THE ENVIRONMENTAL IMPACT OF PLANTING BROADLEAVED TREES ON ACID-SENSITIVE SOILS

Literature Review

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Foreword

Forests impact on acidification of surface waters mainly as a result of the tree canopy capturing pollutants arising from industrial production and intensive farming. Levels of most pollutants, particularly sulphur, have been falling steadily over the past decade, due to the Gothenburg Protocol, which regulates emissions of transboundary pollutants. As a consequence, reduced freshwater acidity and impacts have been detected in Scotland and elsewhere. While levels of pollution have also fallen in Ireland, impacts on surface water acidity have not yet been demonstrated, possibly through insufficient monitoring.

Afforestation is currently permitted in acid sensitive areas only where alkalinity of surface run off, measured under certain conditions, is greater than a predefined threshold. Alternative approaches for deciding on forest location, particularly critical loads, also deserve to be considered, as does the potential use of broadleaved species, particularly native and naturalised trees, in areas designated as acid sensitive.

This report by Marcus Collier and Professor Ted Farrell, based on work carried out in late 2004, addresses the potential use of broadleaves in acid sensitive areas, and brings together and analyses most of the available published and unpublished data on the topic, as well as the opinions of many leading scientists and practitioners.

While information is limited, there are good indications that, if located on the right sites, native trees and shrubs can be established in acid sensitive areas without compromising water quality, and at the same time contribute to gene conservation and other aspects of native biodiversity.

Given the reduction in acid deposition, and the conclusions presented in the report, restoration of native woodland on suitable sites within currently designated acid sensitive areas merits careful consideration from policy makers.

As well as outlining policy implications, the report is a thorough compilation of research findings on interactions between tree cover and acid sensitivity, and provides a good basis for future research in this area.

Dr Eugene Hendrick

Director

Brollach

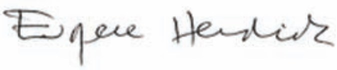
Bíonn tionchar ag foraoisí ar aigéadú uiscí dromchla go príomha mar thoradh ar chlúdach na gcrann ag gabháil truailleáin a eascraíonn ó tháirgeadh tionsclaíoch agus dianfheirmeoireacht. Tá leibhéil formhór na truailleáin, go háirithe sulfar, tar éis a bheith ag titim de réir a chéile sa deich mbliana atá imithe, de bharr Prótacal Gothenburg, a rialaíonn astuithe na dtruailleán trasteorann. Uaidh sin, chonacthas laghdú in aigéadacht fíoruisce agus tionchair san Albain agus in áiteanna eile. Cé go bhfuil leibhéil an truaillithe tar éis titim in Éirinn chomh maith, níl tionchair ar aigéadacht uisce dromchla léirithe go fóill, b'fhéidir de bharr monatóireacht neamhleor. Faoi láthair ní ceadaítear foraoisiú i gceantair aigéad-íogair ach amháin nuair atá alcaileacht an uisce dromchla a ritheann chun srutha, tomhaiste faoi choinníollacha áirithe, níos airde ná tairseach réamhshainithe. Chomh maith tá breathnú tuillte ag cur chuige malartacha le haghaidh beartú ar shuíomh foraoise, go háirithe ualaigh criticiúil, mar aon le húsáid phoitéinseal de speicis leathanduilleacha, go háirithe crainn dúchasach agus eadóirsithe, i gceantair atá ceaptha mar aigéad-íogair.

Tugann an tuarascáil seo ag Marcus Collier agus an tOllamh Ted Farrell, bunaithe ar obair déanta go déanach i 2004, aghaidh ar úsáid phoitéinseal na leathanduilleacha i gceantair aigéad-íogair, agus tugtar le chéile agus anailísítear formhór na sonraí infhaighte ar an ábhar idir foilsithe agus neamhfhoilsithe, chomh maith le tuairimí ag mórán eolaithe agus cleachtóirí ceannasacha.

Cé go bhfuil eolas teoranta, tá comharthaí maithe ann, gur féidir crainn agus sceacha dúchasacha a bhunú i gceantair aigéad-íogair, má chuirtear sna suímh chearta iad, gan cuir isteach ar chaighdeán an uisce, agus ag an am céanna cuir le caomhnú géine agus gnéithe eile de bhithéagsúlacht dúchasach.

Maidir le laghdú an tsil-leagain aigéid, agus na conclúidí curtha i láthair sa tuarascáil, is fiú breathnú cúramach ó lucht déanta polasaí ar athchóiriú coillearnach dhúchasach ar shuímh oiriúnacha laistigh de cheantair atá ceaptha faoi láthair mar cheantair aigéad-íogair.

Chomh maith le imlíniú a dhéanamh ar impleachtaí an pholasaí, is tiomsú críochnúil í an tuarascáil de thorthaí taighde na hidirghníomhaíochta idir chlúdach na gcrann agus íogaireacht aigéid, agus soláthraítear bonn maith le haghaidh taighde na todhchaí sa réimse seo.



An Dr Eugene Hendrick

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Executive summary

In general, there appears to be very little information on the environmental effects of planting broadleaved trees in acid-sensitive areas. Any research for which data are available has largely been carried out in countries with different soil and climatic conditions to Ireland, or on broadleaved species that are not native or near-native to Ireland. Thus, the literature review carried out for this study has yielded little by way of concrete information that may assist in the planning of future forestry initiatives in acid-sensitive areas. However, the deep rooting nature of some deciduous trees has been shown to be a buffer against acidity because they transport neutralising ions to the soil surface. Leaves also can buffer acidity when still on the tree as well as during the decomposing process after leaf-fall. Any broadleaved species that have the ability to grow in the locations where acid-sensitive soils are found, such as oak, birch, and to a lesser extent, rowan, are therefore likely to assist in buffering against acidity but little information is available on their potential for particle scavenging or the buffering of acid episodes. Further research is required to assess if they could induce environmental damage in acid-sensitive areas under, for instance, conditions of significant atmospheric pollution. Amongst the conifers, larch and Scots pine may be relatively benign, but data here are inconclusive. The productivity of these species is relatively low and as they tend to be associated with habitats of high biodiversity, they should be planted not for their commercial potential but with a view to enhancing the environment.

Introduction

In the last twenty years a great deal of research and monitoring has been carried out in North America and Europe into the effects that forest systems have had on habitat quality (Giller et al. 2002). In the UK and Ireland much of this research has examined the effects of afforestation with conifer species, especially in localities with acid-sensitive soils. Particular attention has been paid to areas where conifers were underlain with an acid geology and were perceived to be intercepting atmospheric pollutants. Today, it is mostly agreed that conifer plantations add considerably to the problem of freshwater acidification in these situations (Schöpp et al. 2003). In the light of recent commitments to conservation of biological diversity and to increasing the rate of broadleaf tree planting (Anon. 1996b, Anon. 1997a, Anon. 1999, Collins pers. comm.), the potential impact of broadleaf stands on soil chemistry needs to be examined.

Though there are many potential impacts on the environment of planting any species, the principal objective of this study was to review the literature (published, grey and unpublished) on the possible impacts on water quality of planting broadleaved and/or larch suitable for Irish conditions on acid-sensitive soils. The potential of each of several selected species to contribute to acidification of acid-sensitive areas was to be reviewed. The main tasks of this study were:

1. to identify the important repositories of the appropriate information,
2. to examine and document published and grey literature and summarise the findings,
3. to establish contacts in appropriate agencies abroad in order to gain access to relevant experience and unpublished data,
4. to classify broadleaved and deciduous coniferous trees according to their potential to contribute to acidification of acid-sensitive ecosystems,
5. to indicate those species best suited for planting on acid soils,
6. to assemble information on international best practice in acid-sensitive catchments and possible environmental effects.

In addition to the literature review, it was also intended to classify trees according to their potential to contribute to acidification in acid-sensitive ecosystems. The small amount of published data on this specific topic - broadleaved trees on acid-sensitive soils - has, to date, impeded any definitive conclusions being drawn. About 90% of published information on environmental impacts of trees concerns coniferous species (Mitchell, Moffat, Nisbet pers. comm.), and are included only where they provide useful comparative data with broadleaves. The paucity of published information led to a reliance on personal communications with key scientists. These communications were extremely valuable and form an important part of this review.

Process of forest soil acidification

At its simplest, soil acidification may be viewed as an increase in the hydrogen ion (H^+)concentration of the soil solution. However, as this ignores the importance of the exchange acidity of the soil, it is more meaningful to define soil acidification as a decrease in the base saturation of the soil: in other words, a decrease in the proportion of the cation exchange capacity that is satisfied by basic cations and a corresponding increase in the proportion of exchangeable hydrogen and aluminium on the soil exchange complex.

Changes in the soil acidity are the net effect of a series of contemporaneous processes, some responsible for generating acidity in the soil solution, others neutralising acidity. In temperate regions of the world, the natural tendency in soil development is towards acidification (Ball 1975).

Human activity often results in an acceleration of the process of soil and ecosystem acidification. Crop production, whether in agriculture or plantation forestry, induces acidification in the soil. This may occur by several pathways including cation uptake by roots and nutrient depletion in the harvest. Liming, where practised, can neutralise this acidity. Although not regularily practised in Ireland, liming can have positive effects in forest ecosystems (Eriksson et al. 1983, Fransman and Nihlgard 1995, Schreffler and Sharpe 2003) and may be cost effective (Harriman and Morrison 1981, Stretton 1984, Nisbet 1989, Annerberg 1995, Porcella et al. 1995, Warfvinge and Sverdrup 1995, Bartsch 2000, Gee 2001). However, it is not always successful (Stretton 1984, Larsen and Hesthagen 1995) nor is it always necessary, since acidified upland streams are in fact necessary for salmonid hatching (Hudd 2000).

Atmospheric deposition of acidifying substances may contribute significantly to the acid load on ecosystems. Major sources of these substances include fossil fuel combustion and ammonia emissions, the latter largely as a result of animal production. In the context of acid deposition and induced stress, acidification is sometimes defined as a reduction in the acid neutralising capacity (ANC) of the soil. Acid neutralising capacity is the ability of the soil to neutralise strong acids, is measured in the soil solution, and is the sum of the concentration of basic cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) minus the major anions (Cl^{-}, NO^{3-} and SO_4^{2-}).

Forests, through canopy interception of wet and dry deposition, remove acidifying ions through a scavenging process but in so doing increase their deposition. The ability of an ecosystem to withstand acid load will depend on the magnitude of the deposition and the buffering capacity of the soil.

All soils are buffered to some extent, that is they resist changes in their acid-base status, through one or more processes. In strongly acid forest soils the predominant buffering processes are likely to be cation exchange and aluminium buffering. The capacity of an ecosystem to buffer acidifying pollutant deposition is referred to as its critical load. Critical load can be used in the designation of threshold levels of forest cover in acid-sensitive catchments. Deep soils with a mineralogy consisting of carbonate or ferromagnesian minerals, will have a high critical load, while thin, base-poor soils will have a low critical load. In the context of afforestation, such soils are referred to as acid-sensitive.

Tree roots have an important influence on soil properties and processes. Roots can be a stabilising force especially in upland areas. Roots also greatly increase soil infiltration capacity, providing additional drainage and aeration, again important in upland, wet sites. Deeply penetrating tree roots can buffer acidity in the soil by bringing neutralising ions to the surface. High infiltration capacity can also facilitate more efficient drainage and so reduce the likelihood of acid runoff episodes. Thus, it may be assumed that deeper-rooting trees should have a positive (buffering) effect in acid-sensitive areas.

Leaves can also neutralise acid deposition, essentially in two ways. First, while still attached to the tree, leaves can buffer H^{+} in rainfall (Liu and Côté 1993). Second, as litter on the forest floor the biotic activity engaged in the breakdown of leaves results in the return of nutrients to the soil and their reabsorption by vegetation. This can be an effective buffer as soil pH decreases. However, Irish conifer forests have been traditionally planted on acid sites, as they are more tolerant of such conditions. They often adopt a shallow rooting habit on such soils. These factors, together with their interceptive ability combine to contribute to, rather than buffer, acidifying tendencies in acid-sensitive areas.

Key influencing factors

From the standpoint of this study there are essentially two issues in the discussion on the potential impact of afforestation with broadleaved trees in acid-sensitive areas. The first is the impact of the environment on forests; the second is the impact of the forests on the environment. Both are somewhat interdependent. Here we discuss those influencing factors that have strongest relevance to the study.

Environmental influences on forests

Proximity to the sea

'Sea-salts are the dominant chemical constituents of precipitation in maritime regions' (Aherne et al. 1998a). Bulk precipitation in Ireland is dominated by marine ions, notably sodium and chloride. Wright et al. (1988) claim that the effects of marine deposition cannot account for long-term acidification of freshwaters alone and that this 'sea-salt effect' may be more relevant on thin soils in coastal areas. In Norway, Hindar et al. (1995) show that sea-salt episodes have little long-term effect on the pH of soils in wooded areas and that a natural increase in soil acidification may be a prerequisite for the sea-salt effect to occur. In Scotland it is noted that sea-salt deposition may have an ameliorative effect on the acidification process (Cresser et al. 1995).

Many of these studies were carried out in conifer forests or in forests with broadleaved species that are not native in Ireland (e.g. Rothe et al. 2003) and there are very few studies on the effect or otherwise of broadleaved forests on the interception or deposition of marine ions. Farrell et al. (1998) have shown that the interception of sea-salt is similar for both coniferous and broadleaf stands in the west of Ireland. Epiphytes (lichens and mosses) are probably the principal interceptors in high (and hence old) oak canopies in low nitrogen environments. Though sea-salts are essentially neutral, marine-derived inputs of both cations and anions in Ireland are nonetheless considerable (Farrell et al. 1998).

Geology

Gorham (1953) had shown that, under high rainfall conditions, relief can have a major influence on soil formation. However, this does not take into account the parent material or the land use history. Jenkins et al. (2002) produced a model of surface water acidification in which they illustrate the long-held view that acidification of river systems is not only due to pollutant interception and deposition by conifer forests but also to parent material. This has been considered by many others (e.g. Kelly-Quinn et al. 1997). In an extensive study of acid-sensitive waters in Ireland, Bowman (1991) shows that naturally occurring acid-sensitive waters are to be found in locations with a bedrock consisting of base-poor geologies such as shale, schist, gneiss, granite and sandstone. These areas are mainly along the western seaboard and in the Co Wicklow uplands, as shown in Ryan and Farrell (1998) and EPA (2000), where many soils are classified as being acid-sensitive, as described by Gardiner and Radford (1980). Watercourses in these areas have low alkalinity and therefore a poor buffering capacity. Thus the occurrence of watercourse acidification is dependant on local geology – bedrock and substrate (Farrell et al. 1998). It has also been shown that poor, wet soils with a granite bedrock naturally release high levels of aluminium as well as protons (Guibaud and Gauthier 2003). Donnelly et al. (2003) state that catchments with acid bedrock are particularly susceptible to surface-water acidification. This is prior to any anthropogenic practices.

Nutrients

Bolger et al. (1996) outlined the effects of acid deposition on the nutrient dynamics of an afforested catchment. Generally, the effect on thin soils that are poorly buffered is that the H^+ ions replace Na^+, NH^{4+}, K^+, Mg^+, and Ca^+ and thus leach these nutrients out. Al^{3+} and some heavy metals may be leached from soil particles if pH is low enough (Jennings et al. 2002). This may damage soil microbial life as well as reduce nutrients available to trees. The rate at which roots can take up nutrients may be slowed by this process. Nutrients such as nitrogen may, however, be added through deposition of ammonia and nitrate arising from anthrpogenic effects.

As the impact of afforestation on soil pH is complex (Ovington 1953) the viability of afforestation programmes on poor, wet soils or in acid-sensitive areas will depend on many criteria, not least on nutrient availability. The nutrient budget of a woodland is determined by the input from the atmosphere combined with weathering of parent material, compared with leaching of nutrients and removal of biomass during harvesting.

Conifer plantation forests tend to be nutrient deficient (Pritchett and Fisher 1987) but this may be an oversimplification, as this does not take age and site suitability into account. However, an influencing factor here may be in selecting species of trees that will not only grow but also thrive on acid-sensitive soils. As will be seen, few trees are suited to these soil conditions and fewer are native or naturalised in Ireland.

Environmental influences of forests

Catchments

Nisbet (2001) states "*The role of forestry in surface water acidification has been the most controversial of all water issues*". It is now accepted that trees act as efficient interceptors or scavengers of atmospheric particles such as SO_2, NO_x, O_3 and others (e.g. Reynolds et al. 1999). Canopy interception of airborne pollutants is deemed to be the main process by which forest plantations contribute to the acidification of surface waters (Cape and Fowler 1986, Kelly-Quinn et al. 1997). Conifers, which represent the obvious species choice for most acid-sensitive regions, are particularly efficient as particle interceptors (Ulrich 1983, Anon. 1990b, Brown and Iles 1991, Cannell 1999). Scavenging of pollutants may have a serious and detrimental effect on forest soils (Schlaepfer 1993) as well as in the US (Baker et al. 1996). Conifer plantations, in particular, are recognised as enhancing, via the scavenging process, the degree of dry, wet and occult deposition, which then passes through the canopy and contributes to enhanced soil and freshwater acidification (Harriman and Morrison 1981, 1982, Cape and Fowler 1986, Ormerod et al. 1989, Kelly-Quinn et al. 1996a). The ability of trees to intercept or scavenge atmospheric deposition depends on many variables, including the leaf area (Rode 1999a), woodland height, canopy structure, leaf shape (Beier and Gundersen 1989) and, possibly, elevation (Sickles and Grimm 2003). Conifer woodlands tend to have a higher leaf area index (LAI) and can be taller than broadleaved woodlands on similar soils (Rode 1999a, Augusto et al. 2002). One of the consequences is that a conifer woodland, with its year-round foliage, intercepts a greater volume of rainfall (and hence atmospheric pollutants) than broadleaved woodland (Cannell 1999). Farrell et al. (1998) show, however, that conifer and broadleaved trees may have similar interception characteristics under Irish conditions, which may be due to the epiphytic flora typical of native broadleaved woodland.

Based on leaf damage, broadleaves may be less impacted by direct atmospheric deposition compared with conifers, but it is diffcult to discern exact causes (Badea et al. 2004). However, some broadleaves such as birch are more susceptible to SO_2 and NO_2 than others (Freer-Smith 1984). These studies were, however, carried out in forest conditions that are not common in Ireland. Spiecker (2003) quotes German references that show that where coniferous forest replaces broadleaves, over time a clear and definite lowering of soil pH occurs.

As mentioned, it is generally accepted that, in areas of acid sensitivity, soils can become leached of nutrients and, in wet conditions, this can result in a lowering of runoff pH. (Ormerod et al. 1986, Ramberg 1981). Alexander and Cresser (1995) maintain that tree canopy scavenging may have a high impact on water acidification in upland areas of Scotland. This had been noted earlier by the Forestry Commission in Britain, which in 1990 published a general outline of water acidification and the role that conifer woodlands have in augmenting deposition through pollutant scavenging (Anon. 1990b). Lower pH has had deleterious knock-on effects at catchment and regional levels, particularly where the associated increase in dissolved, non-labile and labile aluminium concentrations have impacted upon freshwater ecosystems in episodic intervals (Ormerod et al. 1990, Omerod and Tyler 1991, Omerod et al. 1993, Kelly-Quinn et al. 1997, Puhr et al. 2000). As discussed above, it is often inferred that conifer forests can scavenge a higher quantity of acidifying pollutants than deciduous forests. Ulrich (1983) claims that conifers are more efficient scavengers than broadleaves such as oak and beech. Yet, a study on beech forests showed that they have similar acidifying effects as Norway spruce (Hagan-Thorn et al. 2004). Still, Brown and Iles (1991) concur with Ulrich in a later study which demonstrated that coniferous forests are more efficient scavengers of ions from the atmosphere than broadleaved forests. There are no studies in these islands that have the same conclusions.

Arguably, one of the more significant impacts of acidification in afforested areas is in the area of freshwater catchment acidification. As soils become more acid, the proportion of exchangeable aluminium and hydrogen ions increases, and concentrations of aluminium in surface waters increases, with potentially negative consequences for surface-water biota. The source of the majority of exchangeable acidity in forest soils is aluminium ions. Driscoll et al. (2003) demonstrate that decreases in the pH of catchment runoff and the ensuing increases in aluminium concentrations have severely diminished several species of plankton, invertebrates and fish and that this can also be linked to eutrophication in estuaries. In a series of seminal studies on the matter in the US, Driscoll et al. (1995) had earlier shown that leaching of aluminium has been linked with increases in freshwater acidification. In Ireland similar effects have been shown in areas which are deemed to be acid-sensitive or poorly buffered (Allott et al. 1990). As mentioned above, bedrock geology or parent material plays an important role in whether acidified runoff mobilises aluminium (Kelly-Quinn et al. 1997). Throughout Europe, aluminium has now been shown to have a serious and detrimental effect on freshwater vertebrates (Stoner and Gee 1985, Ormerod and Tyler 1991, Bradley and Ormerod 2002) and invertebrates (Stoner et al. 1984). This is also true in Ireland (O'Halloran and Giller 1993, Kelly-Quinn et al. 1996a, 1996b, 1997). Though the presence of conifer-afforested catchments in acid-sensitive areas may be associated with freshwater acidification, it is not known what acidifying effects broadleaf afforested catchments in similar conditions might have. This is because comparative studies have not been carried out, though two such studies are being considered in the UK (Nisbet pers. comm.).

Tree characteristics

Fowler et al. (1989) argue that tree height may be of primary importance in assessing the scavenging effects of conifer plantations. They show that forest structure (including density) is important in particle scavenging, not just age, and that in general all afforestation increases nutrient inputs from the atmosphere when compared with open moorland. The age of the tree and the forest stand will in part determine the effects of acid rain on the crown

(Mather et al. 1995) though Whelan et al. (1998) highlighted "*...the need for a better characterisation of canopy architecture in order to improve understanding of its role in affecting water and mineral ion deposition on the forest floor*". This debate has not been resolved.

Miles (1985) claimed (without much scientific support) that alder, Scots pine and Norway spruce are efficient soil acidifiers and that oak and birch cause 'less acidification'. As discussed earlier, afforestation generally leads to a lowering of soil pH and the further acidification of the soil through scavenging is complicated by the species of trees selected for acid-sensitive areas. Genera such as *Abies*, *Picea* and *Pinus* are well suited to, and thrive upon, acid soils (Anon. 1990b). As a consequence their leaf litter, being acidic in nature, can have a poor buffering capacity for episodic acid deposition and throughfall. Ovington (1953) had shown early on that conifers tend to intensify acidity in upper soil horizons, 'more so than hardwoods'. Within a woodland ecosystem there are various nutrient fluxes related to leaf-fall and nitrification (Nordén 1991). Augusto et al. (2002) examined the modification of soil pH and soil solution pH under different species and showed that oak stands have a minor acidifying effect.

One argument in favour of broadleaf afforestation in acid-sensitive areas may stem from the fact that the leaves of broadleaved trees (especially when young) buffer well against atmospheric deposition in the first place (Soares et al. 1995). Later, broadleaf litter decomposes readily and promotes base cation return to the soil (Nordén 1994a and b). This can increase the ANC of the soil and thus ameliorate the effects of acidification. Broadleaf litter, particularly following leaf fall, may buffer against acidifying throughflow. As leaf litter declines in the early spring, it is not known if the buffering capacity of deciduous woodlands also declines (Mitchell, Smith and Tervet pers. comms.). Howard and Howard (1990) showed that the lowest acidity leaf litter was found under broadleaf stands. Also, as deciduous trees have a period of near dormancy in winter any possible scavenging would be reduced. This cessation of activity in winter may, however, prevent the buffering of acid episodes through nutrient uptake (Mason 1996). In general, deciduous tree leaf litter improves soil properties via the pedogenic process and chelation (Pritchett and Fisher 1987).

