CONSERVATION HEDGES – MODERN-DAY ARKS

Martin Gardner[1], Tom Christian[2], William Hinchliffe[3] & Robert Cubey[4]

ABSTRACT

In May 2014, the first planting of the Royal Botanic Garden Edinburgh (RBGE) conservation hedge took place, when the Reverend Anne Brennan planted a tree which had originated as a cutting from the ancient and historic European yew, *Taxus baccata*, in the churchyard of her church at Fortingall, Perthshire. This is one of almost 2,000 plants that will eventually form a conservation hedge of significant scientific and conservation value. The International Conifer Conservation Programme (ICCP), based at RBGE, has actively sought other opportunities to establish conservation hedges via its network of 'safe sites', using a range of different conifer species. This initiative is being driven by the potential for relatively large numbers of genotypes from a single threatened species to be stored in a linear space. It is well established that seed banks have a great capacity to store large amounts of genetic diversity, so we should simply consider conservation hedges in a similar manner. These super-hedges cram relatively large amounts of genetic material into a small space, capturing a great range of wild traits and potentially contributing to the restoration of wild populations. To date, conservation hedges have been planted at five separate locations at RBGE's Edinburgh Garden as well as at four ICCP external 'safe sites'. Although this article focuses on the establishment of conservation hedges using conifers, we have also highlighted some conservation hedges that comprise non-coniferous species.

INTRODUCTION

If botanic gardens are going to have any valid claim to use their collections as a conservation genetic resource, then they need to be more than stamp collections of single individuals. Certainly, in the climate of reduced field work funding and the stifling effect of the Nagoya Protocol for transferring material, every opportunity needs to be taken with all available space being fully utilised to accommodate 'hard-won', naturally sourced plant material. After all, this is what underpins the vital research of botanic gardens and supports the wider, equally important remit of conserving plant biodiversity in the face of global environmental change and mass extinctions. The 35 ha site at the Royal Botanic Garden Edinburgh (RBGE) does not provide too many opportunities for planting trees but nowhere should be considered out of bounds for planting material of scientific and conservation significance – not even the perimeter hedge.

1. Martin Gardner is Coordinator of the International Conifer Conservation Programme (ICCP) at the Royal Botanic Garden Edinburgh.
Address: 20A Inverleith Row, Edinburgh, EH3 5LR, UK.
Email: mgardner@rbge.org.uk
2. Tom Christian is a Consulting Plantsman.
Address: West Lodge of Ballechin, Pitlochry, Perthshire, PH9 OLW, UK.
3. William Hinchliffe is an Arboriculturist at the Royal Botanic Garden Edinburgh.
Address: 20A Inverleith Row, Edinburgh, EH3 5LR, UK.
4. Robert Cubey is Plant Records Officer at the Royal Botanic Garden Edinburgh.
Address: as above

To date, the International Conifer Conservation Programme (ICCP) has developed a network of over 200 dedicated 'safe sites' where almost 14,000 threatened conifers are being monitored (Gardner, 2016). These collaborative sites have been chosen because they provide a good opportunity to protect and manage threatened conifers in the long term. Some of them have relatively large areas available and have accommodated substantial numbers of threatened conifers. For example, Mount Stuart Pinetum on the Isle of Bute has planted almost 1,000 conifers and Bedgebury National Pinetum in Kent over 750. However, these are unusual among the typical 'safe sites' and finding new sites to accommodate similar numbers of plants is quite a challenge. Conservation hedges provide an ideal opportunity for maximising the number of genotypes in a linear space, hence helping to preserve the evolutionary potential of the species. Replacing the Edinburgh Garden's perimeter hedge of *Ilex aquifolium* (holly), which had little or no scientific value and posed a number of horticultural challenges at cutting time, with almost 2,000 trees of *Taxus baccata* with research and conservation benefits provides a very pragmatic solution and maximises the limited space available.

SOME BACKGROUND TO LIVING HEDGES

It is appropriate to reflect on the original concept of hedges in Europe, which dates back to the bronze and iron ages (Pollard *et al.*, 1974). During this period they were first used as a means of containing livestock and later for marking parish boundaries, hence the Enclosure Acts which created legal property rights to land that was previously common land. The English word 'hedge' comes from the Anglo-Saxon *gehaeg*, meaning 'enclosure' (Pollard *et al.*, 1974). Bailetti (2016) describes a hedge as "a continuous row of trees or shrubs, which are maintained to form a boundary or barrier, providing some privacy and protection". He goes on to say: "hedges can be the perfect place for wildlife, particularly for nesting birds and also serve as barriers of sound and pollution, creating boundaries between properties, even serving to deter unwanted visitors". Baudry *et al.* (2000) state that living hedgerows are also "actively managed to prevent expansion into adjacent fields, the majority of which are cut back in some way".

Historically, the most common choice of species for hedges was *Crataegus monogyna* (hawthorn) because its thorn-clad stems were considered to be a good deterrent against straying farm animals and its wood was used for making tool handles. Those of us who are old enough to remember when May Day was an important annual celebration will recall that hawthorn blossom was a key part of the tradition, as well as being used as confetti for spring weddings. Latterly, with the loss of so much woodland habitat in the UK, field hedges have taken on the important function of conservation corridors for wildlife. Species-rich hedges have an approved Habitat Action Plan under the UK Biodiversity Action Plan (Maudsley *et al.*, 2000). Furthermore, under the Hedgerows Regulations 1997, it is against the law to remove most countryside hedges without first obtaining permission from the local Planning Department (DEFRA, 1997). Between 1945 and 1993 almost 50 per cent of British hedges were removed

mainly because of agricultural intensification (Barr & Parr, 1994; Woodland Trust, 2014).

The ICCP conservation hedges differ from the traditional hedgerow in that they are not necessarily plant species-rich as they comprise a single species, as is the case with most hedges in garden settings. However, the aim is to make them ultra-genetically diverse with the focus species, although they will no doubt adopt some of the functions of traditional hedgerows in that they will also support native wildlife – nesting birds, insects and so on. In direct contrast to this, traditional ornamental hedges have been planted to give a neat uniform appearance and the most effective method of achieving this is to use plants from a single clone.

EXAMPLES OF CONSERVATION HEDGES

Apart from being used in the forestry industry for the mass production of uniform conifer cuttings and for maintaining the juvenility in propagules (Libby *et al.*, 1972), hedges have also had the specific purpose of genetic conservation. For example, hedges played a significant role in the 1960s for conserving wild-origin collections of *Pinus radiata*, now the most widely planted pine in the world (Critchfield & Little, 1966), but ironically endangered in the wild (Farjon, 2013a). Likewise, in the 1980s, collections of native *Sequoia sempervirens* were made as a back-up foundation hedge orchard (Libby, 1990). The cones were chosen from large trees of high performance for commercial forestry purposes but later the Redwood League was encouraged to take ownership of the hedge for genetic conservation purposes (Libby *et al.*, 1972). There are some instances when a line of trees can take on the same function as a conservation hedge. For example, during field work by Tom Christian and William Hinchliffe in Japan in 2013, seed collections were made from a planted line of *Picea maximowiczii* trees which had been established as an *ex situ* planting, being progeny from a nearby forest of the same species. This raises the question: when is a hedge a hedge? Perhaps the best answer is: when its growth is controlled by regular cutting. Prior to the conservation hedges developed by the ICCP, the use of ornamental conservation hedges in the UK was extremely limited. The following are examples of those that are known to the authors.

