Poor performance of broadleaf plantations and possible remedial silvicultural systems – a review

Hawe, J.[a*] and Short, I.[b]

Abstract
Over the last two decades planting of broadleaves has been part of forest policy. In addition to the provision of a range of ecosystem services, it is intended that this resource will have a direct economic stimulus through the supply of quality hardwood. A number of challenges must be met in order to achieve this objective, particularly as current observations would indicate that many first rotation broadleaf plantations comprise a relatively high proportion of poor quality stems. A literature review has been carried out on the probable causes of poor performance in broadleaf crops. Silvicultural systems to rehabilitate poor quality stands are discussed. Subsequent papers will deal with these silvicultural systems in more detail.

Keywords: *Broadleaves, silviculture, remedial action, plantation, stem quality, stresses.*

Introduction

This paper provides an introduction to the work of the COFORD/Teagasc/UCD B-SilvRD project with particular regard to the rehabilitation of poor quality broadleaf crops. This review discusses the possible causes of poor performance in broadleaf plantations. Prescriptions and silvicultural systems which may increase quality and performance are described.

Background

The national afforestation programme has resulted in significant increases in broadleaved planting over the past two decades:

- Since 1982 over 55,000 ha of broadleaf woodland have been established (Hendrick and Nevins 2003);
- In 1998 broadleaf planting accounted for 16% of all new planting; by 2010 it had more than doubled to 38% (Forest Service 2011).

This programme represents a considerable increase to the small national broadleaf woodland resource. In time this resource should provide a number of ecosystem services and contribute to the development of an indigenous hardwood timber resource. However, experience to date has shown that the establishment of quality broadleaves on first rotation green-field sites is challenging. Exposure, soil conditions, low intra-species competition due to low stocking densities and weed competition are all aspects of the open, green-field environment which present particular impediments

[a] Sylviron Ltd., Appleyard, Turlough, Castlebar, Co. Mayo.
[b] Broadleaf Silviculture Research Officer, Teagasc Forestry Development Department, Ashtown Food Research Centre, Dublin 15.
[*] Corresponding author: jerry@sylviron.com

to crop quality (Evans 1984, Savill 2003). The potential pitfalls of species selection, provenance selection and availability, ground preparation and a range of post-planting biotic and abiotic challenges are additional issues. Therefore, it is not surprising that first rotation broadleaf woodlands in Ireland contain a high proportion of trees with poor quality stems.

The causes of poor performance, with particular reference to Irish forest conditions, are reviewed in this paper. Silvicultural options that may improve the quality of these broadleaf plantations are also presented.

Species choice

Species choice is a fundamental element of successful plantation establishment and quality timber production. Information on broadleaved species site requirements is available for the UK and Ireland (Anderson 1961, Evans 1984, Hart 1991, Joyce et al. 1998, Pyatt et al. 2001, Horgan et al. 2003). Most broadleaves used for commercial timber production are more exacting in their site demands than the main commercial conifer species (Savill 2003).

The most recent data show that ash is the most widely planted broadleaf species in Ireland (Forest Service 2011). Ash grows best on soils with a pH 5.5 and above (Evans 1984). It forms a component of 13 of the 20 major native broadleaf woodland types in Ireland (Cross et al. 2010). Its inherent vigour and ability to colonise a wide range of sites may in some part contribute to its popularity. However, in the context of commercial timber production, ash is extremely exacting as to site conditions (Hart 1991, Horgan et al. 2003) such that there is very little room for error (Joyce et al. 1998). The best development of ash is on deep, moist, freely draining and fertile soils of about neutral pH. Such good sites are not widely available for planting and attempting to grow high quality ash on other site types is unlikely to be successful (Evans 1984).

In contrast to ash and other broadleaved species such as beech, sycamore and wild cherry, oak is relatively indifferent to site conditions. Joyce et al. (1998) record good, or at least moderate, growth of oak on most of the major soil types, ranging from upland podzols/brown podzolics to brown earths, grey-brown podzolics, and gleys. It may therefore be possible to produce economic oak crops over a wide range of site conditions (Savill 2003).

Few broadleaved species are suitable for growing as pure crops (Savill 2003). Species such as sycamore, cherry or Spanish chestnut perform better in mixtures or as a minor component of broadleaved woodland (Evans 1984, Hart 1991). Other species, such as birch and alder are becoming more widely considered for commercial planting (O'Dowd 2004, Fennessy 2004). These species may be better suited to some of the environmental challenges, outlined above, inherent in afforestation (Worrell 1999, Horgan et al. 2003).

Provenance

Provenance is potentially as important for broadleaved crop quality as species selection. For Britain, Hubert and Cundall (2006) comment: "Many broadleaved trees have been planted over recent decades with relatively little attention being paid to the provenance or origin of the seed used. Yet planting the incorrect provenance can result in the grower struggling with establishment over many years and, in some cases, total failure of the planting stock". Past examples of inappropriate provenance use can be found in relation to ash. The use of *Fraxinus angustifolia* Vahl. and its hybrids has not only resulted in poor quality, uneconomic plantations, but also threatens the integrity of the native ash gene pool (Cahalane et al. 2007). This situation has required considerable State investment in mechanisms to eradicate this species.