Deep rooting in broadleaved forests may be the most significant factor in their ability to buffer acidification (Nisbet pers. comm.). The uptake of nutrients by trees generally includes more cations than anions. In association with other processes (such as improved soil infiltration capacity, bedrock weathering and soil biological activity) this can buffer the effects of low pH. Deep rooting trees such as oak may therefore improve base status, though no conclusive comparative studies with shallow rooting genera, such as *Picea*, were encountered. While acid-sensitive soils may be further acidified by forest growth, afforestation does not appear to cause surface water acidification unless there are mobile anions (for example sulphate) to transmit the soil H^+ into surface water (Kaufmann et al. 1992). Rooting depth is also a function of soil type: deeper rooting tends to occur where there is a deeper water table and in the absence of physical barriers such as pans and hard soil layers.

It is well known that basic cations contribute to acid buffering (Wild 1993) and, as pointed out, broadleaved trees have the ability to increase basic cation reserves at the surface soil, via leaf litter inputs (Sydes and Grime 1981). It seems logical to conclude that planting broadleaved trees rather than conifers would reduce any soil and freshwater acidification. This has been a common theme in personal communications received, although the ameliorative process in broadleaved woodland is not fully understood (Allott, Nisbet pers. comm.). Pritchett and Fisher (1987) maintain that deciduous tree leaf litter 'improves soil properties' via pedogenic processes and chelation. They continue by stating that understorey shrub species can produce a high volume of litter and the resulting decomposition of organic debris (mainly leaves and twigs) reduces acidity by reducing nitrification and increasing mineral cycling. It should be noted that much of the current research on the subject of conifer forest acidification has focused on the potential of riparian buffer zones (Peterjohn and Correll 1986, Ormerod and Tyler 1991, Ormerod et al. 1993, Blackwell et al. 1998, Bergquist 1999) and buffer zones as potential acid-interception sites (Henriksen et al. 1988, Correll 1997, O'Halloran pers. comm.).

Conversely, it has often been maintained that the leaves of introduced or exotic (conifer) species may not readily decompose and so litter reduction and nutrient recycling is slower and less efficient. Thus, the build-up of needle litter in conifer stands may partly be because of the lack of suitable decomposers with the ability to digest leaf matter and thus cycle nutrients (Miles 1985), though there are no modern studies that demonstrate this. If this is the case, however, the lack of neutralising elements may be decreased thus favouring the maintenance of an acid regime in the soil. Though this may favour conifer species (which tolerate acidic soils generally) it may inhibit the growth of other tree species. It was believed that conifers have a higher litter production ability than broadleaved trees in European forests (Bray and Gorham 1964). This has since been hotly disputed and it is now believed that total litterfall is higher in broadleaved than conifer forests (Liu et al. 2004).

Broadleaved species suited to acidic soil conditions

The Heritage Council report on forestry states "*...non-native, species-poor plantations on habitats of conservation importance offer few of the benefits of indigenous mixed broadleaved woodland*" (Anon. 1999). It goes on to make suggestions relating to the impact of afforestation, including the recommendation that a cautious approach should be taken to afforestation in order to avoid alterations to freshwater systems and catchments - "*Large-scale new planting should only occur where the risks of adverse impacts from afforestation are known to be acceptably low*" (p 21). The report concludes that urgent updating of forestry and fisheries guidelines is needed and that sensitive areas need to be identified. These and other recommendations were taken up by the Forest Service when it published its set of environmental guidelines (Anon. 1997a, McAree 2002). Furthermore, whereas earlier plantations were mostly single species conifer crops, today there is increased focus on mixed native woodlands, supported by grant aid programmes (Anon. 1997a, 2000a, 2000b, 2000c, 2000d, 2000g, 2000h).

Research on the potential buffering ability of broadleaved woodlands has focussed on tree species that are native or naturalised in European and North America (Ulrich 1983). These include lime, chestnut, beech, red oak, sycamore (maple) and a range of non-deciduous trees (often in arid areas). Augusto et al. (2002) rank tree species in the order of decreasing acidifying ability, as follows: (*Picea abies, Picea sitchensis, Pinus sylvestris*) ≥ (*Abies alba, Pseudotsuga menziesii*) ≥ (*Betula pendula, Fagus sylvatica, Quercus petraea, Quercus robur*) ≥ (*Acer platanoides, Carpinus betulus, Fraxinus excelsior, Tilia cordata*). It should be noted that they include forest species that are intended for harvest. It is known that harvesting activity reduces soil pH in the long term (Helliwell et al. 1998, Anon. 2000d, Watmough and Dillon 2002) and can have serious impacts on freshwater quality (Aubertin and Patric 1972, Blackie et al. 1980, Hornbeck 1992, Neal et al. 1992, Reynolds et al. 1992, Aust 1994, Gee and Smith 1997, Moffat 2003). These considerations are included in the ranking above. It is unknown what a non-harvested ranking might be, especially in acid-sensitive areas, but it is believed that old plantations are slow to release ions in the absence of harvesting (Nilsson et al. 1982). In any case, epiphytes that are commonly found in older stands have been shown to be effective interceptors of throughfall (Farrell et al. 1998).

Based on the foregoing considerations, we propose that the following trees (listed in alphabetical order) may be suitable for planting on acid-sensitive soils under Irish conditions. For the trees to grow to form a forest ecosystem, other soil and site factors, such as fertility, drainage status and exposure, need to be taken into consideration.

Birch (*Betula pendula* Roth., *B. pubescens* Ehrh.)

The case is strong for the inclusion of native birch in any afforestation of acid-sensitive areas. Birch has long been considered the tree to best 'improve soil and is excellent in the deacidification process thus making [birches] more suitable for silviculture' and thus birch may be better at extracting nutrients than any competitor on poor, acid soils (Gardiner 1968). As a 'soil improver' birch is reported to exert an influence on exchangeable potassium in potassium-deficient soils (Pritchett and Fisher 1987) and pines grow well as companions of birch on poor soils. Nutrient concentrations and pH were positively correlated with the degree of broadleaf occupancy under birch stands (Sanborn 2001). Miles (1981) demonstrated that birch regeneration causes depodzolisation of acidic soils leading to more 'attractive soils for further species colonisation'. Though this may not be proven, Miles noted that soil pH was altered from 3.9 to 4.3 in around 90 years and later he claims that birch 'retards acidification' (Miles 1985). Indeed, birch will form a mull humus in time (as will many tree species) and is suitable on upland sites (Miles and Kinnard 1979, Woodin 1988). It is also shown that simulated rainfall, at pH ranges of between 3.5 and 4.5, is unlikely to affect adversely the growth of birch on a wide range of soils (Ashenden and Bell 1988).

Of the two native species, downy birch (*Betula pubescens*) may suit acid-sensitive areas more. As a forest tree its potential is being investigated (Bulfin 1991, O'Dowd 2004, Hendrick, Pollanen, Tervet pers. comm.) and it is known that, when properly managed, birch can attain a relatively high yield but it is unlikely that it will attain its true potential on poor, waterlogged or exposed sites (Nieuwenhuis and Barrett 2002). Birch is also more ecologically flexible (Nieuwenhuis and Barrett 2002) and it has been shown to be high in biodiversity (Atkinson 1992, Kennedy and Southwood 1999, O'Dowd 2004). It should be noted that 'soil improving' trees cannot prevent soils from being podzolised if local environmental conditions are already conducive to podzolisation of the soil (Augusto et al. 2002).

Larch (*Larix decidua* Mill., *L. kaempferi* (Lamb.) Carr.)

Research papers on larch species in relation to this topic are rare. Some (e.g. Billett et al. 1988) show some positive change in pH levels (i.e. a modest rise in soil pH) in Scottish forest soils under larch. However, larch may also contribute more throughfall acidification than spruce (Hornung et al. 1986) and yet other studies show that larch has less detectable effect than spruce on the acidity of the soil and aluminium concentrations in soil and water (Adamson et al. 1993). Opinion is thus divided on this topic. Larch is a deep rooting species (Pritchett and Fisher 1987) and so it may have the same buffering effects as other deep rooting species, but this is not known for certain. It is clear that there are little data to support the supposition that larch is less damaging than other conifers or as beneficial as other deciduous trees. It is known that European larch grows best on soils with a pH range of between 5 and 7 and so it may not be suited to more acid soils. Japanese and hybrid larch should do better on acidic, wet soils but this has not been established. However, because it is deciduous, larch may have less of a scavenging effect that other conifers and thus may be less acidifying, though this has not been proven.

Oak (*Quercus petraea* (Mattuschka) Liebl.)

Much research has been carried out on oak but mostly on biodiversity aspects rather than on soil preferences (e.g. Winter 1983). Oak has the highest insect richness of any tree species in these islands (Kennedy and Southwood 1999). It has been shown that throughfall is lower than precipitation in oak forests and that acid buffering takes place in the ground flora of oak woodlands (Anon. 1987). Oak produces a high volume of leaf litter. Raulund-Rasmussen and Vejre (1995) show that oak has a high litter decay rate, much higher than spruce and beech. This is more pronounced on loamy sites, probably due to higher earthworm activity. Nielsen et al. (1999) show that oak trees can depodzolise soils under heath towards acid brown soils. Their study showed that phenolic compounds, which can 'sterilise' the soil resulting in low decomposition rate of organic matter, were found to be nearly absent under oak stands. Though oak may have a low scavenging ability (Nordén 1991) as with other broadleaved trees this is only for part of the year. Nornberg et al. (1993) noted a decrease in soil acidity following colonisation by *Quercus robur,* though this was also accompanied by a decrease in soil organic matter. Perhaps the habit of oak to be deep rooting is the best argument for its buffering abilities on acid-sensitive soils.

Rowan (*Sorbus aucuparia* L.)

Rowan is a suitable species for upland planting and will grow on acid soils and fertile peats, though not in waterlogged conditions (Raspé et al. 2000). Rowan leaves are quick to decay and thus may have good buffering capacity (Sydes and Grime 1981), but studies on rowan and any scavenging potential it may have could not be found. Rowan, however, is known for its high biodiversity potential (Winter 1983, Raspé et al. 2000).

Scots pine (*Pinus sylvestris* L.)

Though neither a broadleaved tree nor a deciduous conifer, Scots pine is considered in this study for several reasons. Pine is less sensitive to competition in the upper storey of a woodland than oak, and interacts well with birch (Paluch and Barkowicz 2004). Miles (1985) shows that pine is an efficient acidifier of the soil, which would no doubt be problematic in already acid-sensitive areas, though pine had earlier been described as being good for 'soil amelioration' (Miles and Kinnard 1979). Pine is high in biodiversity (Winter 1983) and may be important for the survival of rare vertebrates (Lurz et al. 1995). However, though Scots pine may be high on the list of acidifying trees (Augusto et al. 2001) it is also shown that Scots pine has a high evapotranspiration potential (Haria and Price 2000). In any case, it has been shown that Scots pine plays a key role in the transition to a mixed-pine woodland (Paluch and Barkowicz 2004). There may be a case for its use in mixed forest stands, approaching a native structure.

Mixed forests

From a biodiversity point of view, as well as from the limited data on the species above, it appears that mixed native woodland may be the most suitable form of afforestation on acid-sensitive soils. Data to support this proposition are not numerous, though Adam (1999) suggests that continuous cover forestry using mixed broadleaf/conifer forests is the ideal way of consuming H^+ and thus buffering acidity. This sentiment is reflected in a Forestry Commission report (Anon. 2004) but it does not mention the potential acid buffering of broadleaves. In a synthesis report, Rothe and Binkley (2001) discuss mixed stands and conclude that there are no general rules on the effects of their leaf litter on soils. It may be that there is a complex interrelationship between species combination and site characteristics and that the canopy of a mixed stand may influence the chemical, physical and biological characteristics of the forest topsoil (Augusto et al. 2002). Rode (1999b) indicates that the organic layer is of great importance to forest nutrition processes and that pine-birch woodlands have a less compact stratification of the organic layer, while oak-birch woodland has a more compact layer and thus better water storage ability. Shelterbelts, consisting of different species (e.g. pine, oak and birch) have a more effective nitrogen uptake than those composed of only a single species (Ryszkowski 1992). *Sorbus aria*, *Sorbus aucuparia, Pinus silvestris* and *Quercus petraea* can tolerate the light levels found under birch canopies, and utilise the nutrient-rich birch litter (Schnitzler and Closset 2003). Smith et al. (2003) claim that the most appropriate woodland type for restoration on acid soils in Irish uplands is oak/birch woodlands dominated by *Quercus petraea* and *Betula pubescens*. This may be followed by interplanting with *Ilex aquifolium* and *Sorbus aucuparia*, as well as *Pinus sylvestris*. A mixed woodland would have high biodiversity potential and would also have a high amenity value (Anon. 2002a). Therefore, from the data available, it seems that a mixed, deciduous/pine woodland is the best choice for afforestation in acid-sensitive areas.

That mixed deciduous woodlands would have environmental impacts is not in doubt. However, the UK approach is now to use mixed species planting (as well as continuous cover forestry and short rotation forestry) in new forests (Anon. 2004). Deciduous leaf litter has the potential for buffering soils in the long term (Pritchett and Fisher 1987, Baur and Feger 1992, Nordén 1994b, 1994c) and if left unharvested, such a woodland ought to continue to buffer acid runoff to streamwater through a variety of secondary (deadwood and in-stream leaf litter) and tertiary (floral regeneration) processes (Newton et al. 1996, Tervet 2001, Nordén et al. 2004). The development of an understorey of diverse species and ages, especially ground flora, may be the most vital factor for acid buffering (Alway et al. 1933, Raulund-Rasmussen and Vejre 1995, van Ranst et al. 2002). This is speculated upon by many commentators (Cruichshanks, Fraser and Nisbet pers. comm.) and, while there are studies that show the detrimental effects of forest floor communities (Hutchinson et al. 1987, Quist 1995), none could be found that refer to any broadleaved, deciduous forests in these islands.

Discussion

As mentioned, there are few data available on the environmental impacts of planting broadleaves, and even less that deal with their potential impact in acid-sensitive areas. Much of the grey literature suggests that there ought to be a beneficial impact on water catchments from deciduous/broadleaved trees and some promote their usage in acid-sensitive or nutrient-sensitive locations (e.g. Anon. 2003d). Still, there are very few or relevant research data to support this viewpoint and thus it may be considered an informed opinion. Indeed, though all those who were contacted during this study believed that though deciduous, broadleaf woodlands ought to have a benign effect upon the local environment in acid-sensitive areas (mainly due to deep rooting and leaf-buffering), they stressed that there is very little research to support this assumption. Leaf litter buffering is not well described in deciduous woodlands, but an interesting factor that may, in time, prove crucial is that as the climate changes and mean temperatures rise, leaf litter production will increase (Berg and Meentemeyer 2002) and presumably may offer more in the way of acid buffering capacity. This alone might be a strong argument in favour of planting broadleaved trees in acid-sensitive areas.

Research carried out in the last 30 years has shown that there is a high species biodiversity in broadleaved woodlands, especially birds and invertebrates (Adams and Edington 1973, Bibby 1989, Ormerod et al. 1990). However, if one is to establish whether there is an impact on acid loading, positive or negative, on forest soils and water catchments a specific programme of research would be required. Catchment studies in other countries are complicated by the near impossibility of being able to replicate study conditions. This is because of differences (large and small) in local climate, altitude, geology, soils, deposition levels, and so on. Models are often utilised as an alternative to this (as described by Martinson et al. 2003) but these too encounter some difficulties (Ferrier et al. 1995, Evans et al. 1998, Schöpp et al. 2003).

It appears that the research on the impact of woodlands on water catchments has focussed almost exclusively on conifer plantations. The reasons for this are many but principally because the data have shown, in every country, that conifer plantations do scavenge pollutants from the atmosphere and that these pollutants are transported to and through the forest floor, contributing to base cation leaching. This may have detrimental impacts on salmonid rivers and streams depending on the amount of deposition, the level of forest cover, the sensitivity of the terrestrial and aquatic ecosystems and the fish populations. Broadleaves ought to have less of a detrimental effect and may even have long-term beneficial effects especially as buffer zones (Ormerod and Tyler 1991, Hubbard and Lowrance 1994, 1997). Peterjohn and Correll (1986) claim that, in a broadleaf riparian buffer zone, plant assimilation of nitrates, in conjunction with soil denitrification processes, may raise pH to more tolerant levels. However, Jennings et al. (2002) state that riparian buffer zones are not efficient acid-buffers.

As Ireland has a small pool of native and naturalised tree species from which to choose (Anon. 2001a, Smith et al. 2003), it is one of the principal limiting factors in this study, since a desirable outcome could be the establishment of woodlands that contribute to biodiversity (Hendrick pers. comm.). Of the native and naturalised trees from which one can select, most, apart from those referred to above, favour dry, fertile and/or alkaline soil conditions (Anon. 2002a).

Because of the limited number of species from which to choose, and because of the lack of data in this area, personal communication during this study yielded several potential courses of action relating to the establishment of new forests in acid-sensitive areas in Ireland. These are shown in Figure 1.

It is clear that a mix of birch (especially *Betula pubescens*), Scots pine, oak (*Quercus petraea*) and perhaps rowan has the best chance of succeeding in acid-sensitive areas. Therefore one suggestion is for a biodiversity woodland programme, possibly within the Native Woodland Scheme (Anon. 2001a)[2], for the establishment of birch, rowan and Scots pine mixed forests. In time, and as the forest soils improve, the new forest may then be interplanted with oak and, if desired, more demanding understorey species. According to the research reviewed, these species ought to have a minimal impact on acid-sensitive soils. They have the best chance of succeeding in acid-sensitive areas but there are few data to show that they will have a reduced scavenging effect compared to a pure conifer stand. That said, their interaction with the soil (deep rooting, high infiltration capacity, and so on) may offset the impact of scavenging.

It is clear that research is needed to ascertain the environmental impact of broadleaved trees in acid-sensitive areas under Irish conditions. Research should take into account the knowledge that international agreements on reducing SO_2 and NO_X output have resulted in a modest but growing decline in these emissions worldwide and a dramatic decline in Europe. This has been noted in several studies on conifer forests in the British Isles (Anon. 2001b, Anon. 2003b, Hill et al. 2002, McCartney et al. 2003).

Amelioration programmes such as liming have been shown to be successful (Warfvinge and Sverdrup 1988, Nisbet 1989, Skeffington and Brown 1992, Porcella et al. 1995) and may be more economically viable (Annerberg 1995, Donnelly et al. 2003, Tervet pers. comm.). However, it is necessary to evaluate all options and examine all the potential effects of afforestation with broadleaved trees.

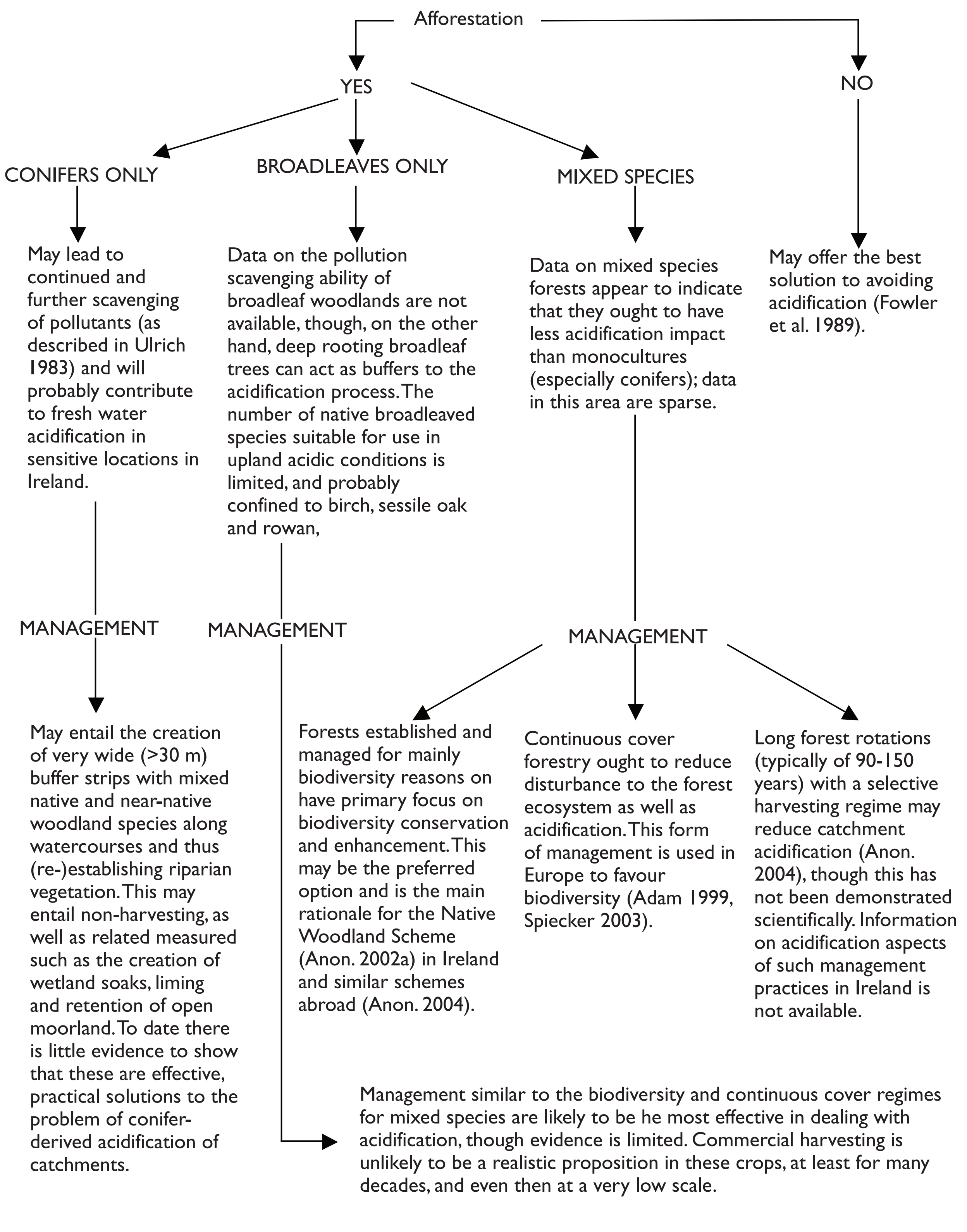
In order to achieve this it is suggested that a partnership approach be taken that involves those consulted during this study. Using the expertise of other countries with similar climates to Ireland, especially countries where there are established stands of broadleaved woodlands, the issue of the scavenging of acidifying substances by deciduous

[2] *It should be noted that currently the Scheme prohibits the establishment of woodland on 'implantable sites' (p. 31) including acid moorland and 'high-lying sites'.*

woodlands might be more fully investigated. To begin the process, it is proposed that a workshop on this subject be organised to ascertain the latest information from other countries, and to gauge the level of interest in the topic.

Any research on broadleaves and acid sensitivity will be time consuming and span many years. Thus it may be more convenient, in the short term, to begin by establishing a model based on the limited data available with the aim of predicting future impacts of planting broadleaved trees on acid-sensitive soils.

Figure 1. Possible options in the afforestation of acid-sensitive catchments.