Royal Botanic Gardens, Kew, Wakehurst, West Sussex

Perhaps one of the first conservation hedges to be planted in the UK was that of *Ulmus minor* at the Royal Botanic Gardens, Kew (RBG, Kew). The material for this hedge was collected from a variety of sites in the UK between 1974 and 1976 by Dr Ronald Melville who was a taxonomist at RBG, Kew with a long-standing interest in this genus (Ed Ikin, pers. comm.). Chris Clennett, the Garden Manager at RBG, Kew, states that "originally the hedges were planted for a short time at Kew then moved to Wakehurst into what is now a staff car park by the Orchards building. The hedges were moved into the landscape when the Millennium Seed Bank was under construction to free up car

parking space for the extra staff being recruited for that building". Today the hedges form a 60 m row beside the Millennium Seed Bank and a longer boundary hedge between the garden and the adjacent parkland.

Bedgebury National Pinetum, Kent

Although *Cupressus macrocarpa* is commonly cultivated in the British Isles, known wild-origin material of this threatened species is very poorly represented. Ninety-nine plants raised from seed collected from Point Lobos State Reserve in California have been planted in a hedge 82 m long which borders the nursery at the Bedgebury National Pinetum (Dan Luscombe, pers. comm.). The hedge was planted in 2009 and comprises ninety-nine genotypes from six accessions (six parent plants). A second hedge has also been planted containing *C. goveniana*, collected under the name of *C. goveniana* var. *pygmaea* from Mendocino Co., Fort Bragg, California. A hybrid of *C. macrocarpa* and *C. goveniana* collected from Gibson Creek near Point Lobos has also been planted in a hedge (Dan Luscombe, pers. comm.).

Atlanta Botanical Garden, Georgia, USA

Ron Determann, Vice President of the Fuqua Conservatory at Atlanta Botanical Garden, is also creating conservation hedges inspired by the RBGE example. He has more than 300 documented clones of the critically endangered *Torreya taxifolia* in his nursery ready to be used in a conservation hedge. Likewise, *Taxus floridana*, also critically endangered (Spector *et al.*, 2011) and growing in the same location as *Torreya taxifolia*, is being propagated for the same purpose. This, along with the near threatened *Tsuga caroliniana*, which has been devastated by the hemlock woolly adelgid (*Adelges tsugae*) (Letheren, 2017), will also be used in a conservation hedge. The latter has been propagated from collections made in Tallulah Gorge State Park from the only population native to the state of Georgia (Ron Determann, pers. comm.).

Kew-Ica project, Peru

In Peru, the Centre for Plant Conservation (CCP) and Sainsbury's Nursery (Kew-Ica project) have undertaken some pioneering work. Led by Oliver Whaley from RBG, Kew, part of this work is underpinned by the belief that hedgerows play an important role in the conservation of biodiversity. They can serve as ecological corridors to connect fragmented sites, a necessity for sustaining habitat restoration with biological development of wildlife cycles (Figs 1 & 2). Most importantly, in those areas with intensive agriculture, native hedges also offer multiple ecosystem services as habitats for pollinating insects, soil improvement and water conservation. In the Kew-Ica project nursery, demonstration hedges have been established using threatened Peruvian trees and shrubs such as *Galvezia fruticosa*, *Tecoma fulva* subsp. *guarume* and *Vallesia glabra*, as well

Fig. 1 *Tecoma fulva* var. *guarume* hedge planted in the Plant Conservation Centre in Agricola Chapi, Ica, on the south coast of Peru. The hedge comprises plants collected along the east–west gradient from the coast into the Andes across the entire distribution of the species. Photo: O. Whaley.

as *Acacia macracantha*, *Parkinsonia praecox* and *Schinus molle*. These hedges not only conserve genetic material but are also used as a shop window for commercial purposes in order to sell plants to partners for restoration programmes. The endemic and highly threatened *Tecoma fulva*, which has a very limited distribution in the Andean *quebrada* and *precordillera* vegetation, has been planted using several hundred plants for conservation purposes. This hedge comprises material collected from throughout its natural range with the plants arranged in the same linear sequence as they were collected in an east–west transect of the Andes. Each hedge is independently irrigated with regulated water consumption in order to obtain data for native hedges (and reforestation). This is especially useful where farms have to minimise water usage for environmental and economic reasons. Lastly, as the water can be controlled for the whole genotype hedge, the phenotypes can be compared and tested for phenology, ornamental potential and, most importantly, resilience to drought and stress (Bailetti, 2016).

THE YEW CONSERVATION HEDGE AT RBGE

The authors have played a major role in the planning and implementation of the yew conservation hedge at RBGE's Edinburgh Garden (Fig. 3) as well as carrying out

Fig. 2 *Prosopis limensis* (huarango) planted as an avenue towards the Andean foothills in Agricola Chapi, Ica, Peru. These trees are landrace varieties that have been selected for their highly productive qualities. They are endangered in the wild due to a Cercidomyiidae gall-midge which causes dieback. Photo: O. Whaley.

targeted field work to collect from heritage and native yews. More specifically, Tom Christian conducted a pilot study (Christian, 2008) of the hedge as part of his BSc Hons in Horticulture with Plantsmanship course at RBGE, with Martin Gardner co-supervising the project. William Hinchliffe leads a team of horticulturists who have planned the whole operation of removing the original hedge and replacing it with recently collected yew trees. One important element of the hedge has been the involvement of a large number of RBGE staff, especially those who are nationals of the countries where the yew is native. To this end Agron Shehi (Albanian), Axel Dalberg Poulsen (Danish) and Vlasta Jamnický (Croatian) were involved in making collections of yews from their own countries. This Garden-wide involvement is highly appropriate as the hedge, which almost encircles the Garden, is intrinsically tied to and indeed embraces the very remit of the institution, which is to conserve biodiversity in the face of global extinction.

The hedge partially surrounds the Edinburgh Garden on three sides (the north, west and south perimeters) and extends for approximately 1 km. It comprises two categories of plants: c. 30 per cent are from cuttings from iconic heritage yew trees throughout the UK and Ireland, and c. 70 per cent are from seed collections made from native trees from across the natural distribution of *Taxus baccata.* Each plant in the hedge is labelled

Fig. 3 The RBGE yew conservation hedge; planting began in 2014. Photo: M. Gardner.

with a unique accession number and qualifier and is digitally mapped. There are 1,000 significant heritage yew trees in Britain (Moir *et al*., 2013), for which the Ancient Yew Group has proposed a classification based on age (Ancient Yew Group, 2012–2018). The four categories are Ancient, Veteran, Notable and Exceptional (Hills & Hindson, 2010). Due to the enormous choice, the task of prioritising heritage trees for the hedge has proved to be quite a challenge. Criteria such as extreme age, inspiring historical tales and novel modern-day uses were used in shortlisting the 37 trees planted. In all we chose seventeen trees from Scotland, eighteen from England, Northern Ireland and Wales, and two from the Republic of Ireland (Table 1). If we postulate that perhaps most heritage yew trees represent genetic material that in many cases is no longer extant in local native populations, then the inclusion of these documented genotypes in a conservation hedge is highly beneficial for the conservation of the species. Finally, part of the development plan for the hedge is to display some of the interpretation on the outside of the perimeter fence; as a result, the public will not necessarily have to access the Garden in order to learn about the conservation hedge.