Based on UK trials, Hubert and Cundall (2006) make the following recommendations on seed sources, which have some application in Ireland:

- Seed stock from eastern continental Europe is usually poorly adapted to Britain in terms of growth rate and reduced survival. It may also be poorly adapted in terms of phenology and resistance to foliar disease. It should not be planted in Britain.
- Southward movement of genetic material within Britain (of the order of hundreds of kilometres) is likely to lead to a loss of vigour compared with local material.
- Northward movement of genetic material within Britain (of the order of hundreds of kilometres) may result in a gain in vigour compared to local sources, but the long-term implications are not known. Such material may prove to be more susceptible to late spring frosts or early autumn frosts which may not be fatal but may lead to poor stem form due to forking. Low temperatures in exceptionally cold winters that may be experienced once or twice in a rotation may be more seriously damaging.

Figure 1: *Birch seedlings of Norwegian and French provenance raised in the same UK nursery. The buds of seedlings on the right (French) have flushed, while those on left (Norwegian) have not, demonstrating the impact of provenance on an attribute that may affect survival after planting (Hubert and Cundall 2006).*

Adaption to local environmental conditions is fundamental to good vigour and growth habit. “In practice the most important improvement occurs because the new crop is well-adapted to the site, adaptation being a highly heritable character” (Zobel and Talbert 1984, p. 270). “Characters affecting timber quality such as straightness of stem or good natural pruning of branches are moderately heritable, so they can be improved…” (Matthews 1989). This suggests that a geographically appropriate and well-adapted native provenance (if available) may be a better choice than one which displays favourable phenotypic characteristics in its native habitat, such as stem form, but which originates from a geographically inappropriate area, particularly where the species displays a high degree of phenotypic plasticity.

The movement of Finnish birch provides a good example, whereby material that grows well in Finland has performed poorly in the UK/Ireland due to the species’ response to local environmental conditions (high phenotypic plasticity). With reference to the recommendations made by Hubert and Cundall (2006) for Britain, birch from Finland, or any area with a continental climate, may not be suitable for planting in Ireland.

Native provenances have evolved and adapted over long time periods and may be considered best suited to local conditions (Boshier and Stewart 2005, Little et al. 2009). However, as Felton et al. (2006) have shown, provenances from neighbouring localities can differ substantially in their performance. Native provenances are preferred for the establishment of commercial broadleaf crops, as reflected in afforestation guidelines with “native Irish” or “registered Irish” material being the first preference in most cases (Forest Service 2003) and Fennessy et al. (2007) highlight the importance of producing quality broadleaf planting stock from home collected seed. However, intermittent mast years and variable levels of seed production impact on native planting stock availability. The expansion of broadleaved planting in Ireland, as outlined previously, has resulted in levels of demand that exceed the capacity to produce native stock and the use of continental European material is widespread in broadleaved afforestation.

With reference to the early expansion of broadleaf planting in the 1990s, Joyce et al. (1998) point out that: “In recent years the rapid increase in the afforestation programme has resulted in demand for native oak seed far exceeding supply”. With increases in broadleaf planting generally, including the additional demands on native provenance material from the Native Woodland Scheme, the supply of native oak has continued to be difficult (Felton et al. 2006). Mechanisms to increase the availability of good quality native Irish material may greatly support broadleaf plantation quality. Felton et al. suggest ways to achieve this, although continuing difficulties in seed stand selection are highlighted also. Fortunately however, much work has been done in relation to the establishment of native seed orchards (Thompson et al. 2009). Taking cognisance of the unintentional use of *Fraxinus angustifolia* in the earlier years of the afforestation programme, the nursery sector can now supply all ash planting stock requirements from native sources (P. Doody, pers. comm.).

Establishment practice

Site preparation

Site preparation for broadleaves should provide a well-aerated, weed free planting position, improve drainage and break up compacted layers (sometimes associated with former agricultural land), in order to facilitate root growth and penetration (Hibberd 1991, Rodwell and Patterson 1994). Rodwell and Patterson did not favour extensive mechanical cultivation in relation to native broadleaf woodland establishment, primarily for ecological reasons. Furthermore, the quality of tree establishment may also be reduced by inappropriate mounding; "care should be taken to avoid bringing up too much subsoil as this does not provide as good a growth medium as topsoil" (Bulfin 1992). Indeed, planting into heavy and/or nutrient poor subsoils may well impede early growth and delay canopy closure.

Ground preparation should provide favourable soil conditions at the planting microsite, while having minimal impact on microtopography and site access. If this is not the case then such operations may promote loss of quality and hinder necessary future management operations.

Plant handling

One of the principal causes of poor survival and slow growth of newly planted trees is damaged plants through poor plant handling (Evans 1984). Root growth potential (RGP) and long-term plant vigour may be reduced through: desiccation; root bruising and tearing; respiratory loss; overheating; nutrient loss; and/or disease outbreak; resulting from even a very brief period of poor handling (O'Reilly et al. 2002, Colombo 2006). Birch is a good example: it establishes readily from planted bare root stock but is "extraordinarily susceptible" to root damage (Worrell 1999). Whereas poor handling of susceptible species such as birch may result in widespread failures, poor handling of more robust broadleaves such as oak may still lead to loss of form, e.g. through shoot dieback (Cabral and O'Reilly 2008).

