Forest Research
An agency of the Forestry Commission

Terrestrial Umbrella: Eutrophication and Acidification of Terrestrial Ecosystems

Final report (May 2004)
of the Forest Research sub-contract to the Department for Environment, Food and Rural Affairs

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1. Summary

The principal roles of Forest Research were to provide expert advice and to deliver a range of site specific environmental, soil and vegetation-related parameters and data-sets required for the evaluation of the Critical Loads calculation methodology. This evaluation includes the testing and calibration of process-based dynamic models of soil chemistry. The data-sets supplied are based upon measurements made in the UK plots within the EC and UNECE-ICP (Forests) Intensive Forest Health Monitoring Network (Level II) which were established in 1994-5. Most data-sets are available from 1996 and include deposition measured as bulk precipitation and throughfall, soil solution chemistry, foliar chemistry, ground vegetation composition and community structure, litter biomass and chemistry, soil chemistry and profile description and crown condition. Additional measurements have been made where required, including litter chemistry and soil solution DOC.

Trend analysis of the some of the long-term data-sets has demonstrated chemical changes indicating some recovery from high pollution loading in the past, and the successful implementation of emission control policies. There is a general downward trend in foliar sulphur concentrations at most sites, corresponding to a reduction in soil solution sulphate concentrations. Foliar sulphur levels at one remote Scots pine plot are now classed as deficient and, if the downward trend continues, the data indicate that sulphur deficiency may become more widespread. There has also been a reduction in foliar aluminium levels at most sites, possibly reflecting the early stages of recovery from acidification which is evident in soil solution pH at a previously highly polluted site in the south Pennines. Data for one plot in East Anglia show opposite trends compared to the general improvement observed across the rest of the sites. Here, a large reduction in soil solution pH and concomitant increase in aluminium concentrations has been observed since 1996, possibly reflecting high ammonia deposition as a result of intensive animal and poultry husbandry in the region. The very high soil solution nitrate concentrations further demonstrate the impact of nitrogen deposition at the site. Soil solution nitrate concentrations are high at two other sites, both upland Sitka spruce experiencing low nitrogen deposition, and may be a result of limited drainage and the nitrogen input from peat mineralisation largely remaining on site. In contrast, a small reduction in soil solution nitrogen levels has been observed at the site in the south Pennines, presumably indicating lower industrial emissions in the area, while a large reduction has been observed in Wiltshire, possibly reflecting increased uptake in response to a thinning operation on establishment of the site.

Critical load exceedance maps for nutrient nitrogen and acidity have been amended to account for forest management activities (thinning, harvesting and fertilisation) that can affect nitrogen and base cation removal or addition. This process has involved updating the uptake term in the Simple Mass Balance Equation based on growth estimates and new nutrient concentration measurements made across the Level II network. Managed and unmanaged woodland have been mapped separately by combining three woodland cover maps from different sources. The managed woodland category has been further categorised into conifer and broadleaf woodland to enable critical load exceedances to defined receptors for each woodland type to be mapped.

2. Policy Relevance

The critical load approach is a key element of emissions reduction policy. Its continuous evaluation and development using current data are crucial for producing updated critical loads exceedance maps for the UK and thus targeting implementation policies towards effective ecosystem recovery. For woodland, the approach must be appropriate to the breadth of environmental conditions and woodland types present in the UK, and also representative of both unmanaged woodland and current practices employed across the managed forest estate.

The current empirical and steady state mass balance critical load methodologies define receptor tolerance to a given pollutant. However, they do not provide information on the response of the receptor to temporal variations in the pollutant, including the periods prior to damage being observed in response to exceedance, and during recovery to reduced pollutant input. Pressure to evaluate the impact of planned reductions in S and N emissions now requires the application of methodologies capable of representing the dynamics of ecosystem change in the above processes. Thus, processed-based dynamic models such as SAFE, MAGIC and VSD (Very Simple Dynamic Model) have been developed (Evans and Reynolds, 2003). The evaluation and testing of these models is reliant on the availability of site specific data-sets, including both input parameters required for running the models and, also, output data-sets on which an assessment of the performance of the models can be based. An evaluation of the performance of dynamic models also requires that long-term, unbroken, data-sets are available. Furthermore, a spatial assessment of their performance can only be made if the individual data-sets have been collected using common protocols and to defined standards as is the case within the UK Intensive Forest Health Monitoring Network, while the ability to assimilate new measurements protocols in an active network is essential.

