been challenging. Pesticides and herbicides have mostly been discarded in favour of more ecologically friendly approaches; most local authorities are moving towards the trapping, trialling and monitoring approach. This focuses on decreasing beetle and larvae populations at distribution nodes, including use of carefully placed deadwood as a feeding ground to attract active beetles. Planting potentially resistant and tolerant species and specimens of elm in different locations and observing their response to DED. Gathering and collating data as well as regular monitoring of priority or targeted areas seems to be the approach most needed and valued at the moment to generally increase the connectivity of the sectors knowledge base to make more informed decisions.

In light of these shifts in DED practice and the continued havens provided to populations of elm species by the Highlands, the establishment of 'Elm Refuges' has been proposed. These areas would provide an actively managed landscape unit to conserve, protect and enhance elm species. Occurring across the Highlands from Ardnamurchan in the south to Tongue in the north they represent distinct regions as well as remote and rural areas, which may prove difficult to manage, especially with diminishing funds and resources of government agencies. Therefore partnerships between citizen science, community stewardship, ENGO's and government agencies will have a vital role in realising these Elm Refuges. Greater knowledge exchange and relationships with other focused elm and DED practice and research community are encouraged and should be actively pursued to highlight the Highlands potential as a stronghold for elm species proliferation and best practice.

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Appendix A – Example of Elm survey

University of the Highlands and Islands Inverness College

Scottish elm survey

Importance of elm in the 21st century

1. Where in Scotland do you live?

Click here to enter text.

Urban ☐ Rural ☐

2. Age Group:

18 - 25 ☐ 26 - 35 ☐ 36 - 40 ☐ 41 - 60 ☐ 60 - 75 ☐ 76+ ☐

3. Vocation?

Click here to enter text.

4. Could you identify an elm tree?

Yes ☐ No ☐

5. Can you identify any areas in which you have seen living or dead elm trees?

Click here to enter text.

6. If so, what other species of tree do you see growing in the same area?

Click here to enter text.

7. Do you know what elm wood is used for? If so what types of products?

Click here to enter text.

8. For you what is the role of elm in the Scottish landscape?

Click here to enter text.

9. What are the social benefits of elm trees?

Aesthetic ☐ Important ecological species ☐ A warning for other species ☐

Other ☐… Click here to enter text.

10. Would you rate the aesthetic importance of elm trees in the landscape?

Very high ☐ High ☐ Medium ☐ Low ☐ unimportant ☐

11. Would you like to see more elm trees in the landscape?

Yes ☐ No ☐ Not bothered ☐

12. If yes, then what locations are most preferable?

Woodland ☐ Farmland ☐ Street trees ☐ Parks ☐

Verges (edge habitats) ☐ Other ☐… Click here to enter text.

13. How aware are you of Dutch elm disease?

Highly ☐ Somewhat ☐ Low ☐ No awareness ☐

14. How is your knowledge on elm influenced by Dutch elm disease?

Completely ☐ Mostly ☐ Somewhat ☐ Little ☐

Not at all ☐

15. Do you consider elm a suitable species for Scotland?

Yes ☐ No ☐ Please elaborate... Click here to enter text.

16. Do you consider elm a suitable species for the Highlands?

Yes ☐ No ☐ Please elaborate... Click here to enter text.

17. Is there anything else you wish to add regarding elm trees (Importance, spread, management, future planting etc)?

Click here to enter text.

Online version: https://surveyplanet.com/559cfeb8a5dd10d153252335

Thank you for your time and contributing to this study of elm trees in Scotland

Return to: euan.bowditch.ic@uhi.ac.uk

Appendix B – Example of Sawmill survey

University of the
Highlands and Islands
Inverness College

Elm and sawmills survey

Do you mill timber from elm species?

Yes ☐

No ☐

If so, what is the average supply (m^3) each year?

How consistent is the supply of elm?

Species:

Wych elm (*Ulmus glabra*)

Mostly ☐

Sometimes ☐

Rarely ☐

Never ☐

English elm (*Ulmus minor var. vulgaris*)

Mostly ☐ Sometimes ☐

Rarely ☐

Never ☐

Smooth leaved (*Ulmus minor var. minor*)

Mostly ☐

Sometimes ☐

Rarely ☐

Never ☐

What are the dominant uses for elm timber?

What is the most common milled form?

How much is elm bought for on average:

Per m^3?

Whole tree?

What was the highest price paid for elm and why?

Is the demand for elm…

High ☐

Medium ☐

Low ☐

Unpredictable (sporadic) ☐

What is the view of elm as a regional timber species (Highlands)?

What is the future for elm as a timber species?

Is there anything else notable about elm species or timber from your point of view?