General guidelines for correct plant handling and storage are readily available (Forestry Commission 2002, Teagasc, undated). The optimum period for lifting and planting should also be observed. For example, sycamore responds better to early season planting when the seedlings RGP is high (O'Reilly et al. 2002). Fundamentally the period of time between lifting and planting should be kept to a minimum.

Planting practice also impacts on crop performance. Tobin (2003) describes the common deformities in ash root systems due to poor planting practice. While young trees do have the ability to recover, plantation vigour, health and longevity are likely to be affected.

Careful handling and storage throughout the establishment process – from nursery to planting site – is critical to good survival, vigour and stem form, and may require close supervision (Tabbush 1988).

Stocking and configuration

It is generally recommended that broadleaves should be planted at close spacing – less than 2 m apart in and between lines – where timber production is a primary objective

(Rodwell and Patterson 1994). COFORD (2002) recommended that seedlings should be planted at a sufficiently high density to restrict lateral branch (and hence knot) diameter development and to encourage height rather than lateral growth. Bulfin (1992) recommends that broadleaves be planted as close as economically possible to ensure good stem form. Although seedlings are planted at relatively high densities on sites established through the afforestation programme, stocking rates are generally lower than those achieved through successful natural regeneration, so the young plantation must grow through its first vital years effectively in a free growth state (Bulfin 2003). This early lack of competition may lead to loss of form.

The potential quality benefits of securing natural regeneration within a woodland environment are discussed later. Joyce et al. (1998) suggested that one means to increase competition is to reduce spacing within the planting lines while maintaining more open gaps between lines. This configuration has been commonplace within the afforestation programme.

One method to reduce the effects of limited stocking densities is through the use of mixtures and the integration of nurse species. The use of mixed species plantations in broadleaved silviculture will be the subject of further communication. However, it is useful to examine how inappropriate mixture configurations may negatively impact on quality.

One rehabilitation trial currently underway demonstrates the likely implications of using an inappropriate mixture configuration. In this case, three rows of oak were planted between single rows of ash. Very poor early growth in the oak – possibly attributable to poor species/provenance choice, and/or inappropriate site preparation – resulted in the oak being heavily suppressed by the ash (see Figure 2). The ash, having so much canopy space, were effectively open grown and also of very poor form. In effect, the configuration provided inappropriate competition.

Appropriate stocking and planting configurations should be used with the aim of providing sufficient intra- and inter-species competition; and critically, management interventions are needed to ensure crop trees are neither suppressed nor released too quickly.

Figure 2: *Heavily suppressed oak (background) dominated by open-grown, poorly-formed ash (foreground).*

Weed control

The statement that weeding helps plants to "survive and thrive" is particularly true of broadleaves (Evans 1984). Weed competition represents the single greatest cause of plant loss and poor growth (Bulfin 1992). Moreover, avoidable delays in reaching thicket stage through poor weed control present a longer timeframe in which open-growing conditions and low levels of competition may result in increased loss of form.

Moisture stress from weed competition reduces the growth of broadleaves (Davies 1985). Cherry, for example, can more than double its annual height and basal area increment when grown in weed free conditions. This is primarily due to favourable soil moisture conditions (Kerr and Evans 1993). However, the regular mowing of competing weeds (grass) may reduce growth to about one quarter of the growth rates achieved by trees established under weed-free conditions. This occurs mainly because mowing stimulates fresh regrowth of the grasses, thus increasing the rate of moisture loss from the soil. An entirely weed-free site or one with a substantial proportion of bare ground adjacent to individual planting positions, maintained for 2-3 years after planting (Joyce et al. 1998) is usually the best way to establish a broadleaved crop (Evans 1984).

Disease

The susceptibility of tree species to disease and pathogens can be increased due to natural stresses, e.g. drought (Desprez-Loustau et al. 2006). Certain diseases such as canker in ash and cherry (*Pseudomonas savastanoi* Gardan et al and *Pseudomonas syringae pv syringae* van Hall, respectively) are quite common in broadleaf plantations. However, their occurrence may be greatly exacerbated by poor establishment and management practice (Joyce et al. 1998). Poor species/site matching, inappropriate provenance selection, poor plant handling and incorrect pruning all represent factors which may cause physical or physiological stress. This stress can predispose trees to attack by pathogens (Schoeneweiss 1981, Wargo 1996). In a Danish study on the occurrence of ash canker, Skovsgaard et al (2010) suggest that the incidence of infection increases with reduced tree vigour related to site factors and possibly silvicultural practice.

Poorly devised monocultures may contribute to the outbreak of disease (Kelty 2006), e.g. where the species/provenance is not well adapted to the site (Larsen 1995). Widespread outbreaks of canker in cherry in Ireland may have been associated with inappropriate planting patterns and it is thought that the susceptibility of the species may be decreased within different mixture configurations (O'Reilly 2006). Pautasso et al (2005) suggest that there is a strong relationship between tree species diversity and susceptibility to fungal pathogens, and propose that mixed species forests have a better ability to buffer disturbances. Larsen (1995) outlines how we can greatly increase our forests resilience to disease through the use of well adapted species and provenances, stand structures and silvicultural systems. The importance of such "effective" silviculture is magnified by the potential additional stresses applied to plantations as a result of climate change (Ray et al. 2008, Green and Ray 2009).