The future participation of Forest Research within the Terrestrial Umbrella provides a basis for an extension of this detailed, long-term environmental data-set, to include additional sites, species and measurements. An on-going process of comparing observed temporal and spatial trends in the principal indicators of ecosystem damage and recovery with outputs from dynamic models will enable the effectiveness of emissions control policies to be monitored and the success of alternative policies to be predicted. Planned experimental work will contribute to a knowledge of the effects of N deposition and its spatial variation in N-saturated forest ecosystems, while the development of the critical load methodology described here also enables the potential for active management of acid or nitrogen-sensitive woodland to be explored.

3. Project Description

Work Package 1: Critical loads and Dynamic Modelling

The overall aim of this Work Package is to develop dynamic models that will enable critical loads related scenario analysis on local and regional scales within the UK. Scenarios involving the evaluation of prospects for the recovery of damaged ecosystems are a particularly high priority. The principal role of Forest Research has been to give support to national critical load modelling and mapping activities. This role has included the provision of data and expert advice on woodland management and forestry practice, and the interpretation and assessment of outputs from the modelling and mapping activities. The data-sets collated for this contract have primarily been based on the UK network of Forest Health Monitoring sites (referred to as the Level II network), which is part of a wider, pan-European monitoring network comprising over 600 sites (see De Vries *et al*., 2003). Full data-sets are available for the original ten sites (see Figure 1), with additional data becoming available over time for the ten new sites established in 2001, which introduce new species and an improved spatial coverage to the network.

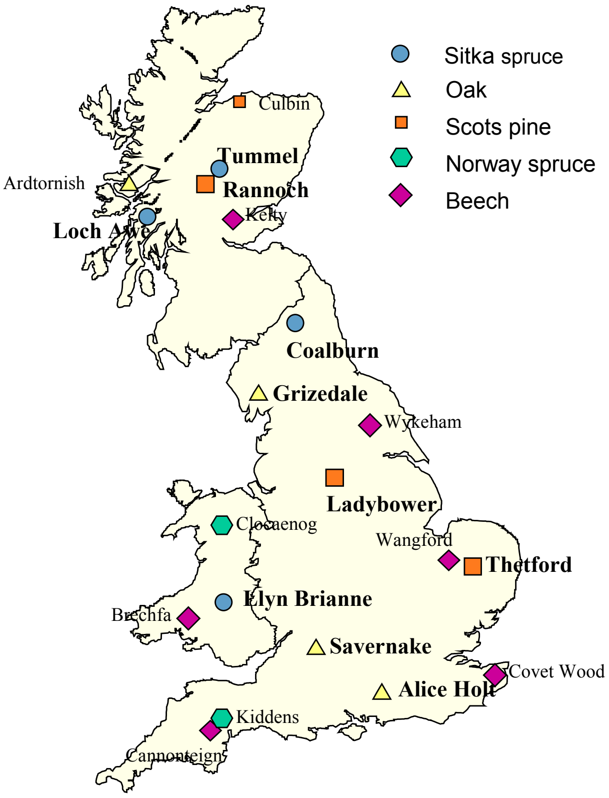

Figure 1. Location of the UK Intensive Forest Health Monitoring Network. The original ten sites for which deposition and soil solution data are available are shown in bold.