Planting the yew hedge at RBGE

Removal of the holly hedge

The existing *Ilex aquifolium* hedge was cut off at ground level and chipped for composting to be used later as a mulch. The stumps were removed using a mini digger. While this was being done, overhanging branches and plants in close proximity were pruned to aid the establishment of the new hedge.

Preparation of the ground

After the stumps were removed, the ground was replenished using RBGE's 'homemade' compost, as the old hedge had depleted the soil of nutrients. This was left to settle.

Planting the trees

The plants were lined out in the nursery in planting order to ensure that the planting took place in the correct sequence. One person oversaw each stage of the process and this was the key to its success. Scotts Pre-Planter Fertiliser (3+16+9+5MgO) was added to the base of each planting hole and after planting a seep hose was laid along the length of the new section to provide regular irrigation during establishment. Each plant was uniquely labelled at the time of planting.

Planning the location of each accession

For most accessions, their position was dictated by when they were ready for planting. The exceptions were the Scottish heritage clones which are planted all together close to one area of the Garden displaying native species (the north-westernmost corner) and in close proximity to the Botanic Cottage. Where possible, the collections with especially interesting stories were planted in highly visible and accessible locations where there is a good opportunity to provide interpretation.

Plant records

Accurate plant records are of paramount importance to this project. Records were managed using collections management software BG-BASE™ (Walter & O'Neal, 1985–2018). Each section of the hedge was given a new location code. The sub-location code (field name: GRID) was used to further divide the location. Sub-location codes run continuously across all the hedge locations, giving a 'walking order' to the hedge. There is no repetition of sub-locations between hedges and very usable inventories can be quickly created for stock checking. The individual plants have also been mapped using the ESRI – ArcMap (ESRI 1999–2017) to provide a spatial record of planting location.

Labelling

An engraved plant label was produced for every plant. It displays the standard information used by RBGE for public display labels except for the native range. Instead, only the country of origin of the accession was engraved in order to better interpret the project and reflect the origin of the plant.

HERITAGE YEWS

Britain has inherited the greatest number of culturally Ancient and Veteran yews in the world; planting yews is part of a tradition that predates the arrival of Christianity in the British Isles (McGeeney, 2014). Sixty-seven per cent of all large-girthed yew trees are found in churchyards (Moir *et al*., 2013) and so many of the trees prioritised for inclusion in the conservation hedge originated there. For millennia, the common yew (often known as the European yew) played a significant role in religion (as well as folklore and medicine). The yew was considered to be a natural emblem of eternity in the Druidic tradition of reincarnation and the later Christian doctrine of the resurrection (Hageneder, 2007). It was previously thought that English churches were most likely established in locations of pagan worship, where yews were situated, in order to Christianise the sites, but this theory is now disputed. Hindson (n.d.) unequivocally states: "This exaggeration has its roots in Victorian guidebooks and wishful local histories", adding "Such yews do exist in British churchyards, but investigations by the Ancient Yew Group (AYG) show that while the myths surrounding them are many, pre-Christian yews themselves are relatively few". To add to the speculation, it is said that one reason for yew trees being planted in churchyards is because they thrived on corpses and supplied excellent wood for making bows (Chandler, 1992). Whatever the truth is, churchyards have been a good source of trees for the RBGE conservation hedge and have provided a host of fascinating stories.

Heritage yews under threat

Not only are native yew habitats across the natural range of *Taxus baccata* under threat but so are heritage yew trees, hence the importance of including them in the conservation hedge. According to Tim Hills (2005), one of the founders of the Ancient Yew Group, 200 lost yew sites have been recorded on their database (Ancient Yew Group, 2012–2018). These losses have a variety of causes, the most common being over-reaction to health and safety concerns, but some have been vandalised by lighting fires in the hollow trunks (Bevan-Jones, 2002; Hills, 2005) and others have been lost in storms (Moir *et al*., 2013). Ten per cent of the large yew trees previously recorded in churchyards have disappeared, the majority over the last hundred years, and churchyards account for the highest number of all recorded lost yew trees, with 223, or 79 per cent, lost (Moir *et al*., 2013).

Although Tree Preservation Orders (TPOs) afford some protection to individual trees, there is no legislation in place that gives adequate protection to heritage trees in the UK. Conservation groups such as the Ancient Tree Forum and the Woodland Trust are calling for the equivalent to Scheduled Ancient Monument status to be applied to old and historic trees. The Woodland Trust has called for:

- the creation of a new designation of 'historic tree' to protect Ancient trees from development pressure,

- changes to be made to Tree Preservation Order legislation, so that dying and dead Ancient trees have greater protection,
- Ancient trees to be identified and conserved throughout the UK Biodiversity Action Plan.

The Conservation Foundation has made significant progress in helping to preserve historic yew trees through its campaign 'We Love Yew', launched by the Conservation Foundation in 2015 and supported by the Heritage Lottery Fund (Rab, 2015). The campaign gives financial support for maintenance work on old yews, along with guidance on their management and propagates from trees that were growing as far back as the 13th century, distributing them to communities and churches.

Heritage yews for the RBGE conservation hedge

Not surprisingly, the shortlist of heritage trees for the RBGE conservation hedge included the Fortingall Churchyard Yew from Perthshire (Fig. 4), which is frequently claimed to be 5,000 years of age but perhaps best considered somewhere between 1,500 and 3,000 (Bevan-Jones, 2002). Whatever its exact age, it is one of the oldest trees ever

Fig. 4 The Fortingall Yew in Perthshire is one of 18 yew trees from Scotland planted in the RBGE conservation yew hedge. It is thought to be the oldest tree in Europe. Photo: T. Christian.

recorded in the British Isles and reputed to be the oldest tree in Europe. Of the Welsh yews, cuttings were taken from some extraordinary trees including that in St James's churchyard in the remote village of Nantglyn in Denbighshire, North Wales (Figs 5 & 6). This old tree has slate steps which lead up to a pulpit in its hollow centre. Legend has it that sermons were preached from the pulpit, including one by the founder of the Methodist Church, John Wesley (Stokes & Roger, 2004).

Perhaps our favourite churchyard yew is the Martindale Yew that dominates the quaint St Martin's Church situated at the head of the picturesque Martindale Valley in Cumbria. There is evidence that a church has been here since at least 1220, perhaps longer, and the yew tree is thought to be 1,300 years old (Mill, 1999). Also in Cumbria, material was collected from the famous four trees at the head of Borrowdale which are celebrated in Wordsworth's poem 'Yew Trees' (Wordsworth, 1888) and date back 1,500 years (Pankhurst *et al.*, 2015). The Ankerwycke Priory Yew, which stands in a water meadow on the flood plain of the River Thames near to Runnymede in Berkshire (Fig. 7), is also represented in the hedge. This colossal tree, estimated to be 2,000 or more years old, is believed to stand at the exact location where King John signed the Magna Carta in 1215 and where Henry VIII courted Anne Boleyn (Stokes & Roger, 2004). Although the island of Ireland has a rich documented history of old yew trees, sadly

Fig. 5 The old yew tree at St James's Parish Church in the village of Nantglyn in Wales, known as the Pulpit Yew. Photo: M. Gardner.