Climatic factors

Exposure

Exposure is one of the principal drawbacks of growing broadleaves in an open field situation. The term combines a number of effects such as elevation, windiness and aspect (Horgan et al. 2003). Stem form of trees planted on open fields may deteriorate due to late spring frost, exposure to cold and desiccating wind (Bulfin and Radford 2000).

Exposure and elevation are closely interlinked. As elevation increases, growing conditions tend to deteriorate. Many broadleaves prefer lowland conditions and are intolerant of higher elevations (Bulfin 1992). Attempting to establish productive broadleaved high forest above 300 m will rarely be worthwhile (Evans 1984). Persistent wind on exposed sites leads to crown deformation and poor growth (Willoughby et al. 2009), a situation that may be reduced by growing broadleaves with a conifer nurse or by retaining any existing cover (Evans 1984).

Frost

Unseasonal frost is particularly damaging for young broadleaves. Late spring frost may have the worst impact, often resulting in loss of apical dominance, forking and misshapen stems (Evans 1984, Kerr and Evans 1993). Over 60% of all incidences of damage recorded by the Forest Service under the Reconstitution scheme in the mid 1990s were attributed to frost (Anon. 1998).

Frost occurrence is linked to topography. Early and late frosts occur mainly on clear still nights when air in contact with surfaces flows down slopes to collect in valleys and hollows (Hart 1991). Frost-tender species, such as ash and beech (see Table 1), should not be planted in such locations. Species choice, therefore, plays an important role in reducing potential frost damage. However, good weed control may also significantly reduce frost damage of tender species because exposed mineral soil is more efficient in the absorption of heat, which is re-radiated at night (Joyce et al. 1998).

Browsing

A number of mammal species trample, browse, fray and strip the bark of broadleaves. They include: deer (*Dama dama* L., *Cervus elaphus* L., *Cervus nippon* Temminck, *Capreolus capreolus* L.); feral goats (*Capra aegagrus hircus* L.); domestic livestock; grey squirrel (*Sciurus carolinensis* Gmelin.); hare (*Lepus timidus* L.) and rabbit (*Oryctolagus cuniculus* L.) The protection of broadleaved trees from damage by mammals is vital if high quality timber is to be grown (Kerr and Evans 1993).

Deer

A recent report commissioned by Woodlands of Ireland on *Deer and Forestry in Ireland* (Purser et al. 2009) highlighted the significant threat to broadleaf plantations from a largely uncontrolled wild deer population. Deer populations in Ireland are increasing at unsustainable rates due to a number of factors. The economic and biodiversity values of forest habitats are significantly impacted by deer and these may

Table 1: *Susceptibility to frost damage of selected broadleaved species (adapted from Evans 1984).*

Frost sensitivity	Species	
Very susceptible	Walnut	*Juglans regia* L.
	Ash	*Fraxinus excelsior* L.
	Spanish chestnut	*Castanea sativa* Mill.
	Oak	*Quercus* spp.
	Beech	*Fagus sylvatica* L.
Moderately susceptible	Sycamore	*Acer pseudoplatanus* L.
	Horse chestnut	*Aesculus hippocastanum* L.
	Some poplars	*Populus* spp.
	Red and Italian alder	*Alnus rubra* Bong. and *Alnus cordata* Desf.
Hardy	Birch	*Betula* spp.
	Hazel	*Corylus avellana* L.
	Hornbeam	*Carpinus betulus* L.
	Lime	*Tilia x europaea* L.
	Elm	*Ulmus procera* Salis.
	Most poplars	*Populus* spp.
	Common and grey alder	*Alnus glutinosa* (L.) Gaertn. and *Alnus incana* (L.) Moench.

reach catastrophic levels over the coming decade if not managed. There is no national deer management policy in Ireland and no co-ordinated system of deer population distribution or density measurement. There is no single authority with jurisdiction over the necessary components of a comprehensive deer management policy. Purser et al. (2009) concluded that the consequences of not addressing deer management would result in deteriorating conservation status of native woodland as well as a reduction in hardwood and conifer wood quality, and an inability of broadleaf woodland to regenerate, thereby compromising their future viability.

Browsing and fraying from deer have severe impacts on stem quality (see Figure 3). Protection, using fencing or tree shelters, and/or localised culling is likely to be ineffective in the medium to long term. High deer numbers are very difficult for any individual forester or grower to address in isolation. Long-term effective control requires the sort of coordinated national approach as outlined in the Woodlands of Ireland report (Purser et al. 2009).