Conclusions

- Bedrock and parent material have a strong influence in the decisions relating to the choice of tree species for afforestation in acid-sensitive areas.
- Generally, there is a lack of information on the effects of broadleaves on acid-sensitive soils throughout the world, not just in Ireland.
- Grey literature reviewed states that broadleaved, deciduous woodlands are to be preferred to conifers on acid-sensitive sites but there are little or no data in support of this.
- Forest literature is more concerned with biodiversity issues.
- Studies on broadleaved forests that were reviewed contained few (if any) references to tree species that were native or naturalised in Ireland.
- Relevant studies on broadleaves and acid buffering capacity are rare and conclusions are not appropriate to current Irish forestry practice.
- Deep rooting tree species can buffer against soil acidification by increasing soil infiltration capacity and by bringing neutralising ions to the surface.
- Some data show that deciduous leaf litter is a better buffer of acidity than conifer needles, but data on native or naturalised trees in Ireland are scarce.
- Some data show that leaf litter improves soil and makes it more suitable for long-term forest development; this includes thin, acid soils.
- There are no broadleaf-afforested catchment studies in these islands and any models available show the effects on acidification in conifer-afforested catchments only.
- There is a broad scientific consensus that mixed, deciduous forests should be better than conifer forests in acid-sensitive areas, but there are no data to support this conclusively.
- There are few (native or naturalised) tree species from which to choose that would suit acid-sensitive upland sites.
- However, birch appears to offer the best prospect of buffering the effects of acid deposition, though there may be a need to alter grant aid conditions.
- Scots pine follows closely in that it has had little adverse acid-related effects in other countries.
- Rowan and oak are also good candidates, but data are weak for these species.
- Data for larch are few, if any, and thus are not conclusive, though opinion agrees that larch may be a good candidate for planting in acid-sensitive areas owing to its deep rooting habit which is known to be useful in buffering acidity.
- Afforestation with a mix of birch and rowan, accompanied in part by Scots pine and oak as companion species, may be the most suitable and have the least potential for net acidification in acid-sensitive areas.
- Data show that upland moorland is the least successful at scavenging pollutants and this would indicate that non-afforestation would be the best option here.
- Research is required in order to identify which of the following four options is best suited to acid-sensitive areas singularly or in combination:
    1. To maintain the present policy of non-afforestation in acid-sensitive areas.
    2. To afforest to a level that does not exceed critical load – irrespective of species.
    3. To afforest to a critical load level with broadleaved species/or mixture indicated in this report.
    4. To afforest with broadleaves to any level of forest cover.

The Appendix contains the bibliography and references for this report and is a list that identifies important repositories of information on the subject.

Appendix

Literature review bibliography and report references

REFERENCE	PRINCIPAL POINT(S)
Aamlid, D. and Horntvedt, R. (2002) Sea salt impacts on forests in western Norway. *Forestry* 75:2, 171-178.	• *Distance from the sea is a key factor in determining sea salt damage.* • *Nutrients and other elements are not affected by salt deposition.*
Adam, M. (1999) Nutrient fluctuations in Sitka spruce (*Picea sitchensis*) plantations: the implications for future forest management practice. *Forestry* 72:3, 249-271.	• *Suggests extending conifer rotation times to allow for consumption of H^+ ions and for the system to regain nutrients lost through clearcutting.* • *Concludes that the introduction of continuous cover forestry that promotes structural and biological diversity is superior to clearcut forestry.* • *Woodlands should be mixed broadleaved or mixed broadleaf-conifer stands.*
Adams, M.W, and Edington, J.M. (1973) A comparison of song-bird populations in mature coniferous and broadleaf woodlands. *Forestry* 46:2, 191-202.	• *It is shown that there are similar numbers of song-birds in both types of woodlands, but there is a wider diversity of species in broadleaf woodlands.*
Adamson, J.K., Hornung, M., Kennedy, Norris, D.A., Patterson, I.S. and Stevens, P.A. (1993) Soil solution chemistry and throughfall under adjacent stands of Japanese larch and Sitka spruce at three contrasting locations in Britain. *Forestry* 66:1, 51-68.	• *The deciduous habit of larch does not influence solute chemistry in the soil.* • *Larch has less detectible effect than spruce on the acidity of the soil and Al concentrations in soil and water.*
Aherne, J., Ryan, D., de Kluizenaar, Y., van den Beuken, R. and Farrell, E.P. (1998a) *Critical loads and levels; Literature review of the current state of knowledge regarding the calculation and mapping of critical loads: Determination and mapping of critical loads for sulphur and nitrogen and critical levels for ozone in Ireland*. Forest Ecosystem Research Group, Report No. 45. Department of Environmental Resource Management, University College Dublin. 40 pp.	• *Key Critical Loads report.*
Aherne, J., Sverdrup, H., Farrell, E.P. and Cummins, T. (1998b) Application of the SAFE model to a Norway spruce stand at Ballyhooly, Ireland. *Forest Ecology and Management* 101, 331–338.	• *The SAFE model appears to omit some variables – this is discussed in relation to Ireland.*
Alexander, C.E. and Cresser, M.S. (1995) An assessment of the possible impact of expansion of native woodland cover on the chemistry of Scottish freshwaters. *Forest Ecology and Management* 73, 1-27.	• *Tree canopy scavenging may have high impact on water acidification in upland areas.* • *Suggests liming accompany new afforestation programmes on acid-sensitive soils.*

REFERENCE	PRINCIPAL POINT(S)
Allott, N., Brennan, M., Mills, P. and Eacrett, A. (1993) *Stream chemistry and forest cover in ten small western Irish catchments*. In: C. Watkins (Ed.) *Ecological Effects of Afforestation*. CAB International, Wallingford, UK. pp 165–177.	• *Discusses short-term acidification from sea-salt in the west of Ireland.*
Allott, N.A., Mills, W.R.P., Dick, J.R.W., Eacrett, A.M., Brennan, M.T., Clandillon, S., Phillips, W.E.A., Critchley, M. and Mullins, T.E. (1990) *Acidification of surface waters in Connemara and South Mayo – current status and causes*. Dublin, Du Quesne Limited. 61 pp.	• *Forestry promotes an increase in acidity and dissolved organic matter, as well as Al, in poorly buffered catchments.*
Allott, T.E.H., Harriman, R. and Battarbee, R.W. (1992) Reversibility of lake acidification at the Round Loch of Glenhead, Galloway, Scotland. *Environmental Pollution* 77, 219-225.	• *There is evidence of recovery from acidifying deposition due to legislative changes in recent years.* • *Lake biotic communities (Diatoms) have been restored to some extent.* • *Suggests restoring to post-damage communities rather than introducing new communities.*
Alway, F.J., Kitteridge, J. and Methley, W.J. (1933) Composition of forest floor layers under different forest types on the same soil. *Soil Science* 36, 387-398.	• *Referenced in Pritchett and Fischer (1987).* • *Reported that the addition of broadleaved tree leaves increased calcium and nitrogen content and reduced acidity of conifer woodland soils.*
Anderson, M.P. and Bowser, C.J. (1986) The role of ground water in delaying lake acidification. *Water Resources Research* 22, 1101-1108.	• *This study outlines the hydrological characteristics of lakes in small to large catchments.* • *This study also points out that there are conflicting trends in lake acidification.*
Annerberg, R. (1995) *Foreword*. In: Henrikson, L. and Bodin, Y.W. (Eds.) *Liming of acidified waters*. Springer-Verlag, Berlin and Heidelberg.	• *This is an assessment of liming as a form of acidification amelioration and looks at relative successes.*
Anon. (1977) Inventory of Outstanding Landscapes in Ireland. An Foras Forbatha, Dublin.	• *An early landscape description for Ireland.*
Anon. (1987) *Llyn Brianne Acid Waters Project: An investigation into the effects of afforestation and land management on stream acidity: First technical summary report.* Welsh Water Authority. 91 pp.	• *Throughfall is more acid than precipitation.* • *Throughfall beneath oak is generally less than precipitation.* • *Acid neutralisation takes place in ground flora in oak woodlands.* • *Streamwater biology has suffered from the scavenging of pollutants.*
Anon. (1990a) *Forests and nature conservation guidelines*. UK Forestry Commission, HMSO, London.	• *Early biodiversity guidelines in UK conifer woodlands.*
Anon. (1990b) *Forests and surface water acidification*. UK Forestry Commission, HMSO, London.	• *A general outline of water acidification and the role that conifer woodlands have in augmenting deposition through pollutant scavenging.*
Anon. (1990c) *Acidic deposition and Adirondack forest soil fertility: An appraisal*. New York State Energy Research and Development Authority Report 90-5.	

REFERENCE	PRINCIPAL POINT(S)
Anon. (1991) *Acid rain - Critical and target loads maps for the United Kingdom.* Air Quality Division, Department of the Environment, London.	• *Review of critical loads for the UK that establishes critical load targets for the UK.*
Anon. (1992a) *Critical loads and acid deposition for UK freshwaters*. Critical Loads Advisory Group – Sub-group on freshwaters: Research Paper No. 5, ECRC, University College London.	• *UK critical loads report.*
Anon. (1992b) *Critical and target loads maps for freshwaters in Great Britain.* Critical Loads Advisory Group: 3rd Report to the Department of the Environment, London, HMSO.	• *UK critical loads report.*
Anon. (1995a) *Critical loads of acid deposition for United Kingdom freshwaters*. Critical Loads Advisory Group – Sub-group on freshwaters, ITE, Penicuik.	• *UK critical loads report.*
Anon. (1995b) *Effects of upland afforestation on water resources: The Blaquhidder Experiment 1981-1991.* Wallingham, Institute of Hydrology Report No. 131, 51 pp.	• *A long-term research programme yielding much information on the effects of afforestation on upland catchments (mainly through acidification).* • *Recommends that forestry programmes be altered significantly in response to data.*
Anon. (1996a) *Mapping and modelling environmental acidification in the United Kingdom*. Critical Loads Advisory Group, Institute of Terrestrial Ecology, Penicuik.	• *UK critical loads report.*
Anon. (1996b) *Growing for the future: A strategic plan for the development of the forestry sector in Ireland.* Department of Agriculture, Food and Forestry, Dublin, Government Publications.	• *Governmental report.* • *The rate of afforestation is currently the highest in Europe with a projected target of 20,000 ha per annum from 1996 to 2030 (though recent governmental cutbacks may reduce or negate this statistic).*
Anon. (1997a) *Sustainable development: A strategy for Ireland*. Department of Environment and Local Government, Dublin, Government Publications. 258 pp.	• *Sets annual broadleaf planting target at 20% of all planting.* • *Sets criteria for sustainable forest management (p59).*
Anon. (1997b) *Deposition fluxes of acidifying compounds in the United Kingdom.* Critical Loads Advisory Group, Institute of Terrestrial Ecology, Penicuik.	• *UK critical loads report.*
Anon. (1997c) *Communication to the Council and the European Parliament on a Community Strategy to Combat Acidification.* Brussels, EC, COM (97) 88 final.	• *The primary air pollutants implicated in the acidification of the EU are* SO_2 *mainly from combustion of oil and coal,* NO_X *mainly from vehicular combustion and* NH_3 *from agricultural activities.* • *Sets interim targets for reduction of emissions, alterations of EU-funded programmes such as CAP as well as recommends a unifying of critical loads.*

REFERENCE	PRINCIPAL POINT(S)
Anon. (1997d) *Modelling surface water acidification in the UK.* Wallingham, Institute of Hydrology Report No. 131, 54 pp.	• *Outline of the MAGIC model and its application.* • *As a result of research three aspects of the acidification process are incorporated in the model: 1. mineral uptake by growing forests; 2. enhanced dry and occult deposition; 3. decreased water yield concentrating pollutants in surface waters.*
Anon. (1998a) *Management plan for forested streams within the Tweed catchment.* The Tweed Foundation, Melrose.	• *Unable to source this publication within the timeframe of the study (out of print).* • *Referenced in Tervet (2001) as identifying catchments with conifer woodland stands as sensitive and requiring careful management.*
Anon. (1998b) *Native Woodlands of Scotland.* UK Forestry Commission, Edinburgh.	• *Outlines Scotland's woodland heritage.*
Anon. (1999) *Forestry and the National Heritage: Policies and priorities*. Kilkenny, The Heritage Council. 64 pp.	• *A cautious approach is recommended to afforestation in order to avoid alterations to freshwater systems and catchments (p. 21).* • *'Large-scale new planting should only occur where the risks of adverse impacts from afforestation are known to be acceptably low'.* • *Urgent updating of forestry and fisheries guidelines in needed.* • *Sensitive areas need to be identified.*
Anon. (2000a) *Irish National Forest Standard.* Forest Service, Department of the Marine and Natural Resources.	
Anon. (2000b) *Code of Best Forest Practice - Ireland.* Forest Service, Department of the Marine and Natural Resources, Dublin.	• *Code of best practice that includes sustainable forest management prescriptions.*
Anon. (2000c) *Forest biodiversity guidelines*. Forest Service, Department of the Marine and Natural Resources, Dublin.	• *Guidelines for biodiversity stressing the importance of mixed species woodlands as well as a mix of canopy heights, tree ages and other parameters.*
Anon. (2000d) *Forest harvesting and the environment guidelines*. Forest Service, Department of the Marine and Natural Resources, Dublin.	• *Guidelines for harvesting that minimise the impact on the soil and other habitats such as rivers.*
Anon. (2000e) *Forestry and archaeology guidelines*. Forest Service, Department of the Marine and Natural Resources Dublin.	• *Archaeology guidelines.*
Anon. (2000f) *Forestry and the landscape guidelines.* Forest Service, Department of the Marine and Natural Resources Dublin.	• *Sensitivity to the patterns in the landscape, cultural heritage and so on mean that existing landscape features such as trees, hedgerows and streams must be protected in new afforestation projects.*
Anon. (2000g) *Forestry and water quality guidelines*. Forest Service, Department of the Marine and Natural Resources, Dublin.	• *Water quality guidelines including buffer areas and species choices.*
Anon. (2000h) *Forests and water guidelines.* 3rd Edition (with amendments). UK Forestry Commission, Edinburgh.	• *This is the most comprehensive set of guidelines to date.* • *Mitigation methods for acidification are listed.* • *Prevention of acidification and sedimentation are paramount.* • *Biodiversity is promoted through a variety of sustainable forest management prescriptions.*

REFERENCE	PRINCIPAL POINT(S)
Anon. (2000i) *Forest conditions in Europe – 2000 Executive Report.* UN/ECE and EC, Geneva. 33 pp.	
Anon. (2000j) *Forest conditions in Europe – 2000 Technical Report*. UN/ECE and EC, Geneva. 85 pp.	• *Ireland had no incidences of air pollution damage to forest canopies in 1998.* • *Irish forests have had few impacts on crown conditions.*
Anon. (2001a) *Native Woodland Scheme.* Forest Service, Department of the Marine and Natural Resources, Dublin. 22 pp.	• *General outline of the Native Woodland Scheme.*
Anon. (2001b) *United Kingdom Acid Waters Monitoring Network*. Department of the Environment, Transport and the Regions, UK.	• *Information brochure with details of a fall in* SO_2 *and* NO_X *emissions between 1980 and 1998 and a corresponding rise in the return of fish (trout) populations in some streams.*
Anon. (2001c) *The Neighbourwood Scheme.* Forest Service, Department of the Marine and Natural Resources, Dublin.	• *Scheme outline and description.*
Anon. (2002a) *Native Woodland Manual: Procedures, standards and decision support for the Native Woodland Scheme*. Forest Service, Department of the Marine and Natural Resources, Dublin. 60 pp.	• *Guide for planners for the Native Woodland Scheme.* • *Outlines acceptable species including birch, Scots pine (though not a native per se) and oak.* • *Outlines 'unplantable sites' (p.31) including acid moorland and 'high-lying sites'.*
Anon. (2002b) *United Kingdom Acid Waters Monitoring Network – Data Report for 2001-2002 (Year 14)*. 178 pp.	• *Data on the UKAWMN.*
Anon. (2003a) *Forest condition in Europe – 2003 Executive Report*. UN/ECE and EC, Geneva. 43 pp.	
Anon. (2003b) *Europe's environment – the 3rd assessment*. European Environmental Agency, Brussels. http://reports.eea.eu.int/environmental_assessment_report_2003_10/en/tab_content_RLR	• *A comprehensive report on the quality of Europe's air, water, forestry and agriculture.* • *Emissions of acidifying gasses have decreased significantly in most EU member states (pre enlargement).*
Anon. (2003c) *United Kingdom Acid Waters Monitoring Network – Data Report for 2002-2003 (Year 15).* 178 pp.	• *Annual report for the UKAWMN.*
Anon. (2003d) *Forests and water guidelines*. UK Forestry Commission, Edinburgh, 66 pp.	• *Areas at risk for scavenging effect should be examined using critical loads criteria before any planting.* • *Broadleaved woodland has not as severe an effect as conifer; however, large-scale planting of broadleaved trees needs to be investigated for potential impact.* • *Existing forests need to be re-designed to ensure a wide range of ages and species mixes as possible.* • *Future plantations pose less risk of scavenging due to reduced emissions.*
Anon. (2004) *United Kingdom Forest Standard: The Government's Approach to Sustainable Forestry.* UK Forestry Commission, Edinburgh.	• *Policy document than includes suggestions such as mixed species planting, continuous cover forestry and short rotation forestry as being the way forward.*

REFERENCE	PRINCIPAL POINT(S)
Appelberg, M., Lingdell, P-E. and Andrén, C. (1995) Integrated studies of the effects of liming acidified waters (ISELAW-Programme). *Water, Air and Soil Pollution* 85, 883-888.	• *Time is an important factor in liming programmes.* • *Long-term changes are slower than was estimated.*
Ashenden, T.W. and Bell, S.A. (1988) Growth responses of birch and Sitka spruce exposed to acidified rain. *Environmental Pollution* 51, 153-162.	• *Rainfall, at a typical pH of between 3.5 – 4.5, is unlikely to affect adversely the growth of birch on a wide range of soils.*
Ashmore, M.R. (1994) *Critical levels and agriculture in Europe.* In: J. Fuhrer and B. Achermann (Eds.) *Critical levels for ozone: A UNECE workshop report.* pp. 22–40.	• *Reports on long-term damage caused by Ozone O3 which is phytotoxic.*
Atkinson, M.D. (1992) *Betula pendula* Roth. (B. verrucosa Ehrh.) and *B. pubescens* Ehrh. *Journal of Ecology* 80, 837-870.	• *Complete morphology and growing description of birch.* • *Roots become horizontal at around 30 cm – significance for shallow soils.* • *Birch requires early mycorrhizal associations to become established successfully.* • *B. pubescens prefers wetter soils, B. pendula drier soils.* • *Birch is a 'soil improver' and may ultimately produce deacidified soils.* • *Birch is extremely high in biodiversity.*
Aubertin, G.M. and Patric, J.H. (1972) Quality water from clearcut forest land? *Northern Logger and Timber Processor* 14-15 and 22-23.	• *Extent of harvest and felling practises has an influence on water quality especially in the area of nutrient loss.* • *Nutrient losses least in areas of regeneration and scrub, in the riparian zone.*
Augusto, L., Ranger, J., Binkley, D. and Rothe, A., (2002) Impact of several common tree species of European temperate forests on soil fertility. *Annals of Forest Science* 59, 233–253.	• *Review of the effect that trees have on certain soils.*
Aust, W.M. (1994) Best management practices for forested wetlands in the Southern Appalachian Region. *Water, Air, and Soil Pollution* 77, 457-468.	• *Harvesting and road construction and after usage lead to heavy impact on afforested wetland areas and freshwater streams.*
Badea, O., Tanase, M., Georgeta, J., Anisoara, L., Peiov, A., Uhlirova, H., Pajtik, J., Wawrzoniak, J. and Shparyk, Y. (2004) Forest health status in the Carpathian Mountains over the period 1997-2001. *Environmental Pollution* 130, 93-98.	• *Tree age, drought, ozone and acid deposition are shown to affect crown condition.* • *Broadleaved trees were less damaged than conifers.* • *The influence of air pollution cannot be differentiated from other factors contributing to defoliation.*
Baker, J.P., van Sickle, J., Gagen, C.J., deWalle Jnr., D.R., Sharpe, W.F., Carline, R.F., Baldigo, B.P., Murdoch, P.S., Bath, D.W., Krester, W.A., Simonin, H.A. and Wigington, P.J. (1996) Episodic acidification of small streams in the northeastern United States: effects on fish populations. *Ecological Applications* 6, 422-437.	• *The effects of acidification on stream populations including the effects of aluminium toxicity.*
Ball, D.F. (1975) *Processes of soil degradation: a pedological point of view.* In: J.G. Evans, S. Limbrey and H. Cleere (Eds.) *The effect of man on the landscape: the highland zone*, 20-27. Council for British Archaeology Research Report, No. 11.	• *In temperate regions of the world, the natural tendency in soil development is towards acidification.*

REFERENCE	PRINCIPAL POINT(S)
Barber, S.A. (1984) *Soil nutrient bioavailability*. New York, John Wiley and Sons. 398 pp.	• *Soluble aluminium in the soil reduces root penetration and increases the possibility of drought.* • *Soluble aluminium is particularly a problem in the subsoil, as they are not readily buffered by liming.*
Barth, H. (Ed.) (1989) *Effects of land use in catchments on the acidity and ecology of natural surface waters: Air Pollution Research Report 13*. Conclusion p. 217. Commission for the European Communities, Brussels.	• *UK studies have shown that remediation using lime is effective in reducing acidity but the long-term efficiency of such techniques has yet to be shown.*
Bartsch, N. (2000) Element release in beech (*Fagus sylvatica* L.) forest gaps. *Water, Air, and Soil Pollution* 122, 3-16.	• *This is a study carried out throughout Germany.* • *Shows that liming increases resilience to acidification and promoted vegetation growth, thus the retention of elements.* • *Spruce has higher deposition rates than beech.*
Battarbee, R.W. (1997) *Introduction*. In: Mackay, A.W. (Ed.) *Surface water acidification: the increasing importance of nitrogen*. Environmental Change Research Centre Research Report No 41, University College London.	• *Unable to source this publication within the timeframe of the study.*
Battarbee, R.W., Flower, R.J., Stevenson, A.C. and Rippey, B. (1985) Lake acidification in Galloway: a palaeoecological test of competing hypotheses. *Nature* 314, 350-352.	• *Diatom species in lakes can be used as indicators of lake acidity due to their sensitivity.* • *Diatom studies in sediments permitted historical reconstruction of acidification.*
Battarbee, R.W., Stevenson, A.C., Rippey, B., Fletcher, C., Natkanski, J., Wik, M. and Flower, R.J. (1989) Causes of lake acidification in Galloway, southwest Scotland: a palaeoecological evaluation of the relative roles of atmospheric contamination and catchment change for two acidified sites with non-afforested catchments. *Journal of Ecology* 77, 651-672.	• *This is a comprehensive review that also details how historical data has been used to confirm previous studies' findings on atmospheric acidic deposition.* • *Finds that non-afforested (peat) catchments with ground cover do not have significant impact on lake acidification.*
Baur, S. and Feger, K.H. (1992) Importance of natural soil processes relative to atmospheric deposition in the mobility of aluminium in forested watersheds of the Black Forest. *Environmental Pollution* 77, 99-105.	• *Dissolved Organic Carbon (DOC) was found to ameliorate effects of aluminium.* • *Soil properties favouring the transport of DOC to mineral soil are important in Al mobilisation.* • *Note: Deciduous tree leaf litter improves soil properties via the pedogenic process and chelation (Pritchett and Fisher 1987).*
Beck, J.P. and Grennfelt, P. (1993) Estimate of ozone production and destruction over northwestern Europe. *Atmospheric Environment* 28, 129–140.	• *Further exploration of the role of O_3 in the acidification process.*
Beier, C. and Gundersen, P. (1989) Atmospheric deposition to the edge of a spruce forest in Denmark. *Environmental Pollution* 60, 257-271.	• *Deposition through canopy varies with distance from forest edge and may be up to twenty times that of an open area.* • *Uses a leaf area index (LAI) method for measurement.*