Fig. 6 The hollowed trunk of the Pulpit Yew has been converted into an outdoor pulpit. The founder of the Methodist Church, John Wesley, is said have preached from here. Photo: M. Gardner.

Fig. 7 The colossal Ankerwycke Yew near Wraysbury, Berkshire is estimated to be over 2,000 years old. It is said that it stands on the spot where King John signed the Magna Carta in 1215 and where Henry VIII courted Anne Boleyn. Photo: M. Gardner.

few have survived. According to Bevan-Jones (2002) many factors have conspired against the survival of the Irish trees, including fierce timber shortages. Material was collected from the original fastigiate Irish yew growing at Florence Court in County Fermanagh, now very commonly cultivated, and from the magnificent Ancient yew from the centre of the cloisters of Muckross Abbey in Co. Kerry. A full list of all the heritage trees included in the hedge can be found in Table 1 in the Appendix. Fig. 8 shows a map that indicates the collections of heritage yews that comprise the RBGE conservation hedge.

Collection protocols

Heritage yews

On obtaining the appropriate permission to collect material, all heritage yew trees were vegetatively propagated in order to obtain clones of the mother trees. Where possible epicormic growths were chosen as these root more readily than branch shoots and the resulting plants often form an apically dominant leading shoot. The cuttings were stored in Lakeland Stayfresh food storage bags, and collections made in remote parts of the British Isles were posted to RBGE so that they could be inserted as soon as possible after collection. Each tree was assigned a field number and an accession number. For each tree a voucher herbarium specimen was also collected.

Native yews

Where possible, seed collections were made from a minimum of ten plants from across a population in order to capture sufficient genetic variation. As with the heritage yew collections, each sampled tree was assigned its own field number before being given an accession number. Voucher herbarium specimens were collected from a range of trees so as to represent any morphological variation found within the population. Where the size of the population allowed, 25 individuals were sampled for DNA (for future population genetics research) by taking leaf material and storing it in silica gel. All collections were accompanied by detailed notes on the location, habitat, population size and conservation needs. In all cases collections were made in full compliance with the local legislation concerning collecting permits. In one instance, when collecting samples from a remote valley in Morocco's Middle Atlas (which represents the southern limit for *Taxus baccata*), an irregularity in the permissions was apparent. For these collections (representing a week of sampling) we self-regulated and destroyed the samples. Replacement collections were made from northern Morocco in the Rif Mountains.

NATIVE YEWS

The natural distribution of *Taxus baccata* spans 45 countries throughout most of Europe to western Asia and north Africa (Farjon & Filer, 2013). It has experienced one of the sharpest declines of all European tree species (Benham *et al*., 2016) and is in regression

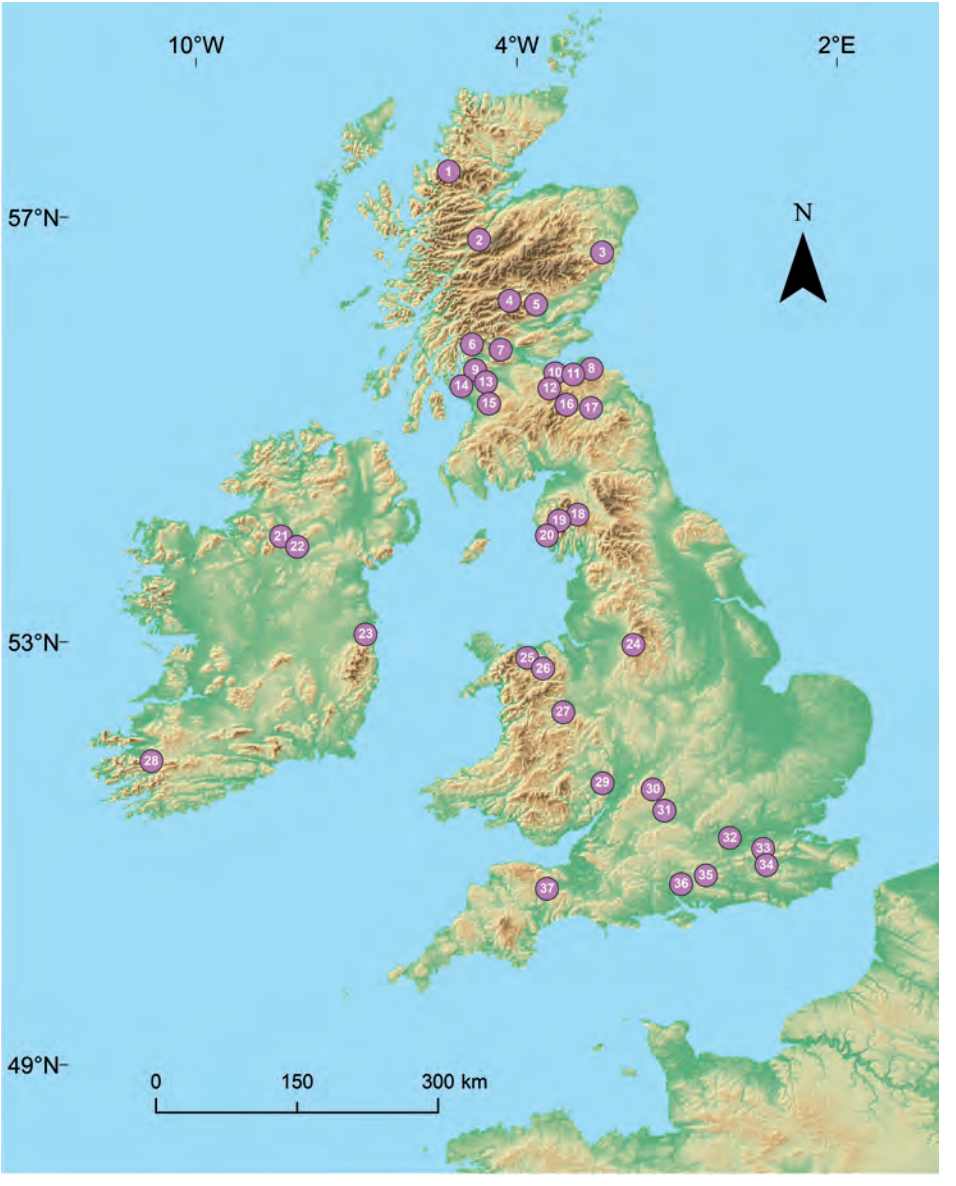

Fig. 8 The 37 locations from where the heritage yews trees were collected. Details about the locations are given in Table 1 in the Appendix. Map drawn by Vanezza Morales.

within nearly its full geographical range (García *et al*., 2000; Thomas & Polwart, 2003; Schirone *et al*., 2010). Although not globally threatened (Farjon, 2013b), it is nationally listed as threatened in many of the 45 countries where it is native (Benham *et al.*, 2016). Because of this, many of these countries, including Albania, Czech Republic, Croatia, Denmark, Georgia, Hungary, Iran, Morocco, Norway, Russia, Sweden and Ukraine,

were chosen to provide material for the conservation hedge. Another aim was to include the geographic extremities of the natural distribution for *T. baccata* and so we targeted the northernmost population in Norway, the southernmost forests in the Rif Mountains of Morocco and the westernmost forest in Ireland. To date, seed collections have been made from 17 countries. These are shown in Fig. 9 and a complete list is detailed in Table 2 in the Appendix.