Many of the measurements are mandatory within the wider framework of the Programme, although the UK undertakes the full suite of measurements, including deposition and soil solution chemical analysis, at a higher proportion of sites than is mandatory. In addition, some measurement programmes, including litter and wood chemistry analysis have been developed specifically in support of national critical loads modelling and mapping. This report describes the contribution that Forest Research has made to the critical load modelling and mapping process, summarises the data-sets that have been made available, and outlines the observed trends in indicator variables including foliar and soil solution chemistry.

4. Key Findings

Task 1: Evaluation and application of empirical and mass balance critical load approaches to soils and vegetation systems – support of the national critical loads mapping programme.

Mapping woodland at a UK scale

The decision to map nutrient nitrogen critical loads exceedance separately to ‘managed’ and ‘unmanaged’ woodland has created difficulties, because of the lack of suitable data compatible with Land Cover Map 2000 (Haines-Young *et al.*, 2000). The decision to map managed and unmanaged woodland separately was made largely to exclude intensively managed conifer woodland from assessments of impacts on the principal receptor (ground vegetation), but also to enable nitrogen (and base cation) removal at harvest to be accounted for. The procedure adopted is described in detail elsewhere (Hall *et al.*, 2003), but is also summarised below.

The distinction between managed and unmanaged woodland is to some extent arbitrary, but in general terms, provides a broad-brush categorisation of the primary objective of woodland management. The distinction is made solely on the grounds of inclusion within the JNCC (EN, CCW, SNH) databases of ancient and semi-natural woodland (ASNW), excluding plantation ancient woodland sites (PAWS). ASNW is assumed to be unmanaged, with the primary objective of management being biodiversity or amenity, and not timber production. The woodland may thus be managed, but it is assumed that timber is not taken off site. Both broadleaf and conifer (Caledonian pine and yew) woodland are theoretically included.

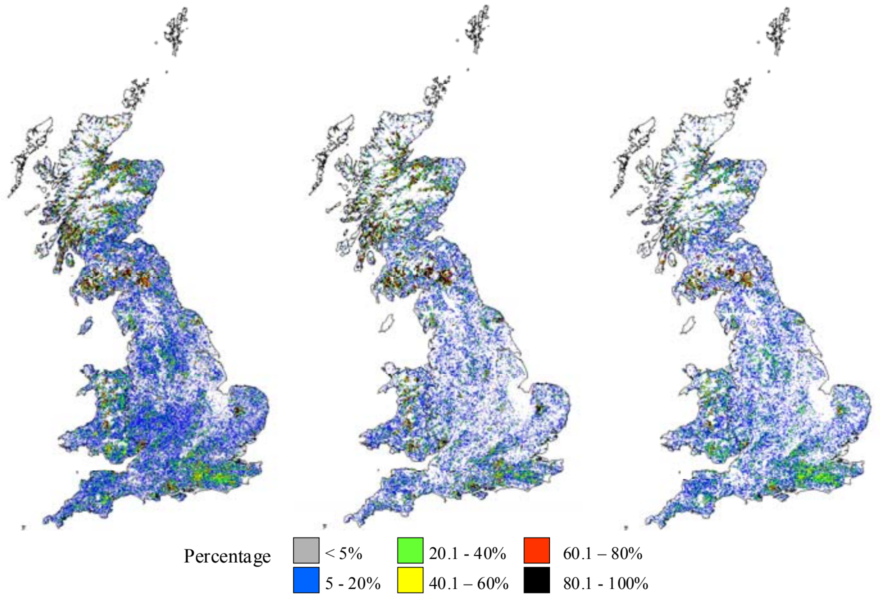

Figure 2. Comparison of total woodland areas for (left) LCM2000 (2.83 Mha), (centre) the combined FR/JNCC data-set (2.34 Mha) and the data-set produced as a combination of the two (1.9 Mha). [Source: Hall *et al*. (2003)].