REFERENCE	PRINCIPAL POINT(S)
Bengtsson, B., Dickson, W. and Nyberg, P. (1980) Liming acid lakes in Sweden. *Ambio* 9, 34-36.	• *Comments on the possible need for diverse species in the woodland stand to prevent 'problems'.*
Berg, B. and Meentemeyer, V. (2002) Litter quality in a north European transect versus carbon storage potential. *Plant and Soil* 242, 83-92.	• *Litter volume ought to be increased with a warmer climate.*
Bergquist, B. (1999) *Impact of land use and buffer zones on stream environments in woodland and agricultural areas - a literature review.* Fiskeriverket Rapport 1999, 3, Fiskeriverket, Goteborg, Sweden.	• *Identifies most promising form of liming for lakes of differing retention times.* • *Recommends that overdosing treatments would ensure successful buffering of acidification in lakes.* • *Speculates that a riparian buffer zone should be 20-30 m in width.* • *Note: species in this study are native conifers in Sweden and thus may not be appropriate in and Irish context.*
Best, G.A. (1994) *Afforestation and forestry practice.* In: Maitland, P.S., Boon, P.J. and McLusky, D.S. (Eds.). *The fresh waters of Scotland*. Wiley, Chichester, UK.	• *Suggests that riparian buffer zones be 10 times the width of the stream or river channel.*
Bibby, C.J., Aston, N. and Bellamy, P. (1989) Effects of broadleaved trees on birds of upland conifer plantations in North Wales. *Biological Conservation* 49, 17-29.	• *A higher proportion of broadleaved trees in new plantations have been shown to increase bird populations slightly (in the UK).* • *This has not yet been shown in Ireland (Pithon et al. 2004).*
Billett, M.F., Fitzpatrick, E.A. and Cresser, M.S. (1988) Long-term changes in the acidity of forest soils in North-East Scotland. *Soil Use and Management* 4:3, 102-107.	• *This study looked at Scots pine, spruce species and larch.* • *Soil acidification and humus accumulation greatest in older stands.* • *Regeneration encourages thick organic horizon and a nutrient and pH sink.*
Binkley, D. (1995) *The influence of tree species on processes and patterns*. In: Mead, D.J. (Ed.) Cornforth, Proceedings of the Trees and Soil Workshop 1994., pp 1-33. University Press, Canterbury, New Zealand.	• *Different species may modify local microclimate as well as the physical properties of the soil in different ways. May also alter biological communities.*
Binkley, D., Driscoll, C.T., Allen, H.L., Schoeneberger, P. and McAvoy, D. (Eds.) (1989) *Acidic deposition and forest soils*. Ecological Studies 72, Springer-Verlag. 149 pp.	• *Introduction contains overview of forest acidification processes, especially the pathways of acidic deposition impacts.*
Blackie, J.R., Ford, E.D., Horne, J.E.M., Kinsman, D.J.J., Last, F.T. and Moorhouse, P. (1980) *Environmental effects of deforestation: an annotated bibliography.* Occasional Publication No 10, Freshwater Biological Association, Ambleside.	• *Literature review that outlines, among other things, the extent of erosion and sediment transport during and after harvesting in several countries.* • *Logging causes wide temperature changes locally.*
Blackwell, M.S.A., Hogan, D.V. and Maltby, E. (1998) *The use of conventionally and alternatively located buffer zones for the removal of nitrate from diffuse agricultural run-off*. Proceedings of the International Association on Water Quality 3rd International Conference on Diffuse Pollution, Volume 1. Scottish Environment Protection Agency, Stirling, Scotland.	• *Recognised that riparian buffer zones in afforested areas are not completely successful at nutrient throughflow interception following woodland harvesting.* • *Constructed wetlands are more successful at intercepting high nutrient runoff during and after harvesting.*

REFERENCE	PRINCIPAL POINT(S)
Bolger, T. (2002) *Examining the effects of land-use, particularly afforestation, on biodiversity.* In: L. MacLennan (Ed.) *Opportunities for biodiversity enhancement in plantation forests*. COFORD Proceedings, Dublin. p. 23-28.	• *Specific studies on flora and fauna are needed in Ireland.* • *Both habitat and landscape features need to be taken into account when assessing the effects of land use on biodiversity.* • *Biodiversity can have conflicting meanings.*
Bolger, T., Heneghan, L. and McCarthy, F. (1996) *Impacts of anthropogenic atmospheric pollution on forest soil processes*. In: P. S. Giller and A. A. Myers (Eds.) Disturbance and Recovery of Ecological Systems. Proceedings of the Royal Irish Academy, National Committee for Biology Annual Seminar, pp 127-135.	• *Soil fauna are likely to be altered by deposition and this may have a knock-on effect to the nutrient dynamics of the catchment system.*
Boon, P. J. (1992) *Essential elements in the case for river conservation*. In: Boon, P. J., Calow, P. and Petts, G. E. (Eds.) *River conservation and management*. Wiley, Chichester, UK.	• *Detailed management prescriptions for river conservation.* • *Asserts that changes in stream and river structure (physically), water quality and the quantity of water have adverse effects on the diversity of the aquatic ecosystem.*
Borg, H., Andersson, P., Nyberg, P. and Olofsson, E. (1995) Influence of wetland liming on water chemistry of acidified mountain streams in Lofsdalen, central Sweden. *Water, Air, and Soil Pollution* 85, 907-912.	• *Liming stabilised pH of water run-off and reed leaching of metals.* • *Local variation of topography and soil type may be significant factor.*
Bowman, J. J. (1991) *Acid-sensitive surface waters in Ireland*. Environmental Research Unit, Dublin. 321 pp.	• *Extensive study of acid-sensitive waters in Ireland.* • *Naturally occurring acid-sensitive waters are mainly found in locations with a bedrock consisting of shale, gneiss, granite and sandstone.* • *Western seaboard mainly as well as the Wicklow uplands.*
Bowman, J.J. and Bracken, J.J. (1993) *Effect of run-off from afforested and non-afforested catchments on the survival of brown trout* Salmo trutta *L. in two acid-sensitive rivers in Wicklow, Ireland.* Biology and Environment: Proceedings of the Royal Irish Academy, 93B, 143–150.	• *Discusses in detail the ecological effects of acid runoff.*
Boyle, G.M., Farrell, E.P. and Cummins, T. (1997a) *Monitoring of Forest Ecosystems in Ireland, FOREM 3 Project, Final Report.* Forest Ecosystem Research Group Report Number 21. Department of Environmental Resource Management, University College Dublin.186 pp.	• *Though a reduction in emissions of acidifying pollutants has occurred, no corresponding trend was noted.*
Boyle, G.M., Farrell, E.P., Cummins, T., and Nunan, N. (1997b) *Monitoring of Forest Ecosystems in Ireland, FOREM4 and 5 Projects, Final Report*. Forest Ecosystem Research Group Report Number 48. Department of Environmental Resource Management, University College Dublin.164 pp.	• *Ireland is heavily influenced by marine ions, notably sodium and chloride.* • *Deposition is higher in the eastern half of the country and is combined with occasional easterly wind which often carries higher volumes of pollutants.* • *Conifers are more tolerant of acid stress.*
Boyle, K., Farrell, E.P. and Gardiner, J.J. (1982) Harvesting: its effect on the physical properties of soils. *Irish Forestry* 39:2, 94-98.	• *Demonstrates the vulnerability of forest soils to harvesting and compaction.*

REFERENCE	PRINCIPAL POINT(S)
Bradley, D.C. and Ormerod, S.J. (2002) Long-term effects of catchment liming on invertebrates in upland streams. *Freshwater Biology* 47, 161-171.	• *Catchment liming does ameliorate the effects of acidification but it can place some wetland species at risk.*
Bradshaw, R.H.W. and Hannon, G.E. (1988) *Human influence in the decline of the Irish forest ecosystem.* pp. 21-30. In: F. Salbitano (Ed.) *Human influence on forest ecosystems development in Europe.* ESF FERN-CNR, Pitagora Editrice, Bologna.	• *Lake islands in Connemara are wooded with a variety of species but are not relict woodlands.* • *Lake island woodland soils are deep mor-mull in contrast to surrounding peat soils.* • *Grazing is the limiting factor.*
Brandtberg, P.-O., Bengtsson, J. and Lundkvist, H. (2004) Distributions of the capacity to take up nutrients by *Betula* spp. and *Picea abies* in mixed stands. *Forest Ecology and Management* 198, 193-208.	• *Results that do not support the thesis that broadleaved tree species take up more nutrients than and conifer tree species .*
Bravington, M.V., Rosenberg, A.A., Andersen, R., Muniz, I.P. and Beddington, J.R. (1990) *Modelling and quantitative analysis of the impact of water quality on the dynamics of fish populations.* In: Mason, B.J. (Ed.) *The Surface Waters Acidification Programme*. Cambridge University Press.	• *Concludes that up to 20 years may pass before evidence of localised fish extinction.*
Bray, J.R. and Gorham, E. (1964) Litter production in forests of the world. *Advances in Ecological Research* 2, 101-157.	• *Conifers have a higher litter production ability than broadleaves in European forests.* • *This has since been hotly disputed (Liu at al. 2004).*
Brogan, J. and Crowe, M. (2004) *A proposed approach to developing a soil protection strategy for Ireland.* Unpublished EPA document, OECD Expert Meeting on Soil Erosion and Soil Biodiversity Indicators. http://webdomino1.oecd.org/comnet/agr/soil_ero_bio.nsf	• *There is a need for soil protection policies in Ireland.* • *Crop production accelerates soil acidification.* • *Soil type and location are key factors when determining the location of new forests.* • *The impact of conifer forestry will vary with soil type, site location and species chosen.*
Brown, A.H.F. and Iles, M.A. (1991) Water chemistry profiles under four tree species at Gisburn, NW England. *Forestry* 64, 2, 169-187.	• *Demonstrates that coniferous forests are more efficient scavengers of ions from the atmosphere than broadleaf forests.*
Brown, D.J.A. (1983) The effect of calcium and aluminium concentrations on the survival of brown trout (*Salmo trutta*) at low pH. *Bulletin of Environmental Contamination and Toxicology* 30, 582-587.	• *Provides evidence of the interrelationship of Ca, Al and pH in fish toxicity and mortality.*
Buckton, S.T., Brewin, P.A., Lewis, A., Stephens, P. and Ormerod, S.J. (1998) The distribution of dippers, *Cinclus cinclus* (L.) in the acid-sensitive region of Wales 1984-95. *Freshwater Biology* 39, 387-396.	• *Noted the interrelationship between the dipper and acidified river systems.* • *Dippers are absent from sites where Al is high.* • *Dippers were found more often in locations with broadleaf trees in the riparian zone and hardly any in areas where there were conifers in the riparian zone.*
Bulfin, M. (1991) *The right trees in the right place*. In: Mollan, C. and Maloney, M. (Eds.) *The right trees in the right place*. pp 99-107. Royal Dublin Society Proceedings, 4, RDS, Dublin.	• *Afforestation on western blanket peats is not productive and damaging to sensitive habitats.* • *Ash, cherry, sweet chestnut, southern beech, sycamore, poplar and birch are well within the same rotation span as Sitka spruce.*

REFERENCE	PRINCIPAL POINT(S)
Burns, J.C., Coy, J.S., Tervet, D.J., Harriman, R., Morrison, B.R.S. and Quine, C.P. (1984) The Loch Dee Project: a study of the ecological effects of acid precipitation and forest management on an upland catchment in south west Scotland – 1: Preliminary investigations. *Fisheries Management* 15,145-167.	• *Unable to source this publication within the timeframe of the study (out of print).* • *Identified in Tervet (2001) as one of many authors who report declines in fish population which can be ascribed to acidification, though at this stage conifer plantations are blamed by only some.*
Cameron, A. D. (1996) Managing birch woodlands for the production of timber. *Forestry* 69:4, 357-371.	• *Birch can produce valuable timber in relatively short rotations on good sites (40 years is possible).* • *Birch on upland, infertile soils is unlikely to produce high quality timber but may benefit wildlife and is best managed for that.* • *Birch may produce pulpwood and firewood on poor sites.*
Campbell, G. and Vincent, K. (1997) *Acid deposition monitoring in the UK.* In: Mackay, A.W. (Ed.) *Surface water acidification: the increasing importance of nitrogen*. Environmental Change Research Centre Research Report No 41, University College London.	• *Unable to source this publication within the timeframe of the study.* • *Identified by commentators as making reference to the beneficial effects that broadleaf tree planting in water catchments may have.*
Cannell, M.G.R. (1999) Environmental impacts of forest monocultures: water use, acidification, wildlife conservation and carbon storage. *New Forests* 17, 239-262.	• *Found that rainfall interception higher for conifer plantations (20 – 85% of total precipitation) and less for broadleaves.* • *Water yield decreases of 1.5 – 2% for every 10% of catchment forested.*
Cape, J.N. and Fowler, D. (1986) Rainfall acidity in northern Britain - exploring the data. *Water, Air, and Soil Pollution* 30, 239-244.	• *Early data on acidification and scavenging effects of afforested areas.* • *Average pH was a poor indicator of acid episode frequency.*
CLAG (1994) *Critical loads of acidity in the United Kingdom.* Critical Loads Advisory Group Summary Report. Department of Environment, UK, 61 pp.	• *Report on critical loads.*
Clayton, J.L., Kennedy, D.A. and Nagel, T. (1991) Soil response to acid deposition, Wind River Mountains, Wyoming: I. Soil properties. *Soil Science Society of American Journal* 55, 1427–1433.	• *One of the many studies that have established the direct connection between habitat damage an (anthropogenic) acidification.*
Clenaghan, C., Giller, P.S., O'Halloran, J. and Hernan, R. (1998) Stream macro-invertebrate communities in a conifer-afforested catchment in Ireland: Relationships to physio-chemical and biotic factors. *Freshwater Biology* 40, 175-193.	• *Shows how conifer-afforested areas can affect biota of freshwater.*
Collins, B.D. and Pess, G.R. (1997) Evaluation of forest practices prescriptions from Washington's watershed analysis programme. *Journal of the American Waterworks Association* 33:5, 969-996.	• *Some forestry management practices are based on 'untested' theories of forestry.* • *Afforestation programmes carried out without a proper review of the total impact based on scientific research.*
Collins, J.F. and Cummins, T. (Eds.) (1996) *Agroclimatic atlas of Ireland*. AGMET, Dublin, 190 pp.	• *Agroclimate atlas of Ireland.*

REFERENCE	PRINCIPAL POINT(S)
Cook, J.M., Edmunds, W.M. and Robins, N.S. (1991) Groundwater contribution to an acid upland lake (Loch Fleet, Scotland) and the possibilities for amelioration. *Journal of Hydrology* 125, 111-128.	• *Shows that buffering of pH in lake waters may be achieved with the extraction of groundwater in the upper levels of the catchment with no ecological effect.*
Cooper, A. (1985) Vegetation and soils of seminatural deciduous woods in northeast Ireland. *Vegetation* 64, 67-74.	• *Soil water status is derivative of human activities.*
Cooper, D.M., Jenkins, A., Skeffington, R. and Gannon, B. (2000) Catchment-scale simulation of stream water chemistry by spatial mixing: theory and application. *Journal of Hydrology* 233, 121-137.	• *Hypothesise that river water can be viewed as a mixture of waters from different landscape types.* • *Sulphate can also be derived from agricultural soils and not only nitrates.*
Correll, D.L. (1997) *Buffer zones and water quality protection: general principals.* pp. 7-20. In: Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (Eds.) *Buffer zones: their processes and potential in water protection.* Hertfordshire. Quest Environmental.	• *Groundwater is influenced by the denitrification process. If a forest is well buffered, the effects of logging are mitigated greatly.* • *As H^+ moved through a wooded buffer zone, plant assimilation of nitrates and denitrification consume them and thus pH increases to less toxic levels (cross-referencing Peterjohn and Correll 1986).*
Correll, D.L., Miklas, J.J., Hines, A.H. and Schafer, J.J. (1987) Chemical and biological trends associated with acidic atmospheric deposition in the Rhode River watershed and estuary. *Water, Air, and Soil Pollution* 35, 63-86.	• *In poorly buffered soils, groundwater is acidified from N fertilisation leached from crops.*
Cosby, B.J., Hornberger, G.M., Galloway, J.N. and Wright, R.F. (1985) Modelling the effects of acid deposition: assessment of a lumped-parameter model of soil water and streamwater chemistry. *Water Resources Research* 21, 51-63.	• *Found that one could group acid-deposition parameters together in order to predict water sensitivity to acidification.* • *Base cation variations are driven by soil properties, not notably PCO_2.*
Cosby, B.J., Jenkins, A., Ferrier, R.C., Miller, J.D. and Walker, T.A.B. (1990) Modelling stream acidification in afforested catchments: long-term reconstructions at two sites in central Scotland. *Journal of Hydrology* 120, 143-162.	• *Showed that a calibrated model can provide an excellent tool for comparison of relative effects of deposition and afforestation on soil and surface water acidification.* • *Model may also be useful in determining the likely effects of the reduction of future deposition with alterations in forestry practises.*
Cosby, B.J., Whitehead, P.G. and Neale, R. (1986) A preliminary model of long-term changes in stream acidity in south-western Scotland. *Journal of Hydrology* 84, 381-401.	• *Assuming that deposition remains at 1984 levels, the model predicts that there will be a general decline in pH.* • *A 50% reduction in deposition is likely to increase pH but not to pre-acidification levels.*
Cresser, M.S., Billett, M. and Skiba, U. (1989) The effect of acid deposition on soils. In: Longhurst, J.W.S. (Ed.) *Acid deposition: Sources, effects and controls.* pp. 169–195. British Library Technical Communications.	• *This is one of the many studies that establish the linkages acidification and anthropogenic activities.*
Cresser, M.S., Dawod, A., Gammack, S., White, C. and Yesmin, L. (1995) *Department of the Environment Report 1993–1995.* Department of Plant and Soil Science, University of Aberdeen, Aberdeen, 141 pp.	• *This study indicated that seasalt deposition may have an amelioration effect on the acidification process.*

REFERENCE	PRINCIPAL POINT(S)
Cronan, C.S. and Grigel, D.F. (1995) Use of calcium/aluminium ration as indicators of stress in forest ecosystems. *Journal of Environmental Quality* 24, 209-226.	• *Ca/Al ratio is an ideal stress indicator or a potential indicator of toxicity in ecological risk management of woodlands.*
Cross, J. (1987) Status and value of native broadleaved woodlands. *Irish Forestry* 44:2, 81-88.	• *Sandy, acidic soils would have carried Quercus robur, pine and birch around the time of the commencement of woodland clearance in Ireland in the Bronze Age.*
Cummins, T. and Farrell, E.P. (2003) Biogeochemical impacts of clearfelling and reforestation on blanket-peatland streams: II – major ions and dissolved organic carbon. *Forest Ecology and Management* 180, 557-570.	• *There are opportunities for replacement forests to increase pH and buffering capacity in acid-sensitive areas.* • *Single-species research is not adequate when seeking to develop new processes of land management.*
Cunningham, D.A., Farrell, E.P. and Collins, J.F. (1999) Soil responses to land-use change - a study in south-west Ireland. *Forest Ecology and Management* 119, 63-76.	• *Soil water content and surface runoff have increased as a result of woodland clearance.* • *Wooded soils drier than on non-wooded sites.* *On acid soils, woodland removal has accelerated podzolisation in well-drained, and gleisation in poor-drained, soils.*
Curtis, C., Allott, T., Hall, J., Harriman, R., Helliwell, R., Hughes, M., Kernan, M., Reynolds, B. and Ullyet J. (2000) Critical loads of sulphur and nitrogen for freshwaters in Great Britain and assessment of deposition reduction requirements with the First-order Acidity Balance (FAB) model. *Hydrology and Earth System Sciences* 4:1, 125-140.	• *UK critical loads report.* • *Afforestation has had a deleterious effect on water catchments.*
Curtis, C., Murlis, J., Battarbee, R., Bull, K., Campbell, G., Fowler, D., Jenkins, A., Monteith, D., Ormerod, S. and Reynolds, B. (1999) *Acid deposition in the UK: a review of environmental damage and recovery prospects*. National Society for Clean Air and Environmental Protection, Brighton.	• *Review of acid deposition in the UK.* • *Concludes that reduction of emissions may be better for long term amelioration.*
de Keersmaeker, L., Neirynck, J., Maddelein, D., de Schrijver, C. and Lust, N. (2000) Soil water chemistry and revegetation of a limed clearcut in a nitrogen saturated forest. *Water, Air and Soil Pollution* 122, 49-62.	• *Though liming enhances vegetation and reduces NO_3 ion concentrations in the soil water, this water is still above safety levels for potability.*
de Kluizenaar, Y. (1997) *Passive sampling of atmospheric sulphur dioxide and ammonia in Ireland.* Forest Ecosystem Research Group, Report No. 19. Department of Environmental Resource Management, University College Dublin. 52 pp.	• *Presents data on dry deposition in Ireland.*
Dimbleby, G. W. (1952) Soil regeneration on the North-East Yorkshire moors. *Journal of Ecology* 40:2, 331-341.	• *Soil will revert to its original type when afforested over time.* • *Birch alters soil type from a thin podzol with an iron pan to a mull horizon with a disintegration of the pan.* • *Liming will bring about mull development faster than birch planting.*

REFERENCE	PRINCIPAL POINT(S)
Dillon, P.J. and LaZerte, B.D. (1992) Response of the Plastic Lake catchment, Ontario, to reduced sulphur deposition. *Environmental Pollution* 77, 211-217.	• *The reductions noticed in Al and pH are due more to emissions regulations than to catchment responses.*
Dobson, M., Hildrew, A.G., Orton, S. and Ormerod, S.J. (1995) Increasing litter retention in moorland streams: ecological and management aspects of a field experiment. *Freshwater Biology* 33, 325-337.	• *Broadleaf leaves are beneficial for invertebrates in an acidified stream.* • *Broadleaf trees were only of major importance in riparian areas when they were sufficiently productive to increase litter and water retention around fallen wood, and may take several tens of years to be effective (Tervet 2001).*
Donnelly, A., Jennings, E. and Allott, N. (2003) *A review of liming options for afforested catchments in Ireland.* Biology and Environment: Proceedings of the Royal Irish Academy, 103B, 91-105.	• *Catchments with acid bedrock particularly susceptible to surface-water acidification.* • *Lack of knowledge on small stream hydrology, residence time in afforested soils and flow paths in Ireland.* • *Liming may be detrimental to wetland ecology especially Sphagnum.* • *It is unsure what the status of liming is under the Water Framework Directive.*
Douglas, G.C. (1995) *Prospects for advanced vegetative propagation and genetic modification of forest species.* In: Pilcher, J.R. and Mac an tSaoir, S.S. (Eds.) *Wood, Trees and Forests in Ireland.* pp. 135-157. Royal Irish Academy, Dublin.	• *Transgenic organisms in forest tree species tend to be used to combat pests and temperature variations.* • *There is a potential for modified trees for tolerance to different soil conditions.*
Driscoll, C.T., Driscoll, K.M., Mitchell, M.J. and Raynal, D.J. (2003) Effects of acidic deposition on forest and aquatic ecosystems in New York State. *Environmental Pollution* 123, 327-336.	• *Acidification has reduced drastically the abundance of aquatic species and there are links to mercury contamination and eutrophication in estuaries.* • *Acidic deposition leads to decline in sugar maple and red spruce in NY.* • *Decreases in pH and increases in aluminium concentrations have diminished species of plankton, invertebrates and fish.*
Driscoll, C.T., Lawrence, G.B., Bulger, A.J., Butler, T.J., Cronin, C.S., Eager, C., Lambert, K.F., Likens, G.E., Stoddard, J.L. and Weathers, K.C. (2001) Acidic deposition in the Northeastern US: sources and inputs, ecosystems effects and management strategies. *BioScience* 51, 180-198.	• *This is a major review of acid deposition studies in the US and Canada.* • *N and S accumulate in forest soils as a result of acid deposition.* • *Reductions in SO_2 emissions have lead to a lowering of S deposition.* • *Recovery will be slow.*
Driscoll, C.T., Postek, K.M., Kretser, W. and Raynal, D.J. (1995) Long-term trends in the chemistry of precipitation and lake water in the Adirondack region of New York, USA. *Water, Air and Soil Pollution* 85, 583-588.	• *This is a study in a watershed that is predominately mixed hardwoods.* • *The study showed no significant change in NO_3 levels.*
Edmunds, W.M. and Kinniburgh, D.G. (1986) The susceptibility of UK groundwaters to acidic deposition. *Journal of the Geological Society* London, 143, 707-720.	• *This article mainly contains a description of the acidification process and details the various areas in the UK that are susceptible.*
Egglishaw, H., Gardiner, R. and Foster, J. (1986) Salmon catch decline and forestry in Scotland. *Scottish Geographical Magazine* 102:1, 57-61.	• *There is a decline in salmonids in Scotland linked heavily to stream acidification from conifer afforestation.*