Native yews under threat

The wood of the yew is not only attractive; it is also among the hardest of all softwood species because of its extremely slow growth rates. Its working characteristics are more like those of heavy hardwood than softwood (Meier, 2015). Because of these properties it has become one of the most useful and highly prized woods of all temperate trees which in turn has led to it being overexploited. One of the earliest and most widespread uses of the wood was for making longbows. There were extensive trade routes across Europe in order to feed the great demand in England for the wood, with the main trading partners Germany and Austria, where the high-altitude, slow-growing yew trees which had a tight grain were targeted (Hageneder, 2007). Such was the destruction that yew is a great rarity in the Tyrol today (Spindler, 1994).

Some of the greatest destruction occurred in the Carpathian Mountains of Eastern Europe in the 17th and 18th centuries when the local Hucul people paid taxes in yew trees, which resulted in 37,800 trees being felled (Kontny, 1937). Historically, *Taxus baccata*'s toxicity to cattle and horses led to its extermination from many woodland habitats which were used for grazing animals (Hageneder, 2007). Thomas & Polwart (2003), however, give a long list of larger mammals, including deer and rabbits, which actively browse yew trees. This dietary attraction has led to poor recruitment in *T. baccata* forest populations, especially in Denmark and Norway. In Denmark it was widespread a millennium ago but only survives today in the forest of Bad Bleiberg (Worsøe, 1985; Svenning & Magard, 1999). Nevertheless, there has been an increase in the number of trees as a result of good management which has included the thinning of the population to allow more light in, in order to encourage regeneration (Vacik *et al*., 2001). A survey of the native yew woodland in the Republic of Ireland (Cross & Lyn, 2013) reported that in Killarney National Park in Co. Kerry one enclosure, erected to protect the yew woodland from grazing pressures, had ironically trapped the deer inside resulting in considerable damage.

In some parts of its distribution, such as the Hyrcanian forest of northern Iran, forest fires pose a major threat to *Taxus baccata*. Here, in the protected areas, fire and large-scale logging have reduced the forested habitat by at least 27 per cent over a period of 30 years from 1970 to 2000 (Korori *et al.*, 2001). More recently, in December 2017, 20 ha of forest containing *T. baccata* located near the town of Amol in the province of Mazandaran were burnt (Hossein Akhani, pers. comm.). Collections of *T. baccata* from this part of Iran were targeted for the conservation hedge but permission was not

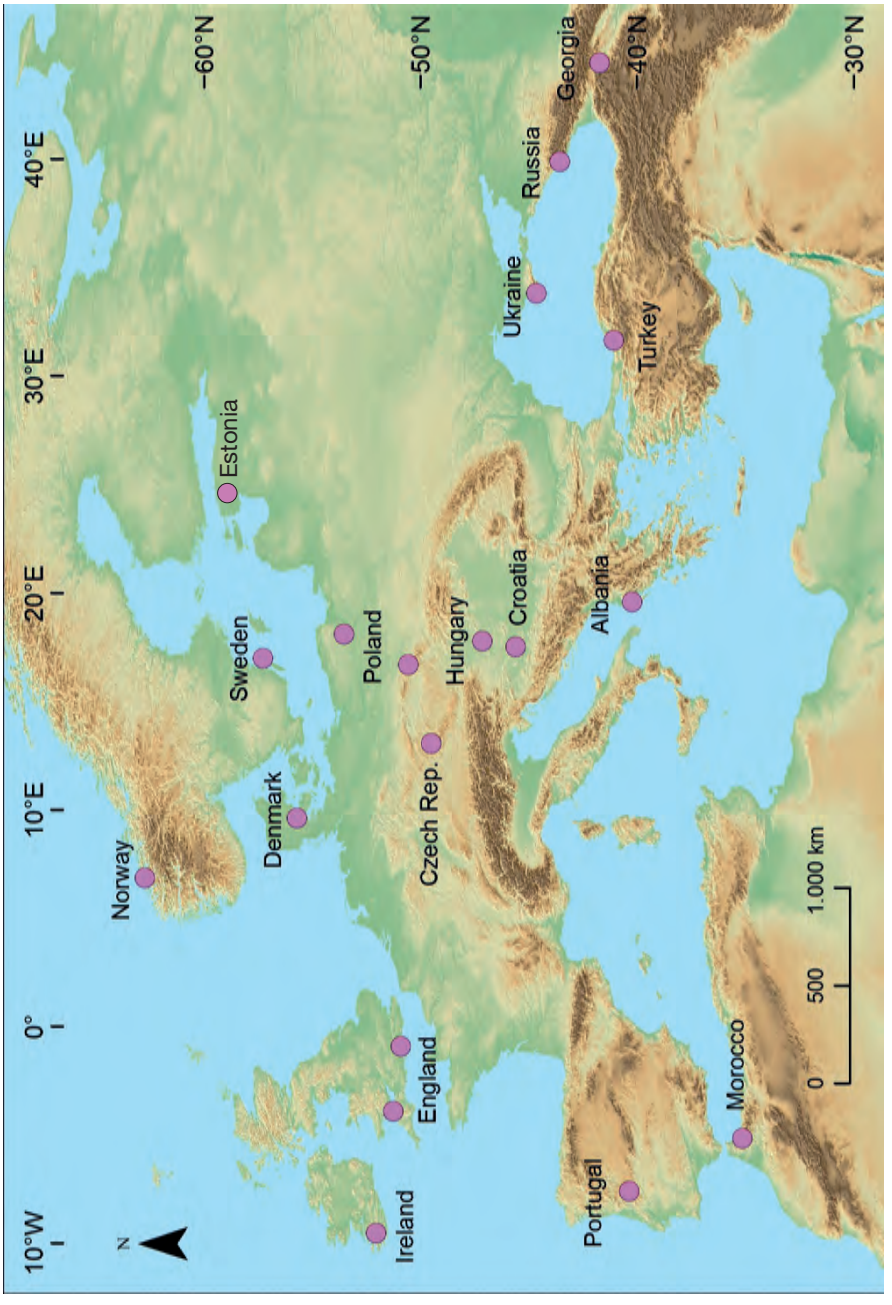

Fig. 9 Map showing 17 countries from which seed collections were made to grow trees for the hedge. Field data for the collections is given in Table 2 in the Appendix. Map drawn by Vanezza Morales.

forthcoming. In mountainous areas of the Mediterranean region, where the risk of fire is even more prevalent, *T. baccata* has been much depleted, especially in Portugal's Serra da Estrela national park, the country's most fire-prone mountain (Connor *et al.*, 2012). Serra da Estrela was a target site for inclusion in the RBGE conservation hedge; here a subpopulation of only 40 to 50 mature trees – all that remains as a result of repeated fires over recent years – were sampled (Alexandre Silva, pers. comm.).

An additional pressure has been put on *Taxus* populations in recent decades since the cancer drug Paclitaxel was first isolated from the bark of the yew tree. This has led to uncontrolled harvesting of all *Taxus* species in order to supply global demand, although from the authors' observations *Taxus baccata* is perhaps less at risk than other species.