Squirrel damage

According to Joyce et al. (1998) the grey squirrel constitutes the most serious threat to the growing of broadleaves in Ireland. Grey squirrels can cause severe damage to broadleaf crops through bark stripping. This is compounded by the species' tendency

Figure 3: *Severe fraying and browsing damage by fallow deer in a young ash plantation.*

to attack older trees – from 10 to 40 years old – which has greater financial impact on the crop (Lawton 2003). Thin-barked species, such as beech and sycamore are most susceptible to attack, to the extent that they are not recommended for planting in those parts of Ireland with high grey squirrel populations. Unfortunately certain operations which aim to promote tree vigour – such as thinning – may exacerbate attack through increased sap flow (Rooney and Hayden 2002).

Carey and Hamilton (2008) report that the grey squirrel has spread dramatically over the past 10 years and is now present in 26 out of 32 counties in Ireland. Sightings west of the river Shannon have been few but there is a real possibility that the grey squirrel will eventually penetrate into woodlands west of the river. Substantial public funds have been invested in broadleaf planting over the last two decades; much of this is now at risk because of its susceptibility to bark stripping by the grey squirrel. While beech and sycamore appeared to be the species mostly at risk, Carey and Hamilton (2008) also reported a number of oak woodlands have been attacked in recent years by grey squirrel, with up to 85% of trees being destroyed. Experience in Britain has shown that other broadleaves are also at risk, particularly when grey squirrel numbers are allowed to go unchecked.

Much like the problem associated with deer, grey squirrel damage may be very difficult to control on a site by site basis. Trapping or other preventative measures are to be encouraged; however, a collaborative approach is required to address the situation on an island-wide basis. There is some evidence to suggest that locally increasing pine marten (*Martes martes* L.) populations may be responsible for a decline in grey squirrel numbers in some areas (Carey and Hamilton 2008).

Management practices

Pruning

Pruning is considered essential if the aim is to produce good quality broadleaved stems (Bulfin 1992). Individuals of any species may require formative pruning or shaping, with oak and beech the most likely due to a lack of apical dominance (Kerr 1992). Formative pruning is carried out on young trees to improve stem form up to a height of 3 m (Bulfin 2003). It involves the removal of multiple leaders and unwanted large branches to promote the development of clear, straight stems. When carried out correctly, formative shaping can be the most effective pruning treatment (Savill 2003) although Kerr and Morgan (2006) dispute this, recommending instead that a more secure way to obtain quality improvement is to use traditional pruning after a period of canopy closure. Formative shaping simulates natural competition which causes trees to lose side branches at an early age (Bulfin 1992). The use of close spacing (> 2,500 stems ha^{-1}) and good genetic stock can significantly reduce the need for this (Savill 2003).

In Lombardy in northern Italy, a plantation of walnut and pear (*Pyrus communis* L.) had the final crop trees pruned three times per year (spring, summer and autumn) for the first 6-7 years (Short 2011). The result of such intensive treatment is that a 20-year-old, 35 cm DBH, walnut tree can be worth €1,500 – a pear tree of the same size is worth double that value. The timber quality and economic rewards for such "hands on" management are obvious.

Thinning

Thinning is carried out for a number of reasons (Savill and Evans 2004):

- To reduce stand density and hence to reduce competition, leaving the remaining trees more space for crown and root development. This promotes stem diameter growth and usable sizes are reached more quickly.
- To remove dead, dying, and diseased trees, or any others that may cause damage to the remaining healthy ones.
- To remove trees of poor form: crooked, forked, or coarse trees, so that future growth is concentrated only on the best trees.
- To provide the owner with some revenue though, if this is not possible, as in some early thinnings, in the expectation of greater returns later in the rotation.
- More occasional reasons include maintaining light beneath the canopy to encourage grass growth for grazing, for providing poles for building, or for amenity, recreational, or ecological reasons.

The removal of diseased stems is important as it will reduce the risk of further infection throughout the remaining stand and therefore delaying thinning increases this risk. It is also important that the first thinning is done in a timely manner to ensure that crop vigour is maintained. Some species, such as ash, respond poorly to thinning once their crowns have become constrained and small. Others, such as beech and sycamore, can remain responsive to thinning even after a long period (Kerr and Evans 1993).

Thinning can also involve the early selection of final crop trees in broadleaved stands. The best trees are marked when they are young and favoured in subsequent thinnings. Because some inevitably become damaged or do not grow as well as expected, it is necessary to mark, at the outset, two or three times the number that will actually form the final crop (Savill and Evans 2004). Those selected are often known as Potential Crop Trees (PCTs). Recommendations for the number of PCTs to be selected in ash stands are given in Table 2.

Short and Radford (2008) provide four criteria to be used in selecting PCTs, as follows:

1. be free from disease;
2. have relatively good stem form;
3. have relatively good vigour; and
4. be evenly distributed throughout the stand.

The assessment of a broadleaf stand and selection of PCTs using the four above criteria could indicate whether the stand is performing poorly. If the required number of PCTs cannot be selected, then an alternative silvicultural regime may be necessary. Evans (1984) and Kerr and Evans (1993) both provide decision trees to assist in choosing the best silvicultural options for managing neglected broadleaf woodland (Figure 4). One of the main deciding factors is the number of relatively good quality, evenly-spaced PCTs present. If the density is less than 300 stems ha^{-1}, then the silviculture recommended is substantially different from that which would normally be carried out. The following section outlines the silvicultural practices involved in producing good quality broadleaved stands.