REFERENCE	PRINCIPAL POINT(S)
Ek, A., Grahn, O., Hultberg, H. and Renberg, I. (1995) Recovery from acidification in Lake Orvattnet, Sweden. *Water, Air and Soil Pollution* 85, 1795-1800.	• *The recovery of the lake in this study was due to a reduction in sulphate deposition that was shown in a biotic study of the lake.*
Emmett, B.A., Reynolds, B., Stevens, P.A., Norris, D.A., Hughes, S., Gorres, J. and Lubrecht, I. (1993) Nitrate leaching from afforested Welsh catchments - interactions between stand age and deposition. *Ambio* 22, 386-394.	• *A conifer stand that is ~30 years old is a net source of inorganic N.*
Environmental Protection Agency. (2000) *Critical loads and levels: Determination and mapping of critical loads for sulphur and nitrogen levels for ozone in Ireland.* Final Report R&D Series No. 7. (Eds.) Aherne, J. and E.P. Farrell, Johnstown Castle, Co. Wexford. pp. 225.	• *Map of critical loads in Ireland.*
Eriksson, F., Hornstrom, E., Mossberg, P. and Nyberg, P. (1983) Ecological effects of lime treatment of acidified lakes and rivers in Sweden. *Hydrobiologia* 101, 145-164.	• *This was an ecological study.* • *Lime application was very successful in restoring stocking levels.*
Evans, C.D. and Monteith, D.T. (2001) Chemical trends at lakes and streams in the UK Acid Waters Monitoring Network, 1988-2000: Evidence for recent recovery at a national scale. *Hydrology and Earth System Sciences* 5:3, 351-366.	• *Contrasts with earlier results by showing widespread evidence on recovery from the effects of atmospheric acidic deposition.* • *During this time period rainfall volume declined slightly so this may be a factor.*
Evans, C.D., Cullen, J.M., Alewell, C., Kopácek, J., Marchetto, A., Moldan, F., Prechtel, A., Rogora, M., Vesely, J. and Wright, R. (2001b) Recovery from acidification in European surface waters. *Hydrology and Earth System Sciences* 5:3, 283-297.	• *Recovery is strongest in the UK, the Czech Republic and Slovenia, moderate in Scandinavia and weakest in Germany.* • *Overall recovery is noted and thus the effects in emission reduction programmes.*
Evans, C.D., Harriman, R., Monteith, D.T. and Jenkins, A. (2001a) Assessing the suitability of acid neutralising capacity as a measure of long-term trends in acidic waters on two parallel datasets. *Water, Air and Soil Pollution* 130, 1541-1546.	• *ANC must be measured indirectly.* • *Alkalinity or pH are better measurements of recovery and acidification.*
Evans, C.D., Jenkins, A., Helliwell, R.C. and Ferrier, R.C. (1998) Predicting regional recovery from acidification: the MAGIC model applied to Scotland, England and Wales. *Hydrology and Earth System Sciences* 2:4, 543-554.	• *This is a report on a model that may be used to predict recovery from acidification.* • *Noted that recent changes in policy due to agreements on climate change may make the model unreliable as local and global emissions decline.*
Farley, D.A. and Werritty, A. (1989) Hydrochemical budgets for the Loch Dee experimental catchments, Southwest Scotland (1981-1985). *Journal of Hydrology* 109, 351-368.	• *Spatial variability is related to differences in afforestation and land management practices.*

REFERENCE	PRINCIPAL POINT(S)
Farmer, G., Barthelmie, R.J., Davies, T.D., Brimblecombe, P. and Kelly P.M. (1987) Relationships between concentration and deposition of nitrate and sulphate in precipitation. *Nature* 328, 787-789.	• *This is a letter to Nature often quoted in articles for its description of the process of acidification – issue was missing from UCD library.*
Farrell, E.P. (1995) Atmospheric deposition in maritime environments and its impact on terrestrial ecosystems. *Water, Air and Soil Pollution* 85, 123–130.	• *Sea salts may induce short-term acidification of podzols under oak.* • *Speculates on environmental factors that drive the pedogenic process in the region of the study.*
Farrell, E.P. (2001) *Ecological impacts of plantation forests on water and nutrient cycles and ecosystem stability*. In: T. Green (Ed.) *Ecological and Socio-Economic Impacts of Close-to-Nature Forestry.* European Forestry Institute Proceedings, 37, pp 27-34.	• *The dynamic nature of forest systems may impair our understanding of these ecosystems so it is important to develop tests for sustainability.* • *Modern demands may exceed the abilities of sustainable forest management. 'Following the establishment of a plantation, a gradual modification of water and nutrient cycles occurs'.* • *'Coniferous forests are generally considered to be more efficient scavengers of ions from the atmosphere than broadleaf species'.* • *Legacy of previous land use (e.g. agriculture) may be prevalent for years after plantation establishment.*
Farrell, E.P. and Boyle, G.M. (1990) Peatland forestry in the 1990s. 1. low-level blanket bog. *Irish Forestry* 47:2, 69-78.	• *'The potential impact of land use in an ecosystem is inversely related to the complexity of the ecosystem'.* • *Productivity on blanket peatland is relatively high but the return on investment is marginal.*
Farrell, E.P. and Boyle, G.M. (1991) *Monitoring a forest ecosystem in a region of low-level anthropogenic emissions, Ballyhooly project final report.* Project number 8860IR0010, Forest Ecosystem Research Group Report Number 4. Department of Environmental Resource Management, University College Dublin, 47 pp.	
Farrell, E.P., Aherne, J., Cummins, T. and Ryan, M.G. (1997) *Fluxes of water and ions in forest ecosystems*. In: Sweeney, J. (Ed.) *Global change and the Irish environment.* pp. 69-77. Dublin, Royal Irish Academy.	• *Ireland's soils heavily influenced by maritime salt. Climate change as predicted my impact heavily on N fluxes as well as maritime ion deposition.*
Farrell, E.P., Boyle, G.M., Cummins, T., Aherne, J. and van den Beuken, R. (1996a) *Continued monitoring of a forest ecosystem in Ireland, Ballyhooly Final Report.* Forest Ecosystem Research Group Report Number 17. Department of Environmental Resource Management, University College Dublin, 122 pp.	
Farrell, E.P., Cummins, T., Boyle, G.M., Smille, G. W. and Collins, J.F. (1993) Intensive monitoring of forest ecosystems. *Irish Forestry* 50:1, 53–69.	• *High salt inputs are more important than N fertilisation for their impact on Irish waters.* • *N output is low below oak stands.*

REFERENCE	PRINCIPAL POINT(S)
Farrell, E.P., Cunningham, D.A. and Collins, J.F. (1996b) *Impacts of pre-twentieth century deforestation on soil development: a view based on current evidence*. In: Giller, P. S. and Myers, A. A. (Eds.) *Disturbance and recovery of ecological systems*. Proceedings of the Royal Irish Academy, National Committee for Biology Annual Seminar, pp 59-67.	• *Discusses the fact that historical deforestation has serious negative effects and that soil productivity has diminished as a result. This has had knock-on significance for re-afforestation programmes in Ireland and elsewhere.* • *On acid soils subjected to high rainfall, deforestation has caused the development of blanket peat soils.*
Farrell, E.P., van den Beuken, R., Boyle, G.M., Cummins, T. and Aherne, J. (1998) Interception of seasalt by coniferous and broadleaved woodland in a maritime environment in western Ireland. *Chemosphere* 36, 985-987.	• *Interception of seasalt similar for coniferous and deciduous species.* • *Epiphytes (lichens and mosses) may be responsible for high interception on oaks.* • *Acid deposition is high in winter (with consequences for deciduous woodland planting programmes).* • *Watercourse acidification is also dependant on local geology – bedrock and substrate.*
Fenn, M.E. and Bytnerowicz, A. (1997) Summer throughfall and winter deposition in the San Bernardino mountains in southern California. *Atmospheric Environment* 31:5, 673-683.	• *Due to dry accumulation and sudden rain episodes, throughfall contained higher ionic concentrations than polluted forests in Europe.* • *Throughfall was not highly acidic compared to rainfall.*
Ferm, A., Hokkanen, T., Moilanen, M. and Issakainen, J. (1992) Effects of wood bark ash on the growth and nutrition of a Scots pine afforestation in central Finland. *Plant and Soil* 147, 305-316.	• *Discusses the positive values of wood ash revealed in this study.*
Ferrier, R.C., Jenkins, A., Cosby, B.J., Helliwell, R.C., Wright, R. F. and Bulger, A.J. (1995) Effects of future N deposition scenarios on the Galloway region of SW Scotland using a coupled sulphur and nitrogen model (MAGIC-WAND). *Water, Air and Soil Pollution* 85, 707-712.	• *This study used a model that predicts a potential increase in N in surface waters.* • *The increase in N is closely linked to age and extent of different stands of woodlands within a catchment.*
Ferrier, R.C., Wright, R.F., Jenkins, A. and Barth, H. (2003) Predicting recovery of acidified freshwaters in Europe and Canadian introduction. *Hydrology and Earth System Sciences* 7:4, 431-435.	
Fey, M.V., Manson, A.D. and Schutte, R. (1990) Acidification of the pedosphere. *South African Journal of Science* 86:7-10, 403-406.	• *Acidification of the soil is greatly intensified by anthropogenic distortions of the nitrogen and sulphur cycles.* • *New (exotic tree) afforestation programmes may accelerate soil acidification more than 'acid rain'.*
Fillion, N., Probst, A. and Probst, J.L. (1998) Natural organic matter contribution to throughfall acidity in French forests. *Environment International* 24:5/6, 574-558.	• *Organic acids in throughfall are weak.* • *Organic contribution to ANC, and thus buffering of pH, is important for waters with a pH of between 3.8 and 6.6.* • *Acid-base properties similar for all sites despite differences in location, geology, climates and vegetation.*
Fjellheim, A. and Raddum, G.G. (1995) Benthic animal response after liming of three south Norwegian rivers. *Water, Air and Soil Pollution* 85, 931-936.	• *There was a relative increase in abundance of acid-sensitive invertebrates downstream of a catchment after liming.*
Foth, H.D. and Ellis, B.G. (1988) *Soil fertility.* New York, John Wiley and Sons. 212 pp.	• *Soil pH is correlated with precipitation and many soils in humid regions are acid.*

REFERENCE	PRINCIPAL POINT(S)
Fowler, D., Cape, J.N. and Unsworth, M.H. (1989) *Deposition of atmospheric pollutants on forests.* Philosophical Transactions of the Royal Society of London, B, 324, 247-265.	• *Tree height is of primary importance in assessing scavenging effects.* • *Forest structure (including density) is important in pollutant scavenging and not just age.* • *Afforestation increases nutrient inputs and pollution from the atmosphere compared to open moorland.* • *Altitude is a limiting factor in this case.*
Fowler, D., Cape, J.N., Leith, I.D., Choularton, T.W., Gay, M.J. and Jones, A. (1988) The influence of altitude on rainfall composition at Great Dunn Fell. *Atmospheric Environment* 22, 1355-1362.	• *Questions whether altitude and tree canopy extent exacerbate scavenging of pollutants.*
Frank, J. (1989) *Acidification of soils caused by the planting of Norway spruce* (Picea abies) *on former birch* (Betula pubescens) *forests in West Norway*. In: Barth, H. (Ed.) *Effects of land use in catchments on the acidity and ecology of natural surface waters: Air Pollution Research Report* 13. pp. 18-25. Commission for the European Communities, Brussels.	• *There is a higher rate of soil acidification in soils under Norway spruce than under birch woodland.* • *This is deemed to be as a result of the reduction of ground vegetation under spruce leading to a raw humus forming.*
Fransman, B. and Nihlgard, B. (1995) Water chemistry in forested catchments after topsoil treatment with liming agents in south Sweden. *Water, Air and Soil Pollution* 85, 895-900	• *This study demonstrated that liming of wetlands stabilised pH of run-off water and reduced metal leaching.*
Freer-Smith, P.H. (1984) The responses of six broadleaved trees during long-term exposure to SO2 and NO2. *New Phytologist* 97, 49-61.	• *B. pubescens is more sensitive to SO_2 and NO_2 than other species such as Malus domestica and Tilia cordata.*
Friberg, N., Rebsdork, A. and Larsen, S.E. (1998) Effects of afforestation on acidity and invertebrates in Danish streams and implications for freshwater communities in Denmark. *Water, Air and Soil Pollution* 101, 235-256.	• *Afforestation with conifers leads to contamination of freshwater with acidic runoff.* • *Government guidelines are misleading in this case.*
Gardiner, A.S. (1968) *The reputation of birch for soil improvement: A literature review.* Forestry Commission Research and Development Paper, 76, London, HMSO.	• *Birch does improve soil and is excellent in the deacidification process thus making them 'more suitable for silviculture'.* • *Concludes birch is better at extracting nutrients than any competitor on poor soils.*
Gardiner, M. and Radford, J. (1980) *Soil associations of Ireland and their land use potential.* Soil Survey Bulletin No. 36, An Foras Taluntais, Dublin, 143 pp.	• *Detailed soil map of Ireland.*
Gee, A.S. (2001) A strategic appraisal of options to ameliorate regional acidification. W*ater, Air and Soil Pollution* 130, 1397-1402	• *Re-afforestation is low (ranked 9 out of 11 possible actions) in acid amelioration possibilities.* • *Reduction of outputs and area liming are more prominent.*
Gee, J.H.R. and Smith, B.D. (1997) Benthic invertebrates in the headwaters of the Wye and Severn: effects of forestry and clear-felling. *Hydrology and Earth System Sciences* 1:3, 549-556.	• *Shows that pH is the limiting factor in invertebrate response and possibly in recovery.* • *Invertebrates did not respond as expected to clear-cut harvesting.*

REFERENCE	PRINCIPAL POINT(S)
Gee, A.S. and Stoner, J.H. (1989) A review of the causes and effects of acidification of surface waters in Wales and potential mitigation techniques. *Archives of Environmental Contamination and Toxicology* 18, 11-130.	• *Within an 11 hour period after snow-melt, a drop in pH from 6.0 to 4.0 and an increase in aluminium, was noted.*
Giller, P., Johnson, M. and O'Halloran, J. (2002) *Managing the impacts of forest clearfelling on stream environments.* COFORD, Dublin.	
Gombert, S., Asta, J. and Seaward, M.R.D. (2004) Assessment of lichen diversity by index of atmospheric purity (IAP), index of human impact (IHI) and other environmental factors in an urban area (Grenoble, southeast France). *Science of the Total Environment* 324, 183-199.	• *Latest study indicating that there is an ecological response to environmental improvement.* • *Concludes that the increase of certain lichen populations is an indicator of the success of the reduction in sulphur emissions.*
Gorham, E. (1953) The development of the humus layer in some woodlands in the English Lake District. *Journal of Ecology* 41, 123-152.	• *Under high rainfall conditions topography appears to be the determining factor on whether a flushed brown earth with a mull humus layer (with an ash, sycamore, oak and hazel community) or a leached podzolic brown earth with a mor humus layer (with oak, birch and rowan communities) is formed.*
Grennfelt, P. and Hultberg, H. (1986) Effects of nitrogen deposition on the acidification of terrestrial and aquatic ecosystems. *Water, Air and Soil Pollution* 30, 945–963.	• *Showed that N deposition may be an essential factor in soil acidification and forest damage as well as lakes and groundwaters.*
Guibaud, G. and Gauthier, C. (2003) Study of aluminium concentration and speciation of surface water in the four catchments in the Limousin region (France). Journal of Inorganic Biochemistry, 97, 16-25.	• *An area not affected by conifer afforestated acidification or acidic deposition, yet poor, wet soils with a granite bedrock naturally release high levels of aluminium as well as protons.* • *Aluminium is not toxic to aquatic life downstream.*
Guirnell, J., Wauters, L.A., Lurz, W.W. and Tosi, G. (2004) Alien species and interspecific competition: effects of introduced eastern grey squirrels on red squirrel population dynamics. *Journal of Animal Ecology* 73, 26-35.	• *Mixed deciduous woodlands are favoured by alien grey squirrels and conifer plantations are favoured by native red squirrels.*
Hagan-Thorn, A., Callesen, I., Armolaitis, K. and Nihlgard. B. (2004) The impact of six European tree species on the chemistry of mineral topsoil in forest plantations on former agricultural land. *Forest Ecology and Management* 195, 373-384.	• *The upper mineral soil under birch and ash had higher base saturation than under oak.* • *Norway spruce has the most acidifying affect on soils with beech having a similar effect.* • *Scavenging abilities probably important at early stage of growth.*
Haque, S.M.S., Billett, M.F., Grayson, S. and Ord, B.G. (1999) Effects of afforestation on ammonification and nitrification rates in former agricultural soils. *Soil Use and Management* 15, 117-122.	• *Potential nitrification is significantly lower than in upland sites.* • *Nitrification and ammonification rates are also lower.*
Haria, A.H. and Price, D.J. (2000) Evaporation from Scots pine (*Pinus sylvestris*) following natural re-colonisation of the Cairngorm Mountains, Scotland. *Hydrology and Earth System Sciences* 4:3, 451-461.	• *Scots pine has high rainfall interception and high evaotranspiration rates – 41% higher than wet heathland.*

REFERENCE	PRINCIPAL POINT(S)
Harriman, R. and Morrison, B.R.S. (1981) Forestry, fisheries and acid rain in Scotland. *Scottish Forestry* 35, 89-95.	• *States that in-stream liming is the only feasible solution to acidification and acid episodes.*
Harriman, R. and Morrison, B. R. S. (1982) Ecology of streams draining forested and non-forested catchments in an area of central Scotland subject to acid precipitation. *Hydrobiologia* 88, 251-263.	• *Streams draining forested catchments have a higher cation concentration of SO_4^{2-} and Cl^- than non-forested stream catchments.* • *The distribution of fish is related to this.* • *Cultivation of spruce and the associated management practices reduces the neutralising capacity of soils.*
Harriman, R., Bridcut, E.E. and Anderson, H. (1995a) The relationship between salmonid fish densities and critical ANC at exceeded and non-exceeded stream sites in Scotland. *Water, Air and Soil Pollution* 85, 2455-2460.	• *Found that there was a positive relationship between ANC and total salmonid densities.*
Harriman, R., Morrison, B.R.S., Birks H.J.B., Christie, A.E.G., Collen, P. and Watt, A.W. (1995b) Long-term chemical and biological trends in Scottish streams and lochs. *Water, Air,and Soil Pollution* 85, 701-706.	• *This study showed that a there is a long-term trend in the decrease in SO_2 resulting in a slow increase in pH with a positive floristic effect.*
Harrison, A.F., Carreira, J., Poskitt, J.M., Robertson, S.M.C., Smith, R., Hall, J., Hornung, M. and Lindley, D. K. (1999) Impacts of pollutant inputs on forest canopy condition in the UK: possible role of P limitations. *Forestry* 72:4, 367-377.	• *Crown condition is linked to phosphorous stress and this is possibly a result of acid deposition.* • *'Soil pH and exchangeable Ca are key factors controlling the mineralisation of organic forms of P in forest soils'.* • *Beech the only broadleaf tree examined in this study.* • *Scots pine also studied.*
Helliwell, R.C., Ferrier, R.C. and Jenkins, A. (1998) A two-layer application of the MAGIC model to predict the effects of land use scenarios and reductions in deposition on acid-sensitive soils. *Hydrology and Earth Systems Sciences* 2:4, 497-507.	• *Describes how the MAGIC model works.*
Helliwell, R.C., Jenkins, A., Ferrier, R.C. and Cosby, B.J. (2003) Modelling the recovery of surface water chemistry and the ecological implications in the British uplands. *Hydrology and Earth Systems Sciences* 7:4, 456-466.	• *If the UK maintains its commitment to reduction of S, rivers will return to 'good' status,* • *Chemical conditions may not be as good.*
Henriksen, A., Lien, L., Traaen, T.S., Rosseland, B.O. and Sevaldrud, I.S. (1990) *The 1000-lake survey in Norway 1986.* In: Mason, B.J. (Ed.) *The Surface Waters Acidification Programme*. Cambridge University Press.	• *An outline of the extent of acidification in Norway.* • *11% of the land surface and 50% of lakes affected by acid deposition.*
Henriksen, A., Wathne, B.M., Rogeberg, E.J.S., Norton, S.A. and Brakke, D.F. (1988) The role of stream substrates in aluminium mobility and acid neutralisation. *Water Research* 22:8, 1069-1073.	• *Research note: In-stream liverworts and mosses are extremely important in the exchange of base cations and Al during acid episodes.* • *Mosses are an important buffer but they may also delay recovery from prolonged acid inflow.*
Hester, A.J., Miles, J. and Gimingham, C.H. (1991) Succession from heather moorland to birch woodland. I: Experimental alteration of specific environmental conditions in the field. *Journal of Ecology* 79, 303-315.	• *One of three sections on succession to woodland (on following pages, same journal).* • *Light is the limiting factor in succession.* • *Plant communities are important for birch succession – shading and nursery species.*

REFERENCE	PRINCIPAL POINT(S)
Hewlett, J.D., Post, H.E. and Doss, R. (1984) Effect of clear-cut silviculture on dissolved ion export and water yield in the Piedmont. *Water Resources Research* 20:7, 1030-1038.	• *This study doubts that clear-cut forestry increases mobilisation and export of dissolved nutrients.* • *Reduction of evaotranspiration after harvest results in increased streamflow, which appears to be the cause of detected small, increases in nutrient loss that are negligible.*
Hill, T.J., Skeffington, R.A. and Whitehead, P.G. (2002) Recovery from acidification in the Tillingbourne catchment, southern England: catchment description and preliminary results. *The Science of the Total Environment* 282-283, 81-97.	• *Recovery may be due to reduction in emissions as much as soil responses.*
Hindar, A., Henriksen, A., Kaste, Ø. and Tørseth, K. (1995) Extreme acidification in small catchments in southwestern Norway associated with a sea salt episode. *Water, Air and Soil Pollution* 85, 547–552.	• *Seasalt episodes have little long-term effect.* • *Soil acidification is a prerequisite for seasalt effect to occur.*
Holden, J. (2003) *Runoff produced in blanket peat covered catchments.* Water Resources Research, 39:7, SWC6, 1-9.	• *Topography and preferential flow paths are important controls on the pattern of runoff even on low-gradient peat.* • *Flows are still not fully understood and should not be simplified.*
Hornbeck, J.W. (1992) Comparative impacts of forest harvest and acid precipitation on soil and streamwater acidity. *Environmental Pollution* 77, 151-155.	• *Severe impact on forest soils from harvesting techniques.*
Hornung, M. (1985) Acidification of soils by trees and forests. *Soil Use and Management* 1:1, 24-27.	• *Silvicultural management practices will be very important as tree species or initial soil conditions in determining the long-term impact.* • *Explores several impacts on forest soils.* • *Oak-beech stands may lead to podzolisation of soils.* • *Speculates that lessening the intensity of harvesting can reduce the base cation depletion.*
Hornung, M., Bull, K.R., Cresser, M., Ullyett, J., Hall, J.R., Langan, S., Loveland, P.J. and Wilson, M.J. (1995) The sensitivity of surface waters of Great Britain to acidification predicted from catchment characteristics. *Environmental Pollution* 87, 207–214.	• *This study used a GIS model to predict soil sensitivity.*
Hornung, M., Stevens, P.A. and Reynolds, B. (1986) *The effects of forestry on soils, soil water and surface water chemistry.* In: Good, J.A. (Ed.) *Environmental aspects of plantation forestry in Wales.* Institute of Terrestrial Ecology, Natural Environment Research Council, Bangor, Wales. p 25-36.	• *Tree roots can increase the rate of soil drying significantly.* • *Larch produces a more acid throughfall than spruce.*
Howard, P.J.A. and Howard, D.M. (1990) Titratable acids and bases in tree and shrub leaf litter. *Forestry* 63:2, 177-196.	*The lowest acidity leaf litter was found under broadleaf stands, with the exception of maple.*