Kingley Vale – Britain's largest native population

Past destruction of *Taxus baccata* in the British Isles is well documented in the famous forest on the chalk downland slopes of Kingley Vale in West Sussex. Prior to 1900 the forest area was much more extensive but many trees were removed in order to extend the surrounding agricultural land, and during World War II many older trees were blown up by the army during military manoeuvres (Williamson, 1975). As a result almost all the yews that remain are less than 200 years old (Bevan-Jones, 2002). Kingley Vale is considered one of the finest examples of yew forest in western Europe and the protection given by the Natural Nature Reserve should help to preserve this important 160 ha site for the long-term future. The seventy-two genotypes (from seven mother trees) collected from Kingley Vale and planted at RBGE will make an important contribution towards safeguarding against further genetic erosion.

Hedges could be seen as a high-risk strategy for conservation, acting as effective conduits for the spread of harmful pathogens. To counter this, our policy has been to duplicate the genetic material held in several hedges located in a geographically wide network. To this end surplus plants from the propagation of the yews for the conservation hedge at RBGE have been used to plant a second hedge at the property of Janey and Barry Lambie at Woodlands Stables in Blairgowrie, Perthshire. This hedge, which is 100 m long and contains 183 trees, initially suffered severe grazing by local roe deer but has now grown back. It is expected to double in length with the use of additional surplus material from the RBGE hedge in the future.

Other conservation hedges

Further opportunities have arisen to plant more conservation hedges at RBGE and other gardens which form part of the network of 'safe sites' for the ICCP. Three hedges are at different stages of development using the threatened Chilean endemic *Prumnopitys andina* (Chilean plum yew). This species has been the subject of field collections since 2003, when RBGE collaborated with the Universidad Austral de Chile (UACh)

in Valdivia on a Darwin Initiative project concerning the conservation of threatened plants in south and central Chile. This project resulted in the publication of *Plantas Amenazadas del Centro-Sur de Chile: Distribución, Conservación y Propagación* (Hechenleitner *et al.*, 2005). As part of the field work, seed was sampled from all eight populations of *Prumnopitys andina*. Additional sampling from these and two newly discovered populations (as the result of RBGE field work in 2017) has continued to the present day. The composition of these hedges and the populations can be seen in Tables 3 & 4 in the Appendix. *P. andina* has an IUCN conservation category of Vulnerable (Gardner, 2013), as it is becoming increasingly threatened due to flooding of Andean valleys as a result of the construction of hydroelectric schemes. For example, the San Fabian population which, as part of a UNESCO designated area, even has protection, is under immediate threat from a planned hydroelectric scheme. If this dam goes ahead then 1,000 old-growth trees of *P. andina* will be lost. The valley has been the focus of many RBGE seed-collecting visits and currently 192 genotypes are represented in conservation hedges (Fig. 10).

In 2016, 151 plants of *Saxegothaea conspicua* were planted in a hedge that surrounds the newly rebuilt Botanic Cottage. To our knowledge this is the first time that *S. conspicua* has been used as a hedging plant. The hedge comprises fifty-nine genotypes

Fig. 10 The *Prumnopitys andina* hedge in the RBGE nursery contains 110 plants from 5 different Chilean provenances. Photo: M. Gardner.

from five accessions collected from Reserva Biológica Huilo Huilo in Chile's Los Ríos Region.

Another hedge planted close to the Botanic Cottage (in 2017) contains 85 plants of *Xanthocyparis vietnamensis.* These plants originate from the ICCP Darwin Initiative Project in Vietnam when, in conjunction with the Central Forest Seed Company of Vietnam (CFSC), cuttings were sent to Edinburgh (Christian, 2012). These cuttings comprised 32 unique genotypes originating from Háng Tong Trong and Hang Co Mountain in the Hà Giang Province. *X. vietnamensis*, which was first discovered in 2002, is a Critically Endangered conifer (Nguyen, 2004; Nguyen & Thomas, 2004). The hedge contains 18 of the 32 genotypes. Again, to our knowledge this is the first time that this species has been used as a hedge.

CONCLUSIONS

Hedges can play an invaluable role in the *ex situ* conservation of biological resources and should be considered as an effective tool in the armoury for those charged with conserving threatened plant species. For example, save for some species of the Pinaceae and Araucariaceae, most of the 29 Critically Endangered conifer species could be effectively cultivated in hedges. Such a policy is being actively encouraged by the ICCP through the IUCN Conifer Specialist Group. One of the most compelling arguments for using hedges for storing genetic material of threatened plant species is that they are space-efficient, acting rather as compactor units of genetic information.

Most botanic gardens already maintain hedges largely for utilitarian purposes. Replacement of these hedges with wild-sourced genetic material of conservation importance would result in an exponential increase in the number of genotypes of threatened plant species being held by botanic gardens. Of course, such hedges should not necessarily be restricted to botanical gardens – any public space with a degree of longevity could be utilised. We would even suggest that hedge mazes should be considered. Not only do these have the potential of providing significant space for the inclusion of many genotypes but they can also act as vehicles to help communicate conservation stories through imaginative interpretation.

Botanic gardens should never lose sight of their main responsibility, which is to integrate *ex* with *in situ* conservation. The plant collections under their care need to be maintained and curated so that they are fit for purpose and therefore poised to make the ultimate contribution – to support population-level restoration in the wild. We believe that the conservation hedge model, with its capacity to hold a large number of genotypes, is better placed than the small number of individuals that are usually representative of a species in botanic gardens. We are living in a golden era for accessing wild genetic resources from around the world. This gives us the opportunity to help preserve the great range of wild traits that have been captured in our sampling, which in turn helps to sustain the evolutionary potential of each plant species. Importantly, the ICCP's network of widely dispersed 'safe sites' has the capacity for replicating and

adding new genotypes – we are avoiding putting all our eggs (plants) in one basket (hedge)!

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APPENDIX

SCOTLAND		No. on map (Fig. 8)
Broich House (Stirlingshire)	Widely layered branches 120 m round; girth of 3.87 m at 1.2 m. Described in 1839 as "one of the finest yew trees in Scotland". At the time it was said to be c. 300 years old.	7
Colinton Hall (Midlothian)**	Robert Louis Stevenson, author of *Treasure Island*, is believed to have played on the branches of this old yew tree when he spent part of his childhood living in the house with his grandfather.	10
Craigends (Renfrewshire)	An enormous male tree which has layered over a large area. The massive central trunk has a girth of over 8 m at ground level. The main uprights have died back and others have fallen horizontally away from the trunk, increasing the tree's range. Layers continue to advance along the riverbank due to the low level of disturbance.	13
Crathes Castle (Aberdeenshire)	Two trees: a topiary specimen which is one of the oldest plantings at this site and a very upright single-stemmed large tree.	3
Dryburgh Abbey (Borders)**	This tree was supposedly planted by monks in 1136, predating the abbey and making it nearly 900 years old.	17
Dundonnell House (Wester Ross)	Measuring 15 x 15 m, this tree is thought to be the most northerly large and ancient tree of *Taxus baccata* in the British Isles.	1
Dunkeld Cathedral (Perthshire)	A large male tree 20 m tall, possibly planted in connection with the building of Dunkeld Cathedral.	5
Finlaystone House (Renfrewshire)**	The 'John Knox Yew', named after the famous religious reformer who was supposed to have given his first sermon under this tree.	9
Fortingall Church (Perth & Kinross)	At 1,500–3,000 years old, this is thought to be the oldest tree in Europe.	4
Great Fraser (Highland)**	Impressive multi-branched tree thought to be the gathering place for the Fraser Clan, where before a battle they would put a sprig of yew in their bonnets.	2
Kelburn Castle (Ayrshire)**	One of two trees said to be more than 1,000 years old, making it older than the castle.	14
Loudon Castle (Ayrshire)**	A very large tree which lost half of its canopy when extensions were made to the nearby castle. Large branches ascend from the trunk from a height of about 3 m then curve down towards the ground, with some layering.	15
Malleny Garden (Midlothian)*	One of 'four disciples' thought to be nearly 400 years old. There were once twelve, but the eight similar trees were felled in 1961.	12
Ormiston Hall (East Lothian)	One of two enormous spreading female trees believed to be up to 1,000 years old with many branches reaching down to the ground, layering and forming a secondary ring of trees.	11