Table 2: *Number of potential crop trees (PCTs) to be selected in ash as per various authors.*

Author	**Selected PCTs (stems ha^{-1})**
Short and Radford (2008)	350
Horgan et al. (2003; p. 107)	350 – 400
Mutch (1998; p. 146)	≈ 330 (≈ 5.5 m spacing)
Garfitt (1995; p. 119)	200 (2 stems per 10 m square) [a]
Blyth et al. (1987; p. 28)	300 – 400 [b]
Evans (1984; p. 53)	≈ 350
Anon. (1955; p. 13)	247 (100 stems $ac.^{-1}$) [c]
Forbes (1904; p. 136)	371 (150 stems $ac.^{-1}$)

[a] Species not provided. Inference is that the number given is for broadleaves in general managed by the "Belgian thinning" system; a form of crown thinning.

[b] Species not provided. Number is given for broadleaves in general.

[c] Number given for heavy crown thinning. No species identified.

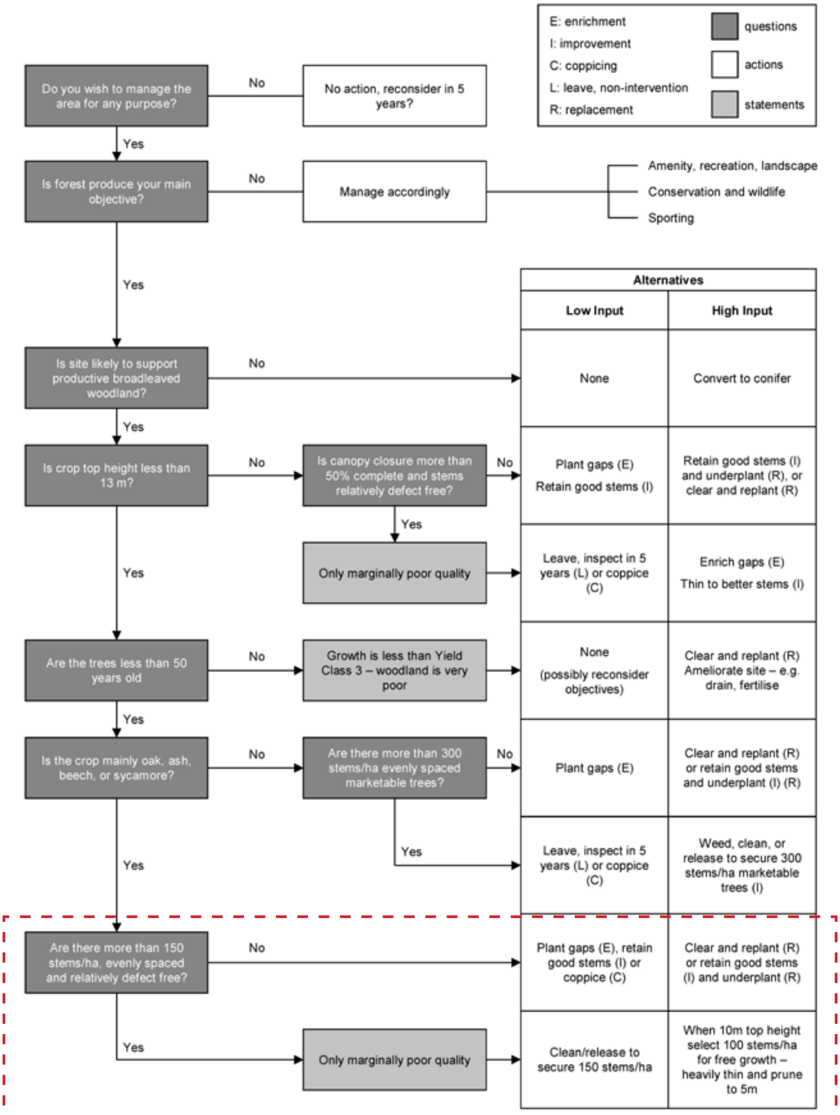

Figure 4: *Silvicultural options for managing neglected broadleaved woodland. Redrawn from Evans (1984) and Kerr and Evans (1993).*

Prescriptions and silvicultural systems to assist rehabilitation

The objective of the prescriptions and silvicultural systems outlined below is to improve the productive capacity of poorly performing broadleaved stands. Figure 4 provides some options; however, only those suggested in the highlighted decision box (red broken line) are considered here. Underplanting is one of the recommendations provided.

The microclimate of woodland is generally more conducive to tree establishment than an open-field situation. Therefore each of the systems outlined that include tree establishment maintain, to a greater or lesser extent, a proportion of canopy cover which will provide protection to the newly establishing trees and help protect them from the stresses of frost, heat, moisture stress and weed competition (Köstler 1956). This could be considered a form of a shelterwood system. The coppice-with-standards, the free-growth and the under-planting systems will be comprehensively reviewed in follow-on papers, but some of the key aspects of these systems are summarised below.