Appendix C – List of respondents and consultees

Organisation/Sector	Number of respondents
RSPB	2
SNH	5
NT	2
Wildlife Manager	4
Forester	12
Crofter	3
Environmental/Conservation	16
Not mentioned	1
Woodworker	1
Land manager	1
Teacher	1
Storyteller	1
Land owner	1
Horticulturist	3
Trees for life	2
Woodland Trust	1
Community Forestry	4

Consultees

Cawdor forestry
Estates owners/managers
Foresters

Edinburgh City Council
Isle of Man Council

Appendix D – Complete tables of Highland Wards and Refuges planting areas

Table 11 – Highland Wards potential planting areas based upon NVC

Highland Wards	NVC (W7,8,9,10,11,16,17)	NVC (W8,9,10,16)
Aird and Loch Ness Ward	2,589.50	133.76
Badenoch and Strathspey Ward	3807	183.9
Nairn Ward	54.6	11.4
Inverness South Ward	863.4	0
Culloden and Ardersier Ward	0	0
Black Isle Ward	0	0
Cromarty Firth Ward	349.9	0
Tain and Easter Ross Ward	0	0
Dingwall and Seaforth Ward	164.5	0
Inverness Ness-Side Ward	0	0
Inverness West Ward	0	0
Inverness Central Ward	0	0
Inverness Millburn Ward	0	0
Thurso Ward	309.9	0
Caol and Mallaig Ward	4,569.50	3214.5
Wick Ward	6,042.90	0
Fort William and Ardnamurchan Ward	5,549	3358.5
Eilean a'Cheo Ward (Skye and raasay)	19,411	0
North, West and Central Sutherland Ward	3,683.50	0
Wester Ross, Strathpeffer and Lochalsh Ward	6,983.50	0
Landward Caithness Ward	37,044.40	4474.9

East Sutherland and Edderton Ward	355.1	16.8
Lewes	0	0
Orkney	0	0
Total	**97,777.7**	**11,393.8**

Table 12 – Highland Refuge areas planting potential based upon NVC

Refuges	NVC (W7,8,9,10,11,16,17)	NVC (W8,9,10,16)
Achnadunie	10.6	0
Cannich	779.9	0
Contin	45.7	0
Contullich	0	0
Glenmore	779.9	367.6
Golspie	0	0
Helmsdale	0	0
Killundine	303.8	474.2
Kingussie	367.9	0
Loch Aline	890.9	731.4
Loch Garry	124.6	0
Loch Lochy	280	168.5
Loch Maree	260.2	0
Loch Ness – East	558	42.5
Loch Ness – West	69.8	3.7
Loch Watten	10,042.40	967.2
Lochbroom	201	0
South-eastern Raasay	118.2	267.4
South-western Raasay	112.4	121.6
Southern Skye	0	0
Tongue	2	0
TOTAL	**14,947.3**	**3,144.1**

Appendix E – Elm hybrids and varieties that show resistance to DED

Table 13 – Resistant species recommended and mostly available from Resistant elms

Elm Hybrid	Species hybridised
Morfeo FL 509	*[U. chenmoui x [(U. glabra x U. minor) x U. minor]*
FL 506	*[U. chenmoui x [(U. glabra x U. minor) x U. minor]]*
Fl 493	*[[((U. wallichiana x U. minor) x (U. pumila x U. minor)) o.p.] x (U. x hollandica "Vegeta" x U. minor)] o.p.*
San Zanobi	*[(U. glabra "Exoniensis" x U. wallichiana) x (U. minor 1 x U. minor 28)] x U. pumila S.2*
Letece	*[[(U. glabra var Exoniensis x U. wallichiana) x (U. minor 1 x U. minor 28)] x [(U. hollandica "Bea Schwarz" x U. hollandica "Bea Schwarz" selfed)]]*
Vada	*[[(U. glabra var Exoniensis x U. wallichiana) x (U. minor 1 x U. minor 28)] x [(U. glabra var Exoniensis x U. wallichiana) x (U. minor 1 x U. minor 28) selfed]*
Columella	*[(U. glabra var Exoniensis x U. wallichiana) x (U. minor 1 x U. minor 28)] selfed*
Patriot	*[[(U. pumila x (U. x hollandica "Vegeta" x U. minor))] x [U. davidiana var. Japonica]]*
Jefferson	*[Ulmus Americana x unknown Ulmus spp)*
Sapparro Autumn Gold	*U. pumila x U. davidiana var. japonica*

European white elm	*Ulmus laevis*
Ademuz	*Ulmus minor var. minor*
Desha Amaniel	*Ulmus minor*
Morton (Accolade)	*Ulmus davidana*
Homestead	*('Commelin' × (U. pumila 'Turkestan' × U. minor'Hoersholmiensis'))*
Pioneer	*Ulmus x hollandica (U. glabra x U. minor)*
Valley Forge	Cultivar of *Ulmus americana*
Resista Range [*Ulmus*]: 1) New Horizon; 2) Rebona; 3) Regal; 4) Rebella.	*1) Ulmus pumila x Ulmus davidiana var. japonica* *2) Ulmus pumila x Ulmus davidiana var. japonica* *3) 'Commelin' and '215' (Ulmus pumila × 'Hoersholmiensis')* *4) U. parvifolia x U. americana*
Plinio	*Dutch cultivar 'Plantyn' (female parent) Ulmus pumila clone 'S.2'*
Fiorente	*Ulmus pumila x Ulmus minor*
FL 462	*FL 148 with U. chenmoui; FL 148 x two U. Pumila spp*
Christine Buisne	*Ulmus minor*