REFERENCE	PRINCIPAL POINT(S)
Howells, G. (1990) *Acid rain and acid waters.* Ellis Horwood, New York.	• *Out of print.* • *Quoted in Mason (1996) as being the seminal synthesis for the discussion on acid deposition and its impact on wetland systems.*
Hubbard, R.K. and Lowrance, R. (1994) Riparian forest buffer system research at the Coastal Plain Experiment Station, Tifton, Ga. *Water, Air and Soil Pollution* 77, 409-432.	• *This study examined three kinds of 30 m buffer strips (using variations of grass and riparian wooded vegetation).* • *The findings were positive for sediment and nutrient interception.* • *Suggestions made on different locations in US.*
Hubbard, R.K. and Lowrance, R. (1997) Assessment of forest management effects on nitrate removal by riparian buffer systems. *Transactions of the American Society of Agricultural Engineers* 40:2, 383-391.	• *Nitrate reductions in shallow groundwater were noted when a forest is undisturbed and when selective thinning was carried out.*
Hudd, R. (2000) *Springtime episodic acidification as a regulatory factor of estuary spawning fish recruitment.* Unpublished PhD dissertation, University of Helsinki, Finland. 42pp + appendices.	• *Spring runoff high in acidity may be important in stimulating hatching.*
Hultberg, H. and Johansson, S. (1981) Acid groundwater. *Nordic Hydrology* 12, 51-64.	• *Some reference on the impact of afforestation on groundwater but no evidence or data to date.*
Humphrey, J.W. and Swaine, M.D. (1997) Factors affecting the natural regeneration of *Quercus* in Scottish oakwoods – I: Competition from Peridium aquilinum. *Journal of Applied Ecology* 34, 577-584.	• *To ensure oak regeneration bracken needs to be controlled.* • *Bracken litter may inhibit nutrient cycling as well as cause shading for seedlings.*
Hutchinson, T.C., Scott, M., Soto, C. and Dixon, M. (1987) *The effect of simulated acid rain on boreal forest floor feather moss and lichen species*. In: Hutchinson, T.C. and Meema, K.M. (Eds.) *Effects of Atmospheric Pollutants on Forests, Wetlands and Agricultural Ecosystems*. pp. 411-426, NATO ASI Series, Ecological Sciences, G16. Springer-Verlag.	• *Acid deposition had a severe and detrimental effect on moss and lichen species in simulated conditions.*
Inoue, M. and Nakano, S. (1998) Effects of woody debris on the habitat of juvenile masu salmon (Oncorhynchus masou) in northern Japanese streams. *Freshwater Biology* 40, 1-16.	• *Woody debris have a positive effect on the habitat, as shown in other countries, and are important for breeding fish.*
Jenkins, A., Boorman, D. and Renshaw, M. (1996) The UK Acid Waters Monitoring Network: an assessment of chemistry data 1988-93. *Freshwater Biology* 36, 169-178.	• *SO_4 is the most significant acidifying ion but NO_3 makes an important contribution also.* *SO_4 is significant for episodic acidification especially in autumn/winter.*
Jenkins, A., Camarero, L., Cosby, B.J., Ferrier, R.C., Forsius, M., Helliwell, R.C., Kopácek, J., Majer, V., Moldan, F., Posch, M., Rogora, M., Schöpp, W. and Wright, R.F. (2003) A modelling assessment of acidification and recovery of European waters. *Hydrology and Earth System Sciences* 7:4, 447-455.	• *Sulphur is the key driver in acidification.* • *If European watercourses are to be returned to conditions suitable for brown trout more reductions in S and N are necessary.*

REFERENCE	PRINCIPAL POINT(S)
Jenkins, A., Cosby, B.J., Ferrier, R.C., Walker, T.A. B. and Miller, J.D. (1990) Modelling stream acidification in afforested catchments: an assessment of the relative effects of acid deposition and afforestation. *Journal of Hydrology* 120, 163-181.	
Jenkins, A., Renshaw, M., Helliwell, R., Sefton, C, Ferrier, R. and Swingewood, P. (1997) *Modeling surface water acidification in the UK.* Report No. 131, Institute of Hydrology, Natural Environmental Research Council, 54 pp.	• *Outlines the process of acidification of soils and surface waters.* • *Acidification not only due to deposition and scavenging but also to local geology.* • *Land use, especially afforestation, is reflected in critical load models.*
Jennings, E., Donnelly, A. and Allott, N. (2002) *Effectiveness of buffer strips for the mitigation of acid runoff from afforested catchments, Final Report.* Environmental Protection Agency, Wexford.	• *No 'mention in either the Irish or the current UK forestry guidelines of the use of buffer strips to mitigate acid runoff'.* • *Buffer strips very effective for nutrient and sediment interception but this is dependant on the hydrology and soil type of the strip.* • *'Desiccation of soil surfaces under forests will also lead to shrinkage and cracking, increasing the amount of water routed through preferential flow pathways'.* • *'If the dominant flow pathways in a buffer strip are such that runoff has sufficient interaction with the soil matrix, the ability to neutralise acidification will then be dependent on soil characteristics'.* • *Soils with a high organic content such as peat tend to have a high acidity. In these soils H^+ and Al^{3+} will dominate exchange sites and previously adsorbed base cations will be leached out in solution. Exchange sites in forest soils may become blocked with non-exchangeable H^+ and Al^{3+}, thus lowering the effective CEC of the soil'.*
Johnson, R.C. (Ed.) (1995) *Effects of upland afforestation on water resources: The Balquhidder experiment 1981-1991.* Report No. 116, Second Edition, Institute of Hydrology, Wallingford, Oxfordshire. 51 pp.	• *Long-term study in an upland catchment area, principally looking at sediment discharges.* • *This catchment is alkaline in nature and no acidification is reported.*
Jones, D.H. (1986) The effect of afforestation on fresh waters in Tayside, Scotland. Zooplankton and other microfauna. *Hydrobiologia* 133, 223-235.	• *The effects (negative) of acidification could not be detected in this study.*
Jordan, C. (1997) Mapping of rainfall chemistry in Ireland 1972–94. *Biology and Environment* 97B: 1, 53–73.	• *About 30% of S and N emissions generated in Ireland are deposited here; the rest is exported.* • *Accurate pH measurements are very difficult to obtain so an estimate of total acid deposition is obtained by calculating the concentrations of the various compounds that contribute to rainfall acidity.* • *This results in effective H^+ calculations as being between 4.3 and 4.75 (1972-1992) in one location.*

REFERENCE	PRINCIPAL POINT(S)
Kaufmann, P.R., Herlihy, A.T. and Baker, L.A. (1992) Sources of acidity in lakes and streams of the United States. *Environmental Pollution* 77, 115-122.	• *While soils may be acidified by forest growth; afforestation does not appear to cause surface water acidification unless there are mobile anions (for example sulphate) to transmit the soil H^+ into surface water.* • *This implies that the anion source remains the major factor in explaining water acidity.*
Kazda, M. and Pilcher, M. (1998) Priority assessment for conversion of Norway spruce forests through introduction of broadleaf species. *Forest Ecology and Management* 102, 245-258.	• *Quercus robur is suited for introduction into spruce forests especially on acid soils and stony sites but it is not commercially viable in the current system.* • *Quercus petraea is less suitable for stony sites.*
Kearney, B. (2001) *A review of relevant studies concerning farm forestry trends and farmers' attitudes to forestry*. COFORD. 16 pp.	• *4 out of 5 adults believe forestry is good for the environment.* • *Most farmers desire conifer forests on poor peaty soils or wet marginal land.*
Kelly, C.K. and Southwood, T.R.E. (1999) Species richness and resource availability: a phylogenetic analysis of insects associated with trees. *Ecology* 96, 8013-8016.	• *Tree abundance is the best predictor of insect-species richness.*
Kelly, D.L. (2002) The regeneration of *Quercus petraea* (sessile oak) in southwest Ireland: a 25-year experimental study. *Forest Ecology and Management* 166, 207-226.	• *Growth of young oaks (Q. patraea) on wet, peat soils was stunted in the early years of this study.* • *This may be due to a combination of anoxia and nutrient deficiency.* • *Old Red Sandstone bedrock may be a limiting factor.* • *'The rise in water tables consequent on forest clearance may help to explain the failure of oak to recolonise areas that have been deforested, especially in regions of strongly oceanic climate'.* • *High light levels and low grazing regime are preconditions for success in oak regeneration.*
Kelly-Quinn, M., Tierney, D., Coyle, S. and Bracken, J.J. (1996a) Factors affecting the susceptibility of Irish soft-water streams to forest-mediated acidification. *Fisheries Management and Ecology* 3, 287–301.	• *Conifer afforested systems have high acidic runoff.* • *Hydrological measurements showed that increased discharge of water via the drainage network reduced contact with the soil (buffering).* • *Potentially toxic levels of inorganic aluminium were associated with afforestation.*
Kelly-Quinn, M., Tierney, D., Coyle, S. and Bracken, J.J. (1997) *A study of the effects of stream hydrology and water quality in forested catchments on fish and invertebrates.* In: AQUAFOR Report, Volume 3, Stream Chemistry, Hydrology and Biota, Wicklow Region, 92. Dublin. COFORD.	• *Underlying acid bedrock a significant factor in watercourse acidification in addition to anthropogenic activities.* • *Highlights how salmonid species and freshwater invertebrates are vulnerable in poorly buffered catchments.* • *Some streams in the West of Ireland are lacking in acid-sensitive invertebrates.* • *Scavenging of pollutants is deemed to be a cause.*
Kelly-Quinn, M., Tierney, D., Roche, W. and Bracken, J.J. (1996b) *Distribution and abundance of trout populations in moorland and afforested upland nursery streams in County Wicklow.* Biology and Environment: Proceedings of the Royal Irish Academy, 96B:3, 127-139.	• *This study established the susceptibility of trout to poorly buffered streams.* • *The study illustrated the detrimental effects on forest-mediated acidification.*
Kennedy, C.E.J. and Southwood, T.R.E. (1984) The number of species of insect associated with British trees: a re-analysis. *Journal of Animal Ecology* 53, 455-478.	• *Seminal work on the insect associations on trees.* • *The four trees with the greatest associations are: Salix spp. – 450 spp., Quercus spp. – 423 spp., Betula spp. – 334 spp. and Crataegus monogyna – 209 spp.*

REFERENCE	PRINCIPAL POINT(S)
Kennedy, C.E.J. and Southwood, T.R.E. (1999) *Species richness and resource availability: A phylogenetic analysis of insects associated with trees.* Proceedings of the National Academy of Science, 96, 8013-8016.	• *Quercus spp. score highest in insect species richness (Figure 3).* • *Salix spp and Betula spp. score very high as well.*
Kerr, G. (1999) The use of silvicultural systems to enhance the biological diversity of plantation forests in Britain. *Forestry* 72:3, 191-205.	• *Existing monocrop conifer woodlands have been adapted to suit wildlife with positive effects.* • *There is a need to reinstate understory species and to permit woodland stands to mature to the old growth stage if biodiversity interests are to be furthered.* • *There are many examples of successful alternative silvicultural systems that benefit wildlife and produce a crop.*
King, J.A., Smith, K.A. and Pyatt, D.G. (1986) Water and Oxygen regimes under conifer plantations and vegetation on upland peaty gley soil and deep soils. *Journal of Soil Science* 37, 485-497.	• *Tree crops may cause irreversible soil shrinkage and cracking leading to altered hydrological behavior.*
Kleinschmit, J. (1999) *Breeding strategies for hardwoods: oak, cherry and rowan.* In: Douglas, G. C. (Ed.) *Strategies for Improvement of Forest Trees*. pp. 37-62. COFORD Proceedings, Dublin.	• *Oak and cherry are valuable hardwood trees.* • *Birch is regarded as having low quality timber.* • *Birch hybrids offer promise particularly B. platyphylla X B. pendula.* • *Cherry can be grown on moderately poor soils.*
Kreiser, A.M., Appleby, P.G., Natkanski, J., Rippey, B. and Battarbee, R.W. (1990) *Afforestation and lake acidification: a comparison of four sites in Scotland.* Philosophical Transactions of the Royal Society of London, B, 327, 377-383.	• *pH-related biological effects show a slight time-lag relative to the onset of air pollution.*
Krug, E.C. and Frink, C.R. (1983) Acid rain on acid soil a new perspective. *Science* 221, 520-525.	• *The effect of acid deposition superimposed on soil acidification as a result of land-use changes is discussed and shown to be difficult to simplify.*
Kuenzler, E.J. (1989) *Value of forested wetlands as filters for sediments and nutrients*. General Technical Report SE – US Dept of Agriculture, Forest Service, Southeastern Forest Experiment Station, Jan 1989 (50). pp 85-96.	
Kulp, J.L. (1995) *Acid rain*. In: Simon, J. (Ed.) *The State of Humanity.* pp. 523-535. Oxford, Blackwell.	• *Estimates that the monetary value of 'free' SO_2 deposition in fertility terms for forests and agricultural crops (such as oil seed rape) is around $500 million per annum in the US alone.*
Kuylenstsierna, J.C.I., Hicks, W.K., Cinderby, S. and Cambridge, H. (1998) Critical loads for nitrogen deposition and their exceedance at European scale. *Environmental Pollution* 102 SI, 591-598.	• *This study outlined extensively how critical loads are been exceeded throughout continental Europe*
Lacey, S.T. (2000) Runoff and sediment attenuation by undisturbed and lightly disturbed forest buffers. *Water, Air and Soil Pollution* 122, 121-138.	• *This is an Australian study that examined the positive benefits of buffer strips in woodlands for intercepting forest sediment runoff.*
Laitung, B., Pretty, J.L., Chauvet, E. and Dobson, M. (2002) Response of aquatic hyphomycete communities to enhanced stream retention in areas impacted by commercial forestry. *Freshwater Biology* 47:2, 313-323.	• *'In biologically impoverished plantation streams, input of woody debris can increase detritus retention and enhance hyphomycete diversity and productivity'.*

REFERENCE	PRINCIPAL POINT(S)
Langan S.J. (1989) Sea-salt induced streamwater acidification *Hydrological Processes* 3, 25-41.	
Langan, S.J. and Wilson, M.J. (1992) Predicting the regional occurrence of acid surface-waters in Scotland using an approach based on geology, soils and land use. *Journal of Hydrology* 138, 515-528.	
Larsen, B.M. and Hesthagen, T. (1995) The effects of liming on juvenile stocks of Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) in a Norwegian river. *Water, Air and Soil Pollution* 85, 991-996.	• *Despite the beneficial effects of liming reported in many other studies, juvenile salmonids did not respond in the short-term.*
Laskowski, R., Niklinska, M. and Maryanski, M. (1995) The dynamics of chemical elements in forest litter. *Ecology* 76:5, 1393-1406.	• *Nutrient input from throughfall is high for some elements but not iron (in oak-hornbeam).* • *Sulphur is the earliest element to be released when litter decomposes.*
Law, A.J. (1986) *Use of broadleaved species in upland forests*. Forestry Commission leaflet, 88, HMSO, London.	• *Out of print but is referenced in many journal articles including Moffat and Boswell (1990).* • *Alder is likely to cause more acidification in riparian zones, more so than oak.*
Law, F. (1956) The effects of afforestation upon the field of water catchment areas. *Journal of the British Waterworks Association* 11, 489-494.	• *This study showed that afforestation can dry out soils thus inhibiting the formation of peat.*
Lawrence, G.B. (2002) Persistent episodic acidification of streams linked to acid rain effects on soil. *Atmospheric Environment* 36, 1589-1598.	• *Atmospheric deposition of sulphur has decreased by around 40% since 1992.* • *Acid episodes are caused by the depletion of exchangeable Ca in mineral soil horizons.*
Lehane, B.M., Giller, P.S., O'Halloran, J. and Walsh, P.M. (2004) *Relative influences of catchment geology, land use and in-stream habitat on brown trout populations in South-Western Ireland.* Biology and Environment: Proceedings of the Royal Irish Academy, 104B:1, 43-54.	• *There were few differences in trout numbers in relation to geology in contrast to Kelly-Quinn (1997) and Allott (1990).* • *Catchments with high buffering capacity showed low levels of trout metrics.* • *Influences of afforestation on limestone areas only seen when forest cover is very large.*
Lepori, F., Barbiere, A. and Ormerod, S.J. (2003) Causes of episodic acidification in Alpine streams. *Freshwater Biology* 48. 175-189.	• *A discussion on S in snowmelt as well as altitude and its effects on acidification.*
Likens, G.E., Wright, R.F., Galloway, J.N. and Butler, T.J. (1979) Acid rain. *Scientific American* 241:4, 43-51.	
Linstead, C. and Gurnell, A.M. (1999) *Large woody debris in British headwater rivers: physical habitat role and management guidelines*. Environment Agency Report W181, WRC, Swindon, UK.	• *This report covers the interactions of woody materials and their potential buffering capacity.* • *Recommends that riparian buffer zones (strips) be about 20 m in width,* • *Recommends that the trees in these zones be mixed age and structure.* • *Recommends that minimal management regime be adopted in riparian buffer zones (strips).*

REFERENCE	PRINCIPAL POINT(S)
Little, D.J., Farrell, E.P., Collins, J.F. (1997) Land-use legacies and soil development in semi-natural ecosystems in the marginal uplands of Ireland. *Catena* 30, 83-98.	• *Showed that woodland clearance over many years has increased leaching and podzolisation of soils.*
Little, D.J., Mitchell, F.J.G., von Engelbrechten, S., and Farrell, E.P. (1996) Assessment of the impact of past disturbance and prehistoric *Pinus sylvestris* on vegetation dynamics and soil development in Uragh Wood, SW Ireland. *The Holocene* 6, 90-99.	• *Unable to source this journal within the study period.*
Liu, G.E. and Côté, B. (1993) Neutralization and buffering capacity of leaves of sugar maple, largetooth aspen, paper birch and balsam fir. *Tree Physiology* 12, 15-21.	• *Leaves act as acid buffers while still on the branch.* • *Buffering capacity is high in leaves with high concentrations of N and Mg.* • *This study does not look at leaf litter.*
Liu, C., Westman, C. J., Berg, B., Kutch, W., Wang, G. Z., Man, R. and Ilvesniemi, H. (2004) Variation in litterfall-climate relationships between coniferous and broadleaf forests in Eurasia. *Global Ecology and Biogeography* 13, 105-114.	• *Total litterfall is higher in broadleaf forests than conifer forests.* • *Litter increases with temperature and precipitation and thus higher global temperatures ('warming') may increase forest litter.*
Löf, M., Thomsen, A. and Madsen, P (2004) Sowing and transplanting of broadleaves (*Fagus sylvatica* L., *Quercus robor* L., *Prunus avium* L. and *Crataegus monogyna* Jacq.) for afforestation of farmland. *Forest Ecology and Management* 188, 113-123.	• *Indicates that sowing a variety of broadleaved trees has the 'potential to become an effective regeneration method'.*
Longhurst, J.W.S. (1991) *Acid deposition: Origins, impacts and abatement strategies.* Springer-Verlag, New York, 315 pp.	
Lurz, P.W.W., Garson, P.J. and Rushton, S.P. (1995) The ecology of squirrels in spruce dominated plantations: implications for management. *Forest Ecology and Management* 79, 79-90.	• *Red squirrel favours spruce woodlands and pine woodland plantations may be key to their survival on these islands.*
Lust, N., Muys, B. and Nachtergale, L. (1998) Increase of biodiversity in homogeneous Scots pine stands by an ecologically diversified management. *Biodiversity and Conservation* 7, 249-260.	• *Scots pine can be a high biodiversity species.* • *Mixed ages of pine offer the best opportunity for biodiversity in future forests.*
Maitland, P.S., Lyle, A.A. and Campbell, R.N.B. (1987) *Acidification and fish in Scottish lochs.* Institute of Terrestrial Ecology, Grange-over-Sands.	• *Acidification has a serious and detrimental impact on fish in lakes.* • *This is slow to abate due to large retention time in deep waters.*
Månsson, K.F. and Falkengren-Grerup, U. (2003) The effect of nitrogen deposition on nitrification, carbon and nitrogen mineralisation and litter C: N ratios in oak (*Quercus robur* L.) forests. *Forest Ecology and Management* 179, 455-467.	• *N deposition has altered oak leaf litter as well as the C: N ratio.*
Martin, A. (1979) A survey of the acidity of rainwater over large areas of Great Britain. *The Science of the Total Environment* 13, 119-130.	• *This is a baseline survey that looked at urban areas mainly.* • *Abstract available only.*

REFERENCE	PRINCIPAL POINT(S)
Martinson, L., Alveteg, M., Mörth, C-M. and Warfvinge, P. (2003) The effect of changes in natural and anthropogenic deposition on modeling recovery from acidification. *Hydrology and Earth System Sciences* 7:5, 766-776.	• *Looks at how the SAFE model showed that the temporal variations in seasalt deposition has a significant impact on the chemistry of run-off.*
Mason, C.F. (1996). *Biology of freshwater pollution*. 3rd Edition. Longman, 356 pp.	• *Impact of acid deposition is dependant on geology and soils.* • *There are two types of fishery problems: 1. fish-kills associated with sudden, episodic deposition and 2. a gradual decline in stocks due to a gradual increase on overall acid levels (decrease in water pH levels in poorly buffered areas).* • *Al is toxic to freshwater biota at a pH of 5.0 – 5.5.*
Mather, R., Freer-Smity, P. and Savill, P. (1995) *Analysis of the changes in forest condition in Britain 1989 to 1992*. Forestry Commission Bulletin, 116. London, HMSO. 53 pp.	• *Age of the tree and the forest stand will determine, partly, the effects of 'acid rain' on the crown.*
Mathews, R.O. and McCaffery, F. (1977) *Chemical analysis of precipitation in Ireland 1966–1975.* Technical Note No. 42, Irish Meteorological Service, Dublin, 68 pp.	• *Report.*
Mathews, R.O., McCaffery, F. and Hart, E. (1981) Acid rain in Ireland. *Irish Journal of Environmental Science* 1, 7–50.	• *Recorded a doubling of low pH rainfall events in Ireland between 1960 and 1979.* • *Commented on in Aherne et al. (1998) as possibly misleading as the acid detectors were not located in the most suitable or relevant locations.*
Matzner, E. and Murach, P. (1995) Soil changes induced by air pollutant deposition and their implication for forests in central Europe. *Water, Air and Soil Pollution* 85, 63-76.	• *This study outlines root and other stresses caused by Al ions and low Mg.*
McAree, D. (2002) *The Forest Service biodiversity plan.* Biology and Environment: Proceedings of the Royal Irish Academy, 102B:3, 183-184.	• *Examples from the newly published forest service guidelines on biodiversity in Irish woodlands.* • *Near native species are being removed in order to protect native species.* • *Committed to Sustainable Forest Management (SFM).* • *Sets target of 30% broadleaf component of Irish forest stand with a minimum of 10% for all new plantings.*
McCartney, A.G., Harriman, R., Watt, A.W., Moore, D.W., Taylor, E.M., Collen, P. and Keay, E.J. (2003) Long-term trends in pH, aluminium, and dissolved organic carbon in Scottish fresh waters; implications for brown trout (*Salmo trutta*) survival. *The Science of the Total Environment* 310, 133-141.	• *Trend of improvement is noted in line with general Europe-wide improvements in freshwater quality in response to reduction of S emissions.* • *Decline of toxic form of aluminium is two-fold.* • *Recovery of trout is likely but may require restocking.*
McGettigan, M. (1996) *Ozone monitoring results and EU threshold exceedances for Ireland in 1995.* Environmental Protection Agency, Wexford. 21 pp.	
McGettigan, M. (1997) *Air quality monitoring: Annual report 1996*. Environmental Protection Agency, Wexford. 40 pp.	