Shelterwood

High-forest systems in which an even-aged stand is established, normally by natural regeneration under a thinned overstorey, are known as shelterwood systems (Savill 2004). Shelterwood systems have advantages over clearfelling, including:

- Protection of frost-sensitive species, and protection against drought and cold winds;
- Protection of the soil from desiccation and weed colonisation;
- Less risk of soil erosion and run-off;
- Less risk of snow and storm damage with certain types of shelterwood;
- The best trees in the remaining stand can enhance their increment once the regeneration felling is carried out;
- Shelterwood systems can be regarded as aesthetically more preferable to clearfelling (Troup 1928, Matthews 1989).

Smith et al. (1997) state that a shelterwood system is superior to all others, except a selection system, with respect to protection of the site and aesthetic considerations.

Generally shelterwood systems utilise natural regeneration from seeding as the source of the new crop with, where required, supplementary planting carried out where insufficient natural regeneration has occurred (Matthews 1989). The pole-stage stands that we are considering in the context of this paper will likely be too young to produce sufficient seed to rely on a high enough level of natural regeneration to replace the stand (see Table 3). For example the best crops of ash seed come from trees between 40 and 60 years of age (Savill 1991). Therefore, underplanting in a shelterwood system is considered because it is an alternative that will maintain a relatively suitable microclimate for young trees.

There are two main shelterwood systems: uniform and group.

Uniform shelterwood system

Stands treated using the uniform shelterwood system are opened up uniformly throughout for regeneration purposes. Where natural regeneration is used, the usual

Table 3: *Seed production of broadleaved trees in Britain (Evans 1988).*

Species		Minimum seed-bearing age (years)
Alder (common)	*Alnus glutinosa* (L.) Gaertn.	15-25
Ash	*Fraxinus excelsior* L.	20-30
Beech	*Fagus sylvatica* L.	50-60
Birch	*Betula* spp.	15
Cherry	*Prunus avium* L.	10
Hornbeam	*Carpinus betulus* L.	10-30
Lime (small-leaved)	*Tilia cordata* L.	20-30
Norway maple	*Acer platanoide*s L.	25-30
Oak (pedunculate)	*Quercus robur* L.	40-50
Oak (sessile)	*Quercus petraea* L.	40-50
Spanish chestnut	*Castanea sativa* Mill.	30-40
Sycamore	*Acer pseudoplatanus* L.	25-30

method is to carry out a seeding-felling followed by secondary fellings. The seeding-felling opens the canopy in order to provide sufficient light for the short-term survival of seedlings from seed shed by the overhead trees (Troup 1928). The remaining trees are removed in one or more fellings at suitable intervals, thereby providing sufficient light for the continued survival of the seedlings (Troup 1928). The last of these secondary fellings is the final felling, which is carried out when the young crop is well established (Troup 1928). The shelterwood system requires long-term planning because, to increase the availability of seed, the stand is managed throughout its life to increase production of good quality seed. Frequent thinnings are carried out during the rotation to ensure that the future seed trees have large crowns and therefore are capable of producing a good crop of seed. The resultant trees should have long, straight stems free from branches which permit light to reach the ground and well-developed root systems so that they should be reasonably wind-firm when the stand is opened out during the seeding and secondary fellings (Troup 1928, Matthews 1989). The uniform shelterwood system was recommended by Everard (1985) as a good compromise between clearfelling and more intensive systems for UK broadleaf forestry. He also suggested that, where natural regeneration is not possible or appropriate; planting should quickly follow after the initial opening of the canopy.

Group shelterwood system

The group shelterwood system has many of the same principles as the uniform shelterwood system but differs in one major aspect: the stand is opened up in an irregular manner around groups of existing advance natural regeneration (Troup 1928, Matthews 1989). As the canopy around these groups is opened up, more favourable conditions exist for continued natural regeneration surrounding the groups. Areas where the canopy is opened up over the coming years gradually get larger until they eventually coalesce and consist solely of the new stand arising from natural regeneration. Similar to the uniform system, dense natural regeneration is required. This is unlikely to be the case for the pole-stage broadleaf stands considered here. However, both the shelterwood systems could be modified such that underplanting could be the means by which the stand is regenerated.

Underplanting

As has been alluded to above, the establishment of broadleaves on green-field sites is problematic because newly planted stock commonly experience multiple stresses, such as those resulting from exposure and aggressive grass / weed growth. When considering silvicultural systems that have potential to rehabilitate poorly performing broadleaf stands, it is prudent to take advantage of the benefits of an existing canopy. Therefore, underplanting seems to be a realistic means by which a young (10–20 years old) stand can be regenerated. Underplanting in an existing stand is common practice in continental Europe to introduce an understorey which will assist in the control of branching, including the development of epicormic branches, if a natural understorey is not already present (Kerr and Evans 1993). In Central Europe underplanting with beech has become common practice. In the 1950s and 1960s it was common practice in the UK to heavily thin oak stands and underplant with conifers to get an early return, whilst also encouraging the best of the oak to grow rapidly (Evans 1984). Underplanting is also carried out in shelterwood systems, where the natural regeneration is patchy and requires filling-in. Underplanting can also be used for the enrichment of an existing stand. Enrichment involves planting extra trees in a stand to increase the stocking of utilizable ones (Evans 1984). There are two main approaches to enrichment planting:

1. Opportunity planting – accept the bulk of existing crop and plant in gaps and poorly stocked areas where they occur;
2. Partial conversion – reject existing crop and systematically plant in swathes cut at intervals to produce strips of "better" forest interspersed with whatever develops from the poor quality woodland.