Table 1 *Taxus baccata* provenance data of cuttings made from cultivated trees. Numbers attributed to each collection correspond to numbers shown on Fig. 8 indicating the location of each collection.

Robert the Bruce (Argyll & Bute)**	Heavily pruned, squat Veteran tree with a girth of 6.1 m. Legend has it that Robert the Bruce took shelter under its canopy from pursuing enemies.	6
Traquair House (Scottish Borders)	One of four trees estimated at 400 years old or more and thought to be remnants from the Ettrick Forest which used to surround the house in medieval times.	16
Whittingehame (East Lothian)**	A remarkable example of a layering yew covering 0.5 ha, which has historical links with Mary, Queen of Scots.	8
ENGLAND, WALES & NORTHERN IRELAND		
Ankerwycke Priory (Berkshire)	A colossal tree estimated at 2,000 years old or more. It is believed to be planted in the location where King John signed the Magna Carta in 1215 and where Henry VIII courted Anne Boleyn.	32
Ashbrittle (Somerset) St John the Baptist Church	Consists of a central stem surrounded by six others which lean outwards. These individual trunks are up to 4.8 m in girth.	37
Bampton (Devon) Saint Mary's Church	One of two trees thought to have been planted between 1483 and 1485. The trunks are encased in a stone jacket to prevent cattle from grazing the foliage and being poisoned.	31
Borrowdale (Cumbria)	William Wordsworth was so impressed by the trees and the surrounding landscape that he wrote a poem called 'Yew Trees' in which he described them as the 'Fraternal Four' (now only three due to one being uprooted in a storm). These trees are at least 1,500 years old.	19
Buttington (Powys) All Saints' Church	A completely hollow tree with a circumference of 8 m, dated 893.	27
Crom Castle (Co. Fermanagh)	One of a pair of large old yews in the gardens of Crom Castle, said to be older than the castle and possibly 800 years old. From the base, the trunks are very contorted and twisted, with a large number of limbs protruding and in some cases lying almost along the ground.	22
Crowhurst (Surrey) St George's Church	A tree believed to be at least 1,000–1,500 years old.	34
Down House (Kent)	Former home of the naturalist Charles Darwin. As a child, Darwin used to swing from the branches of this old tree which has two distinct sides with a large gap between but joined above at about 2.5 m.	33
Florence Court (Co. Fermanagh)	In 1767, a local farmer, George Willis, collected two yew saplings from the slopes of Cuilcagh mountain near Florence Court. The saplings grew into the now familiar fastigiate form known as the Irish yew (*Taxus baccata* 'Fastigiata').	21
Llangernyw (Conway) Saint Digain's Church	This very fragmented tree is thought to be one of the oldest yews in Wales.	25
Martindale (Cumbria)** St Martin's Church	This massive Veteran*** tree dominates the churchyard of St Martin's 'old church' and is one of the finest settings for any churchyard yew. It is estimated to be about 1,000 years old.	18
Much Marcle (Herefordshire) St Bartholomew's Church	An impressive tree with a hollow centre (with seating) thought to be at least 1,500 years old.	29

Table 1 (*continued*)

Muncaster Castle (Cumbria)**	Twin-trunked male tree measuring 20 m with a diameter of 2 m at breast height. In the church cemetery within the cultivated grounds of Muncaster Castle, on top of an ancient burial mound.	20
Nantglyn (Denbighshire) St James's Parish Church	Known as the 'Pulpit Yew' because the hollowed trunk has been converted into an outdoor pulpit, from which sermons have been preached, including one, rumour has it, by the founder of the Methodist Church, John Wesley.	26
Selborne (Hampshire) St Mary's Church	This massive tree over 16 m tall and with a girth of 8 m blew down in a gale on 25 January 1990. The decaying stumps still remain today but a clone from this tree has now been planted back in the churchyard. Our material for the hedge came from Bedgebury National Pinetum.	35
Stow-on-the-Wold (Gloucestershire) St Edward's Church	Two Notable*** yew trees which seem to embrace the main entrance to the church.	30
Taxal* (Derbyshire)** St James's Church	A hollow horseshoe shell; its base is hidden inside a low wall.	24
Twyford (Hampshire) St Mary's Church	A tree only about 5 m tall which has been trimmed into a mushroom shape. The constricting effect of the seating around its girth has caused the roots to bulge in a dramatic manner.	36
IRELAND		
Glasnevin Botanic Garden, Dublin	*Taxus baccata* 'Fructo-luteo'. This distinctive yellow-fruiting form originated in Ireland when it was first discovered in about 1817 on the demesne of the Bishop of Kildare at Glasnevin near Dublin.	23
Muckross Abbey (Co. Kerry)**	Planted in the centre of the claustrophobic cloister of the abbey. The trunk is notable for its spiral shape. It is said to be at least as old as the abbey (which dates from 1448) or older if the theory is true that the abbey was built around an existing tree.	28

Table 1 (*continued*)

* The name Taxal, from *tak* (Middle English), meaning a lease or tenure, and *halh* (Anglian), referring to a nook of land, suggests that there may not be any connection between the yew genus name *Taxus* (from the Greek for 'toxin') and the place name Taxal.
** Also planted at the Woodland Stables, Blairgowrie.
*** Classification of yew ages: Ancient, 800 years old and over; Veteran, over 500 years old; Notable, over 300 years old. Extraordinary are trees which are so ancient that it is impossible to assign an age to them.