REFERENCE	PRINCIPAL POINT(S)
McGettigan, M. and O'Donnell, C. (1995) *Air pollution in Ireland: Emissions, depositions and concentrations 1984–1994.* Environmental Protection Agency, Wexford. 69 pp.	
Miles, J. (1981) *The effect of birch on moorlands.* Institute of Terrestrial Ecology, UK.	• *Birch regeneration causes depodzolisation of acidic soils leading to more 'attractive soils for further species colonisation'.* • *Soil acidity was lowered from 3.9 to 4.3 in around 90 years.*
Miles, J. (1985) The pedogenic effects of different species and vegetation types and the implications of succession. *Journal of Soil Science* 36, 571-584.	• *Alder, Scots pine and Norway spruce are efficient soil acidifiers.* • *Oak causes 'less acidification'.* • *Birch retards acidification.* • *Trees can influence soil properties in forest stands through litter, activities of roots, nutrient uptake and the interception of pollutants by their canopy.* • *Careful planning and selection of tree species may lead to amelioration of soils.*
Miles, J. (1988) *Vegetation and soil change in the British uplands*. In: Usher, M.B. and Thompson, D.B.A. (Eds.) *Ecological change in the uplands.* pp. 57-70. Oxford, Blackwell.	• *Variation in species content and regeneration cycles of birch, pine and oak woodlands in upland areas alter over time.* • *Birch is less destructive.* • *'Transitions between many vegetation types with contrasting pedogenic effects cause marked changes in labile soil properties in decades or less'.*
Miles, J. and Kinnard, J.W. (1979) The establishment and regeneration of birch, juniper and Scots pine in the Scottish Highlands. *Scottish Forestry* 33, 102-119.	• *Birch is a pioneer species and is vulnerable to shade.* • *Birch is associated with the formation of brown podzolic soils with a mull humus.* • *Birch, juniper and Scots pine are good for 'soil amelioration'.*
Miles, J. and Young, W.F. (1980) The effects on heathland and moorland soils in Scotland and Northern England following colonisation by birch *(Betula* spp.). *Bulletin d'Ecologie* 11, 233-242.	• *Noted a change from a mor to a mull humus soil under birch woodland.* • *Also noted increases in pH and exchangeable Ca and Total P.* • *Earthworms and other invertebrates increased substantially.*
Millar, H.G. (1985) The possible role of forests in streamwater acidification. *Soil Use and Management* 1:1, 28-29.	• *No conifers or other mor-forming species should be planted in riparian areas.* • *Salix, Sorbus and Betula species should be utilised in riparian areas as leaf litter decomposes readily.* • *Alder should be avoided.*
Millar, P., Bytnerowicz, A., Fenn, M., Poth, M., Temple, P., Schilling, S., Jones, D., Johnson, D., Chow, J. and Watson, J. (1998) Multidisciplinary study of ozone, acidic deposition and climate effects on a mixed conifer forest in California, USA. *Chemosphere* 35:4-5, 1001-1006.	• *Effects were not observed.* • *Long-term nitrate leaching observed but pH levels remain static.*
Mills, D.H. (1981) The effects of afforestation on salmon rivers and suggestions for their management. *Saumons* 36, 2ème trimestre, 9-11.	• *The presence of trees is just as likely to cause salmonid stress from factors as alteration of invertebrate biota and riparian vegetation.*

REFERENCE	PRINCIPAL POINT(S)
Moffat, A.J. (2003) Indicators of soil quality for UK forestry. *Forestry* 76:5, 75-87.	• *Harvesting operations are considered to be the most harmful to forest soils.* • *Acidification is still perceived to be a threat, despite international agreements. This may be due to excessive N inputs.* • *Acid neutralising capacity (ANC) is more valuable than pH for interpreting soil acidity but this requires knowledge of the 'full suite of acids and bases in the soil'.*
Moffat, A.J. and Bird, D. (1989) the potential for using sewage sludge in forestry in England and Wales. *Forestry* 62:1, 1-17.	• *Sewage sludge is extremely useful in forest fertilizing and there are no toxic effects shown.*
Moffat, A.J. and Boswell, R.C. (1990) Effect of tree species and species mixtures on soil populations at Gisburn Forest, Yorkshire. *Soil Use and Management* 6, 46-51.	• *Soil acidification is affected by choice of broadleaf species.* • *Conifers and alder have caused a reduction in soil pH levels.*
Morrison, B.R.S. and Collen, P. (1992) *The trout (*Salmo trutta *L.) and invertebrate populations of Loch Dee and its inflowing streams.* In: *Acidification, forestry and fisheries in upland Galloway*. Proceedings of the Loch Dee Symposium. Foundation for Water Research, Marlow, Scotland.	• *Unable to source this publication within the timeframe of the study.* • *Identified in Tervet (2001) as one of many authors who report declines in fish population that can be ascribed to acidification, though at this stage conifer plantations are blamed by only some.*
Mullen, K., Fahy, O. and Gormally, M. (2003) Ground flora and associated arthropod communities of forest road edges in Connemara, *Ireland. Biodiversity and Conservation* 12:1, 87-101.	• *Open spaces and broadleaf planting in conifer woodlands may be important for invertebrate diversity.*
Neal, C., Fisher, R., Smith, C. J., Hill, S., Neal, M., Conway, T., Ryland, G. P. and Jeffrey, H.A. (1992) The effects of tree harvesting on stream-water quality at an acidic and acid-sensitive spruce forested area: Plynlimon, mid-Wales. *Journal of Hydrology* 135, 305-319.	• *The effects of conifer deforestation in an acid-sensitive upland area are difficult to observe.*
Neal, C., Reynolds, B., Wilkinson, J., Hill, T., Neal, M., Hill, S. and Harrow, M. (1998) The impacts of conifer harvesting on runoff water quality: a regional survey for Wales. *Hydrology and Earth Systems Sciences* 2:2-3, 323-344.	• *Harvesting has a strong 'local' effect on water pH values for several years.* • *Deafforestation leads to the reversal of acidification when nitrate runoff is low.* • *Harvesting small areas at a time minimised acid effects.*
Neirynck, J., Mirtcheva, S., Sioen, G. and Lust, N. (2000) Impact of *Tilia platyphyllos* Scop., *Fraxinus excelsior* L., *Acer pseudoplatanus* L., *Quercus robur* L. and *Fagus sylvatica* L. on earthworm biomass and physico-chemical properties of a loamy topsoil. *Forest Ecology and Management* 133, 275–286.	• *The presence of mull-forming trees (such as sycamore, lime and ash) leads to higher earthworm biomass and may be used as soil rehabilitators.* • *pH may only change slightly in hardwood stands though there are striking differences between species.*
Newton, M., Willis, R., Walsh, J., Cole, E. and Chan, S. (1996) Enhancing riparian habitat for fish, wildlife and timber in managed forests. *Weed Technology* 10:2, 429-438.	• *This study stresses that leaf litter and dead wood are important for stream biota and woodland microfaunae.*

REFERENCE	PRINCIPAL POINT(S)
Nielsen, K.E., Ladekarl, U.L. and Nørnberg, P. (1999) Dynamic soil processes on heathland due to changes in vegetation to oak and Sitka spruce. *Forest Ecology and Management* 114, 107-116.	• *Nitrification increased with soil depth due to pH elevation.* • *Oak trees depodsolize podzol soils under heath towards acid brown soils.* • *Phenolic compounds can 'sterilise' the soil resulting in low decomposition rate of organic matter.* • *Phenolic compounds were found to be nearly absent under oak stands.*
Nieuwenhuis, M. and Barrett, F. (2002) The growth potential of downy birch (*Betula pubescens* (Ehrh.)) in Ireland. *Forestry* 75:1, 75-87.	• *Properly managed birch can attain a yield class of 10.* • *Though silver birch yield is greater, downy birch is more ecologically flexible.* • *It is not likely that birch will attain its true potential on poor, waterlogged or exposed sites.*
Nilsson, J. and Greenfelt, P. (Eds.) (1988) *Critical loads for sulphur and nitrogen.* Miljörapport 1988:15. Nordic Council of Ministers, Copenhagen. pp. 18.	• *Outlines the definition of critical loads as 'a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge'.*
Nilsson, S.I., Miller, H.G. and Miller, J.D. (1982) Forest growth as a possible cause of soil and water acidification: an examination of the concepts. *Oikos* 39:1, 40-49.	• *New plantations have a high accumulation of cations but this falls with time and in the absence of any harvesting or management activities.* • *Old, slow-growing stands are slow to release ions.* • *This is a Norwegian study where all species, except beech, were conifers. The beeches studied were on glacial till soils.* • *'Forest growth… is unlikely to lead to acidification of streams and lakes despite pronounced and fluctuating soil acidification'.* • *Rainfall more likely to cause stream acidification than biological activity but this can be complicated by geology and soil depth.*
Nisbet, T.R. (1989) *Liming to alleviate surface water acidity.* Forestry Commission Research Information, Note 148, HMSO, London.	• *Information on liming and methods for application.*
Nisbet, T.R. (1990) *Forests and Surface Water Acidification*. Forestry Commission, Bulletin 86, HMSO, London.	• *An outline on the processes of acidification of freshwaters in the UK.*
Nisbet, T.R. (2001) The role of forest management in controlling diffuse pollution in UK forestry. *Forest Ecology and Management* 143, 215-226.	• *Described the critical loads approach to new forestry plantations.* • *States that the new 'Forest and Water Guidelines' (UK) should be effective in dealing with the principal issues of watercourses in afforested areas.* • *Planning and sensitive management practises are required for forest management, including supervision of work and on-site discipline.* • *Retention of riparian buffer areas is necessary.* • *Long-term research (ongoing) is necessary.*
Nisbet, T.R., Fowler, D. and Smith, R.I. (1995) An investigation of the impact of afforestation on stream-water chemistry in the Loch Dee catchment, SW Scotland. *Environmental Pollution* 90:1, 111-120.	• *No evidence was found of the acidification effect when the canopy of the conifer woodland has not yet closed.* • *The reduction in emissions is probably the reason for low levels of deposition but this should not be taken as a trend for the future.*

REFERENCE	PRINCIPAL POINT(S)
Nissinen, A. (1999) *Responses of boreal forest soils to changes in acidifying deposition*. Unpublished Dissertation, 114 pp.	• *Details the process of acidification and its impacts on the boreal region.* • *Believes that S emissions must be brought back to pre-1990 levels at the least.*
Nordén, U. (1991) Acid deposition and throughfall fluxes of elements as related to tree species in deciduous forests of South Sweden. *Water, Air and Soil Pollution* 60, 209-230.	• *Oak has a high interception ability compared to Fagus sylvatica and Acer spp.*
Nordén, U. (1994a) Influence of tree species on acidification and mineral pools in deciduous forest soils of South Sweden. *Water, Air and Soil Pollution* 76, 363–381.	• *Carpinus betula acidified the soil less at a site with lowest base saturation.* • *Quercus acidified soils less at sites with highest base saturation.* • *Quercus has the greatest cation excess accumulation on poor soils.*
Nordén, U. (1994b) Leaf litter fall concentrations and fluxes of elements by deciduous tree species. *Scandinavian Journal Forest Research* 9, 9–16.	• *Referenced in Hagan-Thorn et al. (2004) as discovering that chemical changes found in upper soil horizons were also detectable in lower horizons in 100-year-old broadleaf stands.* • *Ash and lime leaf litter decomposes readily and promotes high base cation return to soil.*
Nordén, U. (1994c) The influence of broad-leaved tree species on pH and organic matter content of forest topsoils in Scania, South Sweden. *Scandinavian Journal Forest Research* 9, 1–8.	• *Lower pH under beech trees than oak in mixed stands.*
Nordén, B., Götmark, F., Tönnberg, M. and Ryberg, M. (2004) Dead wood in semi-natural temperate broadleaved woodland: contribution of coarse and fine dead wood, attached dead wood and stumps. *Forest Ecology and Management* 194, 235-248.	• *The role of dead wood is far greater than previously understood.* • *Dead stumps need to be investigated for their biodiversity implications.* • *Oak has a high potential for supporting invertebrates and other organisms when dead.*
Nornberg, P., Sloth, L. and Nielsen, K.E. (1993) Rapid changes of sandy soils caused by vegetation changes. *Canadian Journal of Soil Science* 73, 459-468.	• *Noted a decrease in soil acidity following the colonisation by oak (Quercus robur).* *This was accompanied by a lowering of soil organic matter.*
Norris, V. (1993) The use of buffer zones to protect water quality: a review. *Water Resources Management* 72, 57-272.	• *Vegetated narrow strips of <10 m are capable of reducing sediment, nutrient or chemical runoff concentrations in small plot experiments.* • *Suggests that buffer strips in forested catchments were likely to be more effective in ameliorating sediment runoff because they were managed for that purpose.* • *Expounded on the advantages of having buffer strips close to the source of the contaminant requiring treatment.*
O'Dowd, N. (2004) *The improvement of Irish birch - Phase 1: Selection of individuals and populations.* COFORD, Dublin.	• *'Birch has the potential to satisfy the 10% minimum commercial broadleaf requirement on sites with poor quality soil' in Ireland.* • *'Growing birch would lead to increased diversity of Irish forestry species'.* • *Birch produces high quality timber.* • *Birch is suitable for riparian zones.* • *Birch has high value for biodiversity.*

REFERENCE	PRINCIPAL POINT(S)
O'Halloran, J. and Giller, P.S. (1993) Forestry and the ecology of streams and rivers: lessons from abroad? *Irish Forestry* 5:1, 35-52.	• *As found by Ormerod (1987), poorly buffered streams are often found to have a reduced invertebrate diversity.* • *Examination of harvesting and other management techniques is necessary.* • *There is a need for predictive models.*
O'Halloran, J., Giller, P.S., Clenaghan, C., Wallace, J. and Koolen, R. (1996) *Plantation forestry in river catchments: disturbance and recovery*. In: Giller, P.S. and Myers, A. A. (Eds.) *Disturbance and recovery of ecological systems*. Proceedings of the Royal Irish Academy, National Committee for Biology Annual Seminar, pp 68-83.	• *There is a complex interaction between forestry and stream catchments.* • *Recovery after harvesting may be in a number of ways.* • *Permitting the felled area to slowly recover through natural regeneration.* • *Replanting immediately and thus ensuring a faster regeneration.* • *No mention of species.*
O'Halloran, J., Walsh, P.M., Giller, P.S. and Kelly, T.C. (2002) *Forestry and bird diversity in Ireland: A management and planning guide.* COFORD, Dublin. 40 pp.	• *A comprehensive guide.* • *Include a recommendation for afforestation with broadleaved and mixed species.*
O'Halloran, J., Walsh, P.M., Giller, P.S., Kelly, T.C. and Duffy, B. (1998) An assessment of avian biodiversity and opportunities for enhancement in Ireland's forests: preliminary results. *Irish Forestry* 55:2, 2-14.	• *Conifers have a role to play in avian conservation but woodlands should be more mixed in species varieties and ages.* • *Conservation of indigenous subspecies, such as the coal tit, my require conifer woodlands.*
Ormerod, S.J. and Tyler, S.J. (1991) The influence of stream acidification and riparian land use on the feeding ecology of Grey Wagtails *Motacilla cinerea* in Wales. *Ibis* 133, 53-61.	• *This study was in broadleaf sites only.* • *The study shows that the presence of broadleaf buffers greatly enhances prey species for wagtails.* • *These buffers would also benefit other birds in a similar fashion.*
Ormerod, S.J., Donald, A.P. and Brown, S.J. (1989) The influence of plantation forestry on the pH and aluminium concentrations of upland Welsh streams: a re-examination. *Environmental Pollution* 62, 47-62.	• *There was a correlation between forest cover, pH and Al concentrations.* • *Forest cover may be a good predictor of Al concentration.*
Ormerod, S.J., Mawle, G.W. and Edwards, R.W. (1986) *The influence of forest on aquatic fauna*. In: Good, J.A. (Ed.) *Environmental aspects of plantation forestry in Wales*. Institute of Terrestrial Ecology, Natural Environment Research Council, Bangor, Wales. p 37-49.	• *This study describes how conifer afforestation (including acidification) in Wales has affected catchments in upland areas.*
Ormerod, S.J., Rundle, S.D., Lloyd, E.C. and Douglas, A.A. (1993) The influence of riparian management on the habitat structure and macroinvertebrate species of upland streams draining plantation forest. *Journal of Applied Ecology* 30, 13-24.	• *Showed further evidence that conifer plantations contribute to Al concentrations in upland streams.* • *Buffer strips are extremely effective in nutrient and sediment runoff, especially at the plantation establishment phase.* • *Buffers of broadleaved trees and open moorland have different effects on stream biota.* • *A blend of different riparian management systems is advocated.*
Ormerod, S.J., Weatherley, N.S. and Merrett, W.J. (1990) The influence of conifer plantations on the distribution of the golden ringed dragonfly *Cordulegaster boltoni* (Odonata) in Upland Wales. *Biological Conservation* 53:4, 241-251.	• *Dragonfly larvae are strongly associated with streamside habitats that are highly eroded and often absent from conifer woodland streams.* • *This probably explained their absence from the conifer woodland of this study.*

REFERENCE	PRINCIPAL POINT(S)
Ovington, J.D. (1953) Studies of the development of woodland conditions under different trees: I. Soil pH. *Journal of Ecology* 41, 13-134.	• *The impact of afforestation on soil pH is very high.* • *Conifers tend to intensify acidity of upper soil, more so than hardwoods.* • *There was the least accumulation of organic matter under broadleaved woodlands and there the most accumulation was under conifer stands.*
Paluch, J.G. and Barkowicz, L.E. (2004) Spatial interactions between Scots pine (*Pinus sylvestris* L.), common oak (*Quercus robur* L.) and silver birch (*Betula pendula* Roth.) as investigated in stratified stands in mesotrophic site conditions. *Forest Ecology and Management* 192, 229-240.	• *Pine is less sensitive to competition than oak and interacts well with birch.* • *Pine forest floor competition is critical to regeneration for transition into oak woodland.*
Patrick, S., Battarbee, R.W. and Jenkins, A. (1996) Monitoring acid waters in the UK: an overview of the UK Acid Waters Monitoring Network and summary of the first interpretative exercise. *Freshwater Biology* 36, 131-150	• *Outlines the work of the Acid Waters Monitoring Network (AWMN).*
Patterson, G.S. and Morrison, B.R.S. (1993) *Invertebrate animals as indicators of acidity in upland streams*. Forestry Commission Field Book 13, London, HMSO, 24 pp.	• *Methods for monitoring upland stream acidity using invertebrates.* • *Table 1 (p.4) lists the main effects of lowering pH on stream ecology.*
Peterjohn, W.T. and Correll, D.L. (1986) *The effect of riparian forest on the volume and chemical composition of baseflow in an agricultural watershed.* In: Correll, D.L. (Ed.). *Watershed research perspectives*. Washington DC, Smithsonian Press.	• *Quoted in Corell (1997) as specifying that as H^+ move through a wooded buffer zone, plant assimilation of nitrates and denitrification consume them and thus pH increases to less toxic levels.* • *However, the prevailing tenet is that buffer zones are not efficient buffers of acidification (Jennings et al. 2002).*
Pigott, C.D. (1983) Regeneration of oak-birch woodland following exclusion of sheep. *Journal of Ecology* 71, 629-646.	• *Exclusion of sheep greatly improves the chances for regeneration of oak and birch.* • *Fencing to exclude grazing resulted in the development of abundant mycorrhizae of oak and birch in the mor-humus.*
Pitelka, L.F. and Raynal, D.J. (1989) Forest decline and acidic deposition. *Ecology* 70:1, 2-10.	• *A synthesis report introducing a special feature on 'acid rain'.*
Pithon, J.A., Moles, R. and O'Halloran, J. (2004) The influence of coniferous afforestation on lowland farmland bird communities in Ireland: different seasons and landscape contexts. *Landscape and Urban Planning* (in press).	• *Lowland forestry will prevent damage to upland habitats such as blanket bogs.* • *Single-species, exotic coniferous monoculture plantations are low quality habitats for birds.*
Porcella, D.B., Driscoll, C.T., Schofield, C.L. and Newton, R.M. (1995) Lake and watershed neutralisation strategies. *Water, Air and Soil Pollution* 85, 889-894.	• *This is a North American study that shows the beneficial effects of liming on a catchment.*
Prévosto, B. and Curt, T. (2004) Dimensional relationships of naturally established European beech trees beneath Scots pine and Silver birch canopy. *Forest Ecology and Management* 194, 335-345.	• *Beech growth is more limited under birch trees than under Scots pine.* • *Below-ground competition may have a stronger effect than light availability for under-story trees in birch/pine pioneer woodlands.*

REFERENCE	PRINCIPAL POINT(S)
Pritchett, W.L. and Fisher, F.R. (1987) *Properties and Management of Forest Soils*. 2nd Edition. John Wiley and Sons. 494 pp.	• *There is a complex inter-relationship between the environment and forest systems.* • *Most forest soils have a substantial reserve of potential acidity.* • *Quercus spp. and Pinus spp. are deep rooting trees.* • *Betula, Carpinus and Tilia spp. are shallow rooting trees.* • *Deciduous tree leaf litter improves soil properties via the pedogenic process and chelation.* • *Birch is reported to exert an influence on exchangeable potassium in potassium-deficient soils and thus pines grow well as an understory of birch in poor soils.* • *Reports that understory species can accumulate a high volume of litter and the resulting decomposition of organic debris (mainly leaves and twigs) reduced acidity and stimulated nitrification and mineral cycling.* • *Beech leaves are too slow to decompose and thus are not efficient buffers.* • *Oaks may not be sufficiently shade-tolerant to be understory trees in buffering woodlands.* • *The technique of underplanting conifers with deep rooting hardwoods (to provide acid-buffering leaf-fall) is considered too costly and considering the varying degrees of success (in limited trials, admittedly) not recommended practise for commercial forestry.*
Puhr, C.B., Donoghue, D.N.M., Stephen, A.B., Tervet, D.J. and Sinclair, C. (2000) Regional patterns of streamwater acidity and catchment afforestation in Galloway, SW Scotland. *Water, Air and Soil Pollution* 120, 47-70.	• *'This study demonstrates that at a regional level catchment afforestation results in a decrease in pH and an increase in total dissolved aluminum, non-labile aluminum and labile aluminum concentrations in runoff under high flow conditions'.* • *Tree age should not be used to assess scavenging effects as ages vary and are subjective.* • *Mean Forest height (MFH) is assessed from satellite imagery and used in this model.*
Puxbaum, H. and Gregori, M. (1998) Seasonal and annual deposition rates of sulphur, nitrogen and chloride species to an oak forest in north-eastern Austria (Wolkersdorf, 240 m A.S.L.). *Atmospheric Environment* 32:20, 3557-3568.	• *European forests may not receive a higher deposition of 'major ions' that US forests as speculated by Lindberg et al. (1990).* • *This is a throughfall study only and does not look at the buffering capacity of oak leaves.*
Quilchano, C., Haneklaus, S., Gallardo, J. F., Schnug, E. and Moreno, G. (2002) Sulphur balance in a broadleaf, non-polluted, forest ecosystem (central-western Spain). *Forest Ecology and Management* 161, 205-214.	• *Discusses how canopies can intercept and absorb S.* • *Trees are moderately efficient in using S.* • *N and P are limiting factors in broadleaved woodlands.*
Quist, M.E. (1995) Reversibility of damage to forest floor plants by episodes of elevated hydrogen- and ion-ion concentrations in the soil solution. *Plant and Soil* 176, 297–305.	• *Acid episodes may cause irreversible forest-floor damage by altering the plant communities.*
Ramberg, L. (1981) Increase in stream pH after forest drainage. *Ambio* 10:1, 34-35.	• *Acidification usually occurs in stream outflow points.*
Raspé, O., Findlay, C. and Jacquemart, A. (2000) *Sorbus aucuparia* L.. *Journal of Ecology* 88, 910-930.	• *Sorbus aucuparia prefers base-rich, well-drained soils but will grow on acid soils that are well drained.* • *Rowan is susceptible to high summer temperatures.* • *Rowan is pioneer species and requires full light.*