Appendix F – Financial implications tables

Table 14 – No Action strategy financial implications break-down

No change – loss of 25% of elm population and subsequent diminishing health (spread of DED over 20 years)			
		Cost	**Gain**
Standing timber loss (Notional timber loss cost based upon local markets)		675,200	
Hectares of elm (25% of 337.7 ha)	84.4		
No. Trees (500/ha)	42,200		
Loss of timber value (No.trees*120*4)	20,256,000		
Removal costs	6,752,000		
Net loss	13,504,000		
Per year	675,200		
Per hectare	160,000		
Per hectare per year	8,000		
Ecosystem services loss (annually)	86,473	86,473	
Ecosystem services gain (potential)	0		0
Tree surveying cost	0		
Removal (£160 per tree)	0	0	
Restocking costs (annual)	344,614	17,231	
Cost of saplings (1750/ha)	69,419		
Cost of labour (No.trees/25*14)	38,875		
Cost of tubing and staking	236,320		
Expansion costs	0	0	

Cost of saplings			
Cost of labour (No.trees/25*14)			
Cost of tubing and staking			
Expansion potential gains (timber)	0	0	
Establishment costs			
Total (costs/Gains)		778,904	0
Total cost per hectare	184,574		
Total gain per hectare	0		
Annual landscape loss (including notional timber and ecosystem services loss)	778,904		
Annual financial/operational costs	17,231		

Table 15 – Reactive strategy financial implication break-down

Reactive Strategy – loss of 18% of elm population and subsequent diminishing health (spread of DED – however this will be limited by active removals)			
		Cost	**Gain**
Standing timber loss (Notional timber loss cost based upon local markets)		486,400	
Hectares of elm (18% 0f 337.7 ha woodland)	61.8		
No. Trees (500/ha)	30,400		
Loss of timber value (No.trees*120*4)	14,592,000		
Removal costs	4,864,000		
Net loss	9,728,000		
Per year	486,400		
Per hectare	160,000		
Per hectare per year	8,000		
Ecosystem services loss (annually)	62,261	62,261	
Ecosystem services gain (potential)	0		0
Tree surveying cost (10 days@£100/day)	1,000	1,000	
Removal	1,945,600	97,280	
Restocking costs (annual)	248,252	12,413	
Cost of saplings (1750/ha)	50,008		
Cost of labour (No.trees/25*14)	28,004		
Cost of tubing and staking	170,240		
Expansion costs	0	0	
Cost of saplings			
Cost of labour (No.trees/25*14)			
Cost of tubing and staking			

Expansion potential gains (timber)	0	0	
Establishment costs (5 years £250/hectare)	76,000	3,800	
Total (costs/Gains)		663,154	0
Total cost per hectare	216,564		
Total gain per hectare	0		
Annual landscape loss (including notional timber and ecosystem services loss)	548,661		
Annual financial/operational costs	114,493		

Table 16 – Refuge strategy financial implications break-down

Refuge Strategy – Strategic 4% removal of infected trees in refuges around DED sensitive zone (10% loss first 5 years, then 5% next 15 years)			
		Cost	**Gain**
Standing timber loss (Notional timber loss cost based upon local markets)		190,000	
Hectares of elm	23.8		
No. Trees (500/ha)	11,875		
Loss of timber value (No.trees*120*4)	5,700,000		
Removal costs	1,900,000		
Net loss	3,800,000		
Per year	190,000		
Per hectare	160,000		
Per hectare per year	8,000		
Ecosystem services loss (annually)	24,212	24,212	
Ecosystem services gain (potential - planting expansion)	22		22,528
Tree surveying cost (40 days@£100/day)	4,000		
Removal (annually over 5 years)	226,400	45,280	
Restocking costs (annually over 20 years)	96,974	4,849	
Cost of saplings (1750/ha)	19,534		
Cost of labour (No.trees/25*14)	10,939		
Cost of tubing and staking	66,500		
Expansion costs (annually over 5 years)	110,495	22,099	
Cost of saplings	18,095		
Cost of labour (No.trees/25*14)	30,800		

Cost of tubing and staking	61,600		
Expansion potential gains (timber)	176,000	0	176,000
Establishment costs	57,188	2,859	
Total (costs/Gains)		289,299	198,528
Total cost per hectare	194,005		
Total gain per hectare	8,359		
Annual landscape loss (including notional timber and ecosystem services loss)	219,061		
Annual financial/operational costs	79,087		
Annual landscape gain	198,528		