Country and location	Field data	RBGE		Blairgowrie	
		Accessions	Genotypes	Accessions	Genotypes
Albania Prefecktora Vlore, Llogara National Park, Mali i Qorres	Sample from only five trees seen (the older ones cut and badly mutilated). Apparently several hundred small trees nearby. Probably the only location left in Albania.	4	55	5	16
Croatia Pozega-Slavonia, Papuk Mountain (Papuk Geopark), Mali Debeljak	A small forest at 690 m asl of only 20 trees on a north-facing slope in dense *Fagus sylvatica* forests with *Abies alba*. Trees range in size from 8 to 15 m tall.	6	37		
Czech Republic Domažlice District, Mt Netreb	A population of about 200 mature individuals ranging from 300 to 700 years old. This is the smallest of about four populations in the Czech Republic.	7	86		
Denmark Vejle, Munkebjerg	A site of around 3 ha which, together with Marselisborg, makes up a 13 ha population – the only one in Denmark. Population increasing.	12	73	9	91
England West Sussex, Kingley Vale National Nature Reserve	A 160 ha Site of Special Scientific Interest which is the largest yew woodland in the British Isles.	7	72		
England North Devon, Martinhoe, West Woody Bay to Hollow Combe	Population estimated to contain around 200 individuals scattered along a 7 km stretch of coast from Lee Abbey to Trentishoe. In the west it occurs in *Quercus petraea* dominated woodland and in the east on open rocky slopes which are goat-grazed. Seed sampled from western end of population.	7	69		
Estonia Hiiumaa island, Takhuna Peninsula, Takhuna Nature Reserve (forming part of the Hiiumaa Biosphere Reserve)	Population contains around 400 mature trees (out of a total Estonian population of c. 2,000) covering an area of c. 50km² with much regeneration. Fresh water swamp, mixed forest on calcareous gravels dominated by *Picea abies* and some *Pinus sylvestris* on the driest areas.	Seed collected from 11 trees, germinated successfully but all died within their first year.			
Georgia Kakheti, Batsara-Babaneuri Reserve	A 240 ha area of *Taxus baccata* (one of the largest in the world) with many old trees between 500 and 1,000 years old.	9	75	7	38
Georgia Kartlei, Borjomi-Kharagauli National Park	Large population spread through mature *Picea orientalis* woodland, 7–8 m tall, 80 cm diameter. Parts of forest destroyed in 2008 conflict.	13	83	1	22
Georgia Tusheti, foothills of Kakheti range, Aragvi River gorge	Eleven very old trees (c. 1,000 years old) on edge of mixed deciduous forest with *Fagus orientalis*. Limestone.	3	25	2	7

Table 2 *Taxus baccata* provenance data of seed collections from natural populations. See also Fig. 9.

Country and location	Field data	RBGE		Blairgowrie	
		Accessions	Genotypes	Accessions	Genotypes
Hungary Veszprém Co. Bakony, Mt Montis, Miklóspál	One of only two locations for yew in Hungary and at 267 ha the largest in Central Europe.	7	21	2	2
Iran	Caspian Hyrcanian mixed forests.	Material yet to be collected			
Ireland County Kerry, Killarney National Park, Reenadinna wood	One of six native yew woodlands in Ireland covering an area of 25 ha. Forms very dense woodland mostly of yew but shows little regeneration.	7	71		
Morocco Rif Mountains, Chefchaouen Province, Parc National Talassemtane, base of Jebel Bousliman	A localised population of up to 100 individuals of mainly young trees. Morocco is the southernmost country for the distribution of *Taxus baccata* with the High Atlas being the most southern locations on M'Goun and in the Gorges de l'Ak-ka n'Tazert where a few old mutilated yew trees survive (Romo *et al.*, 2017).	Plants at seedling stage and due for planting in 2021/22			
Norway Otterøya island, Midsund Kommune	The world's northernmost native population with 23 individuals along a narrow strip of forest (13 seed sampled). Mostly occurring on south-facing slopes 2–10 m asl.	9	68	7	10
Poland Dolnoslaskie, Sudety Mountains, Cisowa Góra	Mixed forest on gently sloping ground with moist soils. Dominated by *Quercus petraea*, *Abies alba*, *Picea abies* and *Fagus sylvatica*. Population extending to c. 18.5 ha containing 757 mature individuals.	14	80	3	17
Poland Kujawsko-Pomorskie, Wierzchlas	Dense *Tilia cordata* forest on flat ground. Understorey dominated by *Taxus baccata* and *Corylus avellana.* Mature specimens of *Taxus baccata* number 3,500, distributed across c. 36 ha.	14	97	5	30
Portugal Município Manteigas, Serra da Estrela Natural Park, São Pedro. Barroca do teixo (Zêzere valley) close to the Río Barroqueira.	The largest group of naturally occurring *Taxus* but a highly fragmented population, estimated to be between 40 and 50 mature individuals. Fire is the main threat but some trees have been cut. No regeneration has been recorded.	5	28		
Russia Krasnodar Territory, Lazarevsky District, Sochi National Park	A very large population covering c. 300 ha with many old-growth trees up to 1,000 years old.	5	23		

Table 2 (*continued*)

Country and location	Field data	RBGE		Blairgowrie	
		Accessions	Genotypes	Accessions	Genotypes
Sweden Öland island, Skaftekarr, the Idegransreservatet in Boda Ecopark	In coniferous forest on flat, moist ground with mature *Picea abies* and *Pinus sylvestris*. *Taxus* is dominant in the understorey, sometimes layering and suckering to form impenetrable masses. Threatened by invasive species.	8	63	1	1
Turkey Zonguldak Alapli Yew Forest Reserve, Zonguldak Province	A small, remnant forest of about 100 old-growth trees. One of these is said to be the oldest tree in Turkey and is thought to be more than 2,000 years old.	6 accessions. Plants at seedling stage and due for planting in 2021/22			
Ukraine (Crimea) Chatyr-Dag Mountain, Crimea Grand Canyon, Auzan-Uzen River	In the Crimea yew is relatively common with an estimated 57 stands (Pridnya, 2002), often found in scattered small populations.	6	45	1	1

Table 2 (*continued*)

Planting site	Planting date	Wild collection site						Genotypes (+ repropagations)
		Corral de Salas	Fundo Los Ciervos	Los Lleques	Alto Bíobío	P.N. Conguillío Laguna Verde	San Fabián de Alico	Total
RBGE Nursery	2008 (E17) & 2018 (E14)	15	20 (+43)	5 (+5)	9 (+9)	–	4	53 (+57)
RBGE Gateway	2009 (BG4)	10	14	5	2	–	6	37
Oxford BG, Harcourt Arboretum	2017	–	–	4	–	3	124	131
Mount Stewart, Northern Ireland	2015	–	3	–	55	–		58
Ballyedmond Garden	2016	9	14	5	3	5	–	36
		34	51 (+43)	19 (+5)	69 (+9)	8	134	315 (+57)

Table 3 Locations of *Prumnopitys andina* hedges, provenance details and number of genotypes (+ asexual repropagations via cuttings).

Site name	Region	Location	Population size
Corral de Salas	VII Maule	Sector Quebrada Ballical, road from Currillinque to Corral de Salas.	About 100 mature trees
Fundo Los Ciervos	VIII Bíobío	Fundo Los Ciervos, passing into El Toro hydroelectric power station and crossing the Río Polcura	Very large population of over 2,000 mature trees along a 25 km stretch adjacent to the river
Fundo Los Lleques	VIII Bíobío	Near Pinto, Fundo Los Lleuques	About 150 trees over an area of around 4–5 ha
Alto Bíobío	VIII Bíobío	Alto Bíobío, adjacent to the Río Quenco	Large population of at least 2,000 trees extending discontinuously for around 25 km along the bottom of the valley
Melipeuco	IX Araucanía	Melipeuco, Parque Nacional Conguillío	Population of less than 100 individuals
San Fabián de Alico	VII Maule	San Fabián de Alico, Valley of the Río de Los Sauces	In excess of 1,000 old-growth trees

Table 4 Provenance and population sizes of *Prumnopitys andina* used in the conservation hedge.