Coppice

Coppice is a forest crop raised from shoots produced from the cut stumps (called stools) of the previous crop (Evans 1984). Almost all broadleaf tree species coppice vigorously. European species that coppice freely are oak, ash, hornbeam, sycamore, lime, alder, hazel and Spanish chestnut (Troup 1928). There are a number of forms of coppice (see Table 4). However, only simple coppice and coppice-with-standards are described here.

Coppicing has been suggested by Evans (1984) and Kerr and Evans (1993) as a possible silvicultural system that may be employed to treat some poor quality woodlands. The current high demand and resultant price for fuelwood make coppicing appear increasingly attractive. The system may also allow the manager to select a number of stools and single their shoots with a view to allowing these to grow to

Table 4: *Coppice types and terminology (Evans 1984).*

Type	Description	Comment
Simple coppice	Crop consists entirely of coppice, all of which is worked on the same cycle (even aged).	May consist of only one species (pure) or several (mixed).
Coppice-with-standards	Two storey forest. Coppice (underwood) with scattering of trees (standards) being grown to timber size.	Standards may be of seedling origin (maidens) or develop from a stump shoot left for the purpose (stored coppice). Standards retained for a period of 3-8 coppice cycles.
Stored coppice	Tree or stand of coppice origin as a result of growing coppice on beyond its normal rotation.	Many woodlands, resembling high forest, are stored coppice owing to decline in coppice working this century.
Short rotation coppice	Arbitrarily designated as coppice worked on a rotation of less than 10 years to produce stick size material.	Provides material for many rural crafts. Recent interest in production of biomass for energy.
Pollards	Trees cut off at 2-3 m above ground so that the shoots which sprout are not in danger from browsing.	Regenerative mechanism identical to coppice. Formerly component of "wood-pastures" now little practiced in traditional form.
Underwood	General name for all coppice or scrub occurring under another tree crop.	

sawlog size, either by storing the coppice as an even-aged crop or by producing a coppice-with-standards system (see below). Coppicing a poorly performing crop may also facilitate supplementary stocking of gaps via natural regeneration or planting.

Coppice-with-standards

Coppice-with-standards is a silvicultural system that produces a multi-storied stand consisting of a lower storey of an even-aged coppice underwood and an uneven-aged partial upper storey of standard trees grown at wide spacing which is treated as high forest (Matthews 1989, Nyland 2002, Harmer 2004). The lower storey is regularly cut to produce small material whilst the objective of the upper storey is to produce large timber. Coppice-with-standards was at one time the principal system applied to the growing of hardwoods in Great Britain (Forbes 1904, Guillebaud 1927, Begley 1955). With the advent of a strong demand for small dimension hardwood timber for fuelwood, the system may once again have potential. The B-SilvRD project has established a coppice-with-standards pilot trial, which should provide useful information to this end for Ireland.

Free-growth

Free-growth is a silvicultural technique which stimulates crown development of selected trees, in order to achieve maximum radial stem increment (Jobling and Pearce

1977). It focuses management on a relatively small number of stems and maximises potential volume production and therefore reduce the length of the rotation compared to conventional management. The free-growth system involves the selection of final crop trees at an early stage in the rotation and then maintaining space around the crowns of the selected trees. A pilot trial site of a modified free-growth system in ash has been established in Ireland, which will provide information on the potential of this system.

Conclusions

There are many factors that can affect the performance of a broadleaf stand, some of which are under the control of the forester, others less so. The results can have a serious impact on the productivity and quality of a broadleaf crop, and therefore the potential economic returns. The Irish forest industry has, quite understandably, been focussed predominantly on producing high yielding conifer crops. Much of our silviculture is highly systematic, especially when compared with some of the broadleaf silviculture commonly employed in continental Europe. Broadleaf silviculture needs to be more subtle than the clearfelling system currently employed in Ireland if economic returns are to be achieved from the developing resource, especially if some of this resource is unable to produce quality timber without novel interventions. It is hoped that this paper, together with further planned communications, will stimulate discussion on broadleaved silvicultural practice. The following are the main practical implications that emerge from this review:

- Appropriate species and provenance choice are the foundation of successful plantation establishment. Incorrect choices are very difficult to rectify at a later date. Foresters should consider species choice carefully and realistically. Foresters also require ready access to suitable provenances of a chosen species.
- Ground preparation should improve the planting medium without physically compromising future management access.
- Broadleaves are often more suited to mixtures than to pure crops. Despite the added challenges of managing mixed species crops, they may convey some advantages. Their increased use should be promoted.
- Deer and squirrel damage are major issues impacting on broadleaved establishment and quality. The forest industry should continue to build upon the work carried out in this area and encourage a national collaborative approach to address these problems.
- Throughout the rotation, broadleaved plantation quality relies on timely and appropriate management interventions. This relies on on-going development of silvicultural systems adapted to first-rotation broadleaf plantations in Ireland.

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