REFERENCE	PRINCIPAL POINT(S)
Raulund-Rasmussen, K. and Vejre, H. (1995) Effect of tree species and soil properties on nutrient-immobilization in the forest floor. *Plant and Soil* 168/169, 345–352.	• *Oak has a high litter decay rate, much higher than spruce and beech.* • *This is more pronounced on loamy sites probably due to higher earthworm activity.*
Reuss, J.O. and Johnson, D.W. (1986) *Acid deposition and the acidification of soils and waters*. Springer-Verlag, New York, 120 pp.	• *Outlines the processes involved in acidification process.* • *No mention of the effects of broadleaved trees.*
Reuss, J.O., Cosby, B.J. and Wright, R.F. (1987) Chemical processes governing soil and water acidification. *Nature* 329, 27-32.	• *This is a literature review article.* • *Showed that mobile inorganic anions from rainfall (acid rain), perhaps from sea-salt, release H^+ ions generated by root uptake of cations.* • *After S deposition is reduced the ANC of the soil will stay below the level it was prior to acidification until the base cation pool has been replenished.*
Reynolds, B., Lowe, J.A.H., Smith, R.I., Norris, D.A., Fowler, D., Bell, S.A., Stevens, P.A. and Ormerod, S.J. (1999) Acid deposition in Wales: the results of the 1995 Welsh Acid Waters Survey. *Environmental Pollution* 105, 251-266.	• *Though deposition of S is decreasing inputs to streams in acid-sensitive areas remained high.* • *N contributed to 60% of the acid input of Welsh streams and rivers.*
Reynolds, B., Neal, C. and Norris, D.A. (2001) Evaluation of regional acid-sensitivity predictions using field data: issues of scale and heterogeneity. *Hydrology and Earth System Sciences* 5:1, 75-81.	• *Simplification of models is dangerous and misleading especially when they lead to policy alterations.* • *'Uncertainty and scale' are the main issues of concern that are not currently resolved.*
Reynolds, B., Stevens, P.A., Adamson, J.K., Hughes, S. and Roberts, J.D. (1992) Effects of clearfelling on stream and soil water aluminium chemistry in three UK forests. *Environmental Pollution* 77, 157-165.	• *The effects of felling are largely determined by nitrogen dynamics.* • *Where harvesting increases nitrification, waters are acidified.* • *This may enhance the leaching of base cations and Al.*
Reynolds, B., Wood, M.J., Truscott, A.M., Brittain, S.A. and Williams, D.L. (2000) Cycling of nutrient base cations in a twelve year old Sitka spruce plantation in upland mid-Wales. *Hydrology and Earth System Sciences* 4:2, 311-321.	• *Except Mg, base cations are being depleted.* • *Mature trees demand less calcium and can 'tap' deeper sources of Ca in the soil profile.*
Robison, E.G. and Beschta, R.L. (1990) Identifying trees in riparian areas that can provide coarse woody debris to streams. *Forest Science* 36:3, 790-801.	• *Proposed that the design of a riparian wooded buffer strip be 20 m in width at least.* • *Developed a model of buffer strips where trees that enhance stream characteristics are not harmful.* • *Did not specify any trees that are native, near-native or naturalised in Ireland.*
Rode, W. (1999a) Influence of forest growth on former heathland on nutrient input and its consequences for nutrition and management of health and forest. *Forest Ecology and Management* 114, 31-43.	• *Canopy interception of water is not correlated with canopy interception of nutrients.* • *Pine has a higher leaf area index (LAI = 5.5) than birch (LAI = 2.2) in similar stands.* • *This implies that the interception of water and nutrients (N) is higher for pine than for birch.* • *Pine intercepts N for use of understory species, i.e. pine aids conversion to broadleaved woodland.*

REFERENCE	PRINCIPAL POINT(S)
Rode, W. (1999b) The interaction between organic layer and forest growth and forest development on former heathland. *Forest Ecology and Management* 114, 117-127.	• *The organic layer is of great importance to forest nutrition processes.* • *Pine-birch woodlands have a less compact stratification of the organic layer.* • *Oak-birch woodland has a more compact layer and this better water storage ability.*
Rothe, A. and Binkley, D. (2001) Nutritional interactions in mixed species forests – a synthesis. *Canadian Journal of Forest Research* 31, 1855-1870.	• *There is a complex interrelationship between site, species combination and management.*
Rothe, A., Ewald, J. and Hibbs, D.E. (2003) Do admixed broadleaves improve foliar nutrient status of conifer tree crops? *Forest Ecology and Management* 172, 327-338.	• *The beneficial effects that broadleaved trees have on conifer stands appear to be less clear than conventional wisdom.*
Rosenqvist, L. Th. (1978) Alternative sources for acidification of river water in Norway. *Science of the Total Environment* 10, 39-49.	• *The development of acid humus is important element in the process of acidification.* • *Traditional reduction of litter by burning was important in controlling acidification and the demise of burning practises contributed to a reduction of pH.*
Ryan, M. and Farrell, E.P. (1998) *Assessing the sensitivity of surface waters to acidification*. Forest Ecosystem Research Group Report Number 25. Department of Environmental Resource Management, University College Dublin, 34 pp.	• *Outlines the acidification process.* • *Summarised the criteria used for designation of acid-sensitive surface waters.* • *Role of organic acids is not clearly understood in relation to freshwater acidification.*
Ryszkowski. L. (1992) Energy and material flows across boundaries in agricultural landscapes. pp 270-284. In: Hansen, A.J. and di Castri, F. (Eds.) *Landscape Boundaries: Consequences for biotic diversity and ecological flows*. Ecological Studies, 92, Springer-Verlag.	• *Shelterbelts consisting of tree mixes (e.g. pine, oak and birch) have a more effective N uptake that those only composed of one species.* • *'When the proportion of shelterbelts, forests and meadows in a watershed area increases than the amount of leached chemical compounds decreases'.*
Sanborn, P. (2001) Influence of broadleaf trees on soil chemical properties: A retrospective study in the Sub-Boreal Spruce Zone, British Columbia, Canada. *Plant and Soil* 236:1, 75-82.	• *Birch is the main broadleaf species in this study.* • *Nutrient concentrations and pH were positively correlated with the degree of broadleaf occupancy under birch stands.*
Schaedle, M., Thornton, F.C., Raynal, D.J., Tepper, H.B. (1989) Response of tree seedlings to aluminium. *Tree Physiology* 5:3, 337-356.	• *Response to Al toxicity is graded from 'sensitive' to 'resistant'.* • *Mostly North American species but Betula pendula and Populus spp. are deemed to be resistant to toxicity at young age.*
Schindler, D.W. (1988) Effects of acid rain on freshwater ecosystems. *Science* 239, 149-157.	• *Looks at the acidification process and its impact on stream ecology.*
Schlaepfer, R. (Ed.) (1993) *Long-term implications of climate change and air pollution on forest ecosystems*. Progress Report of the IUFRO Task Force on Forest, Climate Change and Air Pollution. IUFRO, Vienna, World Series, 4.	• *A pH of less than 3.0 is generally required to cause foliar damage.* • *Acidic deposition (via 'acid rain') affects tree species mainly through epicuticular wax but this does not imply damage to the tree as a whole.* • *Scavenging of pollutants may have a more detrimental effect on Europe's forests.*

REFERENCE	PRINCIPAL POINT(S)
Schnitzler, A. and Closset, D. (2003) Forest dynamics in unexploited birch (*Betula pendula*) stands in the Vosges (France): structure, architecture and light patterns. *Forest Ecology and Management* 183, 205-220.	• *Forest architecture and structure change during succession with a decrease in birch in favour of beech.* • *Sorbus aria, Sorbus aucuparia, Pinus silvestris and Quercus petraea appreciate the light patterns permitted under birch canopies and the nutrient rich litter of birches.*
Schöpp, W., Posch, M., Mylona, S and Johansson, M. (2003) Long-term development of acid deposition (1880-2030) in sensitive freshwater regions in Europe. *Hydrology and Earth System Sciences* 7:4, 436-446.	• *Charts the history of acid deposition in Europe.* • *This is used to inform recovery models such as MAGIC.*
Schreffler, A.M. and Sharpe, W.E. (2003) Effects of lime, fertilizer and herbicide on forest soil and soil solution chemistry, hardwood regeneration, and growth following shelterwood harvest. *Forest Ecology and Management* 177, 471-484.	• *This was a study looking at how broadleaved trees may be grown on acid-sensitive soils.* • *Aluminium toxicity was not a problem.*
Sickles, J.E. and Grimm, J.W. (2003) Wet deposition from clouds and precipitation in three high-elevation regions of the Eastern United States. *Atmospheric Environment* 37, 77-288.	• *'This study illustrates the major and perhaps dominant role that clouds may play by delivering considerable ion loads to montane (sic.) ecosystems in selected elevation ranges where these ecosystems may be especially vulnerable'.*
Skeffington, R.A. and Brown, D.J.A. (1992) Timescales of recovery from acidification: implications of current knowledge for aquatic organisms. *Environmental Pollution* 77, 227-234.	• *The reduction in S deposition levels lead to a decline in cation concentrations.* • *Timescale to remediation is not improved by faster cuts in emissions rather than by liming.*
Skiba, U. and Cresser, M. (1989) Prediction of long-term effects of rainwater acidity on peat and drainage water chemistry in upland areas. *Water Resource* 23, 1477–1482.	• *Predicts that acidification rates may increase with increased conifer afforestation.*
Smith, G.F., Kelly, D.L. and Mitchell, F.J.G. (2003) *Establishing native woodlands in former woodland conifer plantations in Ireland.* In: Humphrey, J., Newton, A., Latham, J., Gray, H., Kirby, K., Poulsom, E. and Quine, Chris. (Eds.) *Restoration of wooded landscape.* pp. 158. UK Forestry Commission, Edinburgh.	• *The most appropriate woodland type for restoration on acid soils in Irish uplands is oak woodland dominated by Quercus petraea and Betula pubescens.* • *This may be followed by Ilex aquifolia and Sorbus aucuparia.* • *Scots pine is also suitable but has not been native in Ireland since the 1st millennium AD.* • *New trees need to be protected from browsing.*
Smith, R.A. (1872) *Air and rain*. London. Longmans, Green.	• *The first description of 'acid rain'.*
Soares, A., Ming, J.Y. and Pearson, J. (1995) Physiological indicators and susceptibility of plants to acidifying atmospheric pollution: A multivariate approach. *Environmental Pollution* 87, 159-166.	• *Species with high levels of foliar nitrate assimilation have excellent buffering capacity.*
Sogn, T.A., Stuanes, A.O. and Abrahamsen, G. (1999) The capacity of forest soil to absorb anthropogenic N. *Ambio* 28:4, 346-349.	• *N varies during forest successional process.* • *There is no significant increase of N-related acidification.*

REFERENCE	PRINCIPAL POINT(S)
Spiecker, H. (2003) Silvicultural management in maintaining biodiversity and resistance of forests in Europe – temperate zone. *Journal of Environmental Management* 67, 55-65.	• *Continuous cover forestry favours biodiversity.*
Stevens, P. A., Ormerod, S.J. and Reynolds, B. (1997) *Final report on the acid waters survey.* Institute of Terrestrial Ecology, Bangor, Wales.	• *Acidification of surface waters is implicated in the severe damage to and/or complete loss of fish populations and other freshwater fauna.*
Stone, E.L. (1975) *Effects of species on nutrient cycles and soil change*. Philosophical Transactions of the Royal Society of London, B, 271, 149-162.	• *Questions the veracity of the theory that broadleaved tree species are deemed to be 'soil improvers',i.e. Ovington (1953) and others.* • *The removal of biomass will double or triple nutrient non-availability.*
Stoner, J.H. and Gee, A.S. (1985) Effects of forestry on water quality and fish in Welsh lakes and rivers. *Journal of the Institution of Water Engineers and Scientists* 39, 27-45.	• *Demonstrated the relationship between conifer afforestation in upland sites and fish decline.* • *Indicated that toxicity to trout is present.*
Stoner, J.H., Gee, A.S. and Wade, K.R. (1984) The effects of acidification on the ecology of streams in the upper Tywi catchment in west Wales. *Environmental Pollution* (Series A), 35, 125-157.	• *Salmonids are significantly affected by afforested upland streams.* • *Macroinvertebrates also severely affected.*
Stott, T. and Marks, S. (2000) Effects of plantation forest clearfelling on stream temperatures in the Plynlimon experimental catchments, mid-Wales. *Hydrology and Earth System Science* 4:1, 95-104.	• *Found that clearfelling has an effect on temperature by raising it slightly.* • *Sensitive harvesting elevated temperatures but by a lesser degree.*
Stretton, C. (1984) Water supply and forests - a conflict of interests: Cray Reservoir, a study. *Journal of the Institution of Water Engineers and Scientists* 38, 323-330.	• *Planning inadequacies lead to catastrophic affect on water quality.* • *Liming and awaiting the maturity of the forest stand are the best options for amelioration.*
Sullivan, T.J. (2000) *Aquatic effects of acidic deposition*. Lewis, 373 pp.	• *Differences in forest canopy, particularly between coniferous and broadleaved stands, can cause large differences in dry deposition as well as occult deposition.* • *Older stands intercept more pollutants.* • *Younger stands take up more N.* • *Increased growth in European forests is partly due to increased N deposition.*
Sundström, E. and Hånell, B. (1999) Afforestation of low-productivity peatlands in Sweden – the potential of natural seeding. *New Forests* 18, 113-129.	• *Scots pine and birch (B. pubescens) are commonly planted on blanket peats.* • *Natural seeding is preferable for the establishment of birch.*
Sydes, C. and Grime, J.P. (1981) Effects of tree leaf litter on herbaceous vegetation in deciduous woodland: II. An experimental investigation. *Journal of Ecology* 69, 249-262.	• *Rowan leaves are the fastest 'to disappear' when fallen in a woodland.* • *Leaf litter has an important role in regeneration of woodlands as well as nutrient recycling.*
Taylor, G.E., Johnson, D.W. and Andersen, C.P. (1994) Air pollution and forest ecosystems: a regional and global perspective. *Ecological Applications* 4:4, 662-689.	• *Some air pollutants are affecting managed and unmanaged forests in North America.* • *The problem must not be oversimplified, as there is a complex interdependence among parameters.* • *Complex modelling may be the only way to fully understand these processes.*

REFERENCE	PRINCIPAL POINT(S)
Tervet, D.J. (2001) *Forest management in acidified catchments: a review.* EU LIFE project (Ref.: LIFE99 ENV/UK/000182), 120 pp.	• *This is the most comprehensive review of acid deposition to date.* • *Explored extensively the role of the riparian area and made suggestions on the management of these areas, particularly as sediment and nutrient traps or filters.* • *Plantations should be 20 m from watercourse and wider strips should be permitted where conifer stands exceed 20 m in height.* • *'Existing scrub vegetation should be retained and a variety of native deciduous trees and occasional conifers planted (or retained) for give variable shade, leaf litter with different breakdown rates…' with the ensuing beneficial knock-on effect for biodiversity.* • *Alders should be avoided in acid-sensitive areas.* • *Retro management of existing conifer plantations should be carried out and new buffer zones established.* • *Noted that some models have predicted that continued use of upland areas for forestry could prevent salmonid recovery indefinitely.*
Teske, M.E. and Thistle, H.W. (2004) A library of forest canopy structure for use in interception modeling. *Forest Ecology and Management* 198, 341-350.	• *Literature review.* • *Leaf Area Index hierarchy index – Irish species not included.*
Thompson, D.B.A., Stroud, D.A. and Pienkowski, M.W. (1988) *Afforestation and upland birds: consequences for population ecology*. In: Usher, M.B. and Thompson, D.B.A. (Eds.) *Ecological change in the uplands*. pp. 237-260. Oxford, Blackwell.	• *At least 34 species of upland birds are at risk from afforestation programmes mainly through loss of nesting and feeding sites.* • *The distribution of at least 14 other species is substantially reduced.* • *Another 8 species is likely to decline.*
Thurmond, D.P., Miller, K.V. and Harris, T.G. (1995) Effect of streamside management zone width on avifaunal communities. *Southern Journal of Applied Forestry* 19:4, 166-169.	• *Mature riparian woodland (in North America) was richer in birdlife than new plantation woodland or exposed riparian areas.*
Tietema, A. and Beier, C. (1995) A correlative evaluation of nitrogen cycling in the forest ecosystems of the EC projects NITREX and EXMAN. *Forest Ecology and Management* 71, 143-151.	• *The links between N input to woodlands, N concentrations within woodlands and N output are clearly demonstrated.* • *Unwilling to make generalisations due to the limited number of sites assessed.*
Tipping, E., Carrick, T.R., Hurley, M.A., James, J.B., Lawlor, A.J., Lofts, S., Rigg, E., Sutcliffe, D.W. and Woof, C. (1998) Reversal of acidification in upland waters of the English Lake District. *Environmental Pollution* 103, 143-151.	• *Decreases in water acidification follow decreases in atmospheric deposition of sulphur.* • *Reduction in emissions not shown, in the short-term, by a reduction in freshwater acidification.*
Truscott, A.M., Mitchell, R.J., Palmer, S.C.F. and Welch, D. (2004) The expansion of native oakwoods into conifer cleared areas through planting. *Forest Ecology and Management* 193, 335-343.	• *Natural spread of oaks into clearfelled areas is unlikely and so planting is essential.* • *Birch succession is likely to last for 50 years before oaks begin to dominate.* • *Browsing must be eliminated to ensure success.* *Soils are not examined in this study.*

REFERENCE	PRINCIPAL POINT(S)
Ulrich, B. (1983) *Interaction of forest canopies with atmospheric constituents: SO_2, alkali and earth alkali cations and chloride*. In: Ulrich, B. and Pankrath, J. (Eds.) *Effects of accumulation of air pollutants in forest ecosystems*. pp. 33–45. Reidel, Dordrecht, The Netherlands, 389 pp.	• *Conifers are more efficient collectors (scavengers) than broadleaves such as oak and beech.*
van Ranst, E., de Conick, F., Roskams, P. and Vindevogel, N. (2002) Acid-neutralising capacity of forest floor and mineral topsoil in Flemish forests (North Belgium). *Forest Ecology and Management* 166, 45-53.	• *Soil sensitivity to acidification is correlated with the soil texture class so soil texture classifications will be a good indicator of soil sensitivity.* • *With the turnover of organic matter and the uptake of nutrients, alkalinity is produced and neutralises part of the acidity.* • *It is difficult to separate anthropogenic sources of acidification from 'natural' sources it is more appropriate to access the acid-neutralising capacity of the soil.* • *ANC predominantly due to silicates present in the top 10 cm of soil.* • *ANC is closely related to soil texture class so existing soil maps are ideal to assess the sensitivity of soils for acidic pollution.*
van Schöll, L., Keltjens, W.G., Hoffland, E. and van Breemen, N. (2004) Aluminium concentration versus the base cation to aluminium ration as predictors for aluminium toxicity in *Pinus sylvestris* and Picea abies seedlings. *Forest Ecology and Management* 195, 301-309.	• *Dissolved base cations may positively affect the growth of Picea abies but not Pinus sylvestris thus Picea may partly alleviate the toxic effects of aluminium toxicity.*
von Brömmssen, U. (1988) Close-up on soil – weathering can't keep pace. *Acid* 6, 30-31.	• *Outlines the consequences of cation exchange and weathering on forest soils.* • *Maintains that a reduction in emissions, and hence input, will help young soils recover from acid deposition.*
Walsh, P., O'Halloran, J, Kelly, T. and Giller, P. (2000) Assessing and optimising the influence of plantation forestry on bird diversity in Ireland. *Irish Forestry* 57, 2-10.	• *New planting subsidies to farmers may prevent damage to sensitive upland habitats.* • *This may result in higher timber yields as well.*
Warfvinge, P. and Sverdrup, H. (1988) Soil liming as a measure to mitigate acid runoff. *Water Resources Research* 24:5, 701-712.	• *Careful soil and hydrological characterisation is important to ensure the limestone dosage.* • *Treated areas are shown to be sufficient to increase in-stream reduction of pH.*
Waring, R.H. and Schelsinger, W.H. (1985) *Forest ecosystems: Concepts and management*. Academic Press, San Diego.	
Watmough, S.A. and Dillon, P.J. (2002) The impact of acid deposition and forest harvesting on lakes and their forested catchments in south central Ontario: a critical loads approach. *Hydrology and Earth Systems* 6:5, 833-848.	• *Ca levels in lakes have been dramatically falling due to acidification of catchments.* • *Harvesting has a large impact on lake acidity.*
Watt, W.D., Scott, C.D., Zamora, P.J. and White, W.J. (2000) Acid toxicity levels in Nova Scotian rivers have not declined in synchrony with the decline in sulfate levels. *Water, Air and Soil Pollution* 118, 203-229.	• *Noted year-to-year fluctuations (but no long-term trend) that appear to be linked by organic acid production.*

REFERENCE	PRINCIPAL POINT(S)
Weatherley, N.S., Rundle, S.D., Lloyd, E.C. and Ormerod, S.J. (1993) The effects of riparian management on the abundance of macroinvertebrates in streams draining conifer plantations. *Biological Conservation* 63, 171-176.	• *Despite an overriding influence of stream acidity a number of taxa were influenced by forest management.* • *Different management techniques can generate a range of habitat types necessary to support different invertebrate taxa.*
Wesley, M.L. and Hicks, B.B. (2000) A review of the current status of knowledge on dry deposition. *Atmospheric Environment* 34, 2261-2282.	• *Deposition models have been improving gradually over the years.* • *Many parameterisations used in models need to be improved upon.*
Weston, D.G. (1995) The effectiveness of buffer zones in conifer-afforested catchments. *Journal of the Institution of Water and Environmental Management* 9:4, 396-404.	• *Buffer zones were shown to decrease pH runoff but this depends on soil geomorphology.* • *Soils containing organic matter were more effective that mineral soils in improving water quality.* • *SO_4 and NO_3 reduced, but chloride is elevated a little.* • *Buffer zones should contain an anaerobic component with a high content of organic matter in order to encourage denitrification.* • *This should be followed by followed by a zone with a high cation exchange and holding capacity.* • *Buffer zones have high ecotonal values and should consist of non-coniferous vegetation.* • *'Buffer zones do not provide a comprehensive means of ameliorating soil-water quality in upland conifer-afforested catchments'.* • *The lifespan of buffer areas has not been established.*
Whelan, M.J., Sanger, L.J., Baker, M. and Anderson, J.M. (1998) Spatial patterns of throughfall and mineral ion deposition in a lowland Norway spruce (*Picea abies*) plantation at the plot scale. *Atmospheric Environment* 32:20, 3493-3501.	• *One of the results of this study was to 'highlight the need for a better characterisation of canopy architecture in order to improve understanding of its role in affecting water and mineral ion deposition on the forest floor'.*
Wild, A. (1993) *Soils and the Environment.* Cambridge University Press. 287 pp.	• *Chapter 9 deals with the impact of acidification processes on soils.*
Wilson, B.R., Moffat, A.J., and Nortcliff, S. (1997) The nature of three ancient woodland soils in southern England. *Journal of Biogeography* 24, 633-646.	• *Results did not support Miles' (1981) results in that soil acidity did not alter significantly.*
Winter, J.G. (1983) *The catalogue of phytophagous insects and mites on trees in Great Britain.* Forestry Commission Booklet No. 53. London, HMSO. 57 pp.	• *A complete listing of phytophagous insects.* • *Used by ecologists in the UK and Ireland extensively for biodiversity studies baseline data.*
Woodin, S.J. (1988) *Acidic deposition and upland conservation: an overview and the way ahead.* In: Usher, M.B. and Thompson, D.B.A. (Eds.) *Ecological change in the uplands*. pp. 355-364. Oxford, Blackwell.	• *Sphagnum very susceptible to acid deposition (and n increases).* • *Birch will form a mull humus in time and is suitable for upland sites.* • *Wider spacing of trees encourages a diverse ground vegetation and thus a more efficient buffer to acid episodes.*
Wright, R.F., Norton, S.A., Brakke, D.F. Frogner, T. (1988) Experimental verification of episodic acidification of freshwaters by sea salts. *Nature* 334, 422-424.	• *Seasalt effects cannot account for long-term acidification of freshwaters alone.* • *The seasalt effect may be more relevant on thin soils in coastal areas.*

REFERENCE	PRINCIPAL POINT(S)
Zimmermann, S., Braun, S., Conders, M. and Blaser, P. (2002) Macronutrient inputs by litterfall as opposed to deposition into two contrasting chestnut forest stands in southern Switzerland. *Forest Ecology and Management* 161, 289-302.	• *Elemental return through litterfall is much higher than by occult deposition.* • *The annual return of Ca, Mg and K corresponds to 35% of easily available pool of these nutrients.* • *These nutrients 'contribute to the replenishment of the exchange complex with nutrient cations and to the capability of the soil to buffer acidity'.*