The maps were arrived at by assuming that data from the National Inventory of Woodland and Trees (NIWT: Forestry Commission, 2003) represents total woodland area. ASNW was excluded from NIWT, resulting in maps of managed and unmanaged woodland. Managed woodland was then further sub-divided between coniferous and broadleaf woodland, on the basis of NIWT. Mixed woodland, coppice and young trees were assumed to be in the deciduous woodland category, while ground prepared for planting, clear-fell and open space within the forest were all excluded. Woodland cover arrived at through this methodology did not agree with LCM2000 data for a number of methodological reasons given by Hall *et al*. (2003). In order to produce estimates of woodland cover compatible with LCM2000, a procedure was adopted in which the woodland cover (from LCM2000) for those 1 km grid-squares where both data-sets reported woodland were scaled according to the proportions given in the combined FR/JNCC data-set. Further details are given in Hall *et al*. (2003). A comparison of the three data-sets (FR/JNCC, LCM2000 and the final maps of woodland cover published in Hall *et al*., 2003) is given in Figure 2.

Updating of the uptake term in the SMB calculation

Nutrient off-take during management and harvesting activities can represent an important part of the uptake term in the simple mass balance critical load equation. The uptake term used in the SMB calculation has been updated during the course of this contract, with the current value for each of the Level II plots on which these values are based given in Table A1.1. These individual plot values are also used as input terms for the dynamic acidification models including SAFE and MAGIC which are evaluated elsewhere in this report (Task 2).

Nitrogen and base cation uptake over the course of a rotation are based on estimates of biomass and tree nutrient concentrations at final harvest. Cumulative volume production is based on Yield Models for Forest Management (Edwards and Christie, 1981), also accounting for biomass removal during thinning operations for relevant species. The rotation length is based on felling at maximum mean annual increment (MAI) for the conifer species, while in the case of oak, the rotation is extended beyond maximum MAI to 120 or 140 years to reflect current practice. Overbark volumes (as given in the Yield Tables) are converted to underbark volumes using industry-accepted species-specific conversion factors (Hamilton, 1975) and then used to calculate biomass. For deciduous species, branch biomass, is calculated additionally, accounting for small diameter timber taken off site for pulp and firewood. Site specific measured stemwood and bark nutrient concentrations together with published values of branch nutrient concentrations (Allen *et al*., 1974: for oak only) are then used to estimate total quantities of base cations and nitrogen taken offsite during the rotation. Uptake is assumed to occur at a constant rate over the course of the rotation. The oak plots are assumed to be thinned, while of the conifer species, Sitka spruce is assumed unthinned, and Scots pine thinned. The mean uptake of the seven conifer and three broadleaf plots are assumed to represent their respective forest types, with corrections applied to account for the difference in absolute yield between the Level II plots and the Forest Enterprise managed estate as a whole. Further details are given in Hall *et al*. (2003 & 2004).

Wood nitrogen and base cation concentration
The uptake term in the SMB calculation requires site specific values for wood nutrient concentrations. Three previous analyses of wood chemistry in a sample of the UK Level I (Freer-Smith and Kennedy, 2002) and Level II Sitka spruce plots (Crow, unpublished) provided contrasting values for, primarily, the nitrogen and also the base cation content of stem wood. Methodological differences were evident between the three studies, largely relating to the protocol for sub-sampling the stem wood. In addition, there was a longer period between sample collection and analysis in the study of Freer-Smith and Kennedy. There was also a difference in timing between the two studies, with samples collected in early July by Crow in comparison to samples collected in late summer and early autumn by Freer-Smith and Kennedy. Data from the latter study form the basis of the biomass and N- and BC-uptake estimates used in both empirical critical load mapping and dynamic critical load modelling. In January 2003, further cores samples were collected from two Level II Sitka spruce sites to provide an indication of whether the discrepancy between the studies were a result of methodological differences including delays in sample preparation, or a function of the time of year at which the samples were collected. The results suggested that it is most likely that the differences largely reflect the timing of sampling and the lower values, currently assumed in calculations of uptake are valid and should continue to be used. However, more information is needed on the annual variation in wood macro-nutrient content, and if values are higher during a significant part of the growing season, this should be taken into account in estimates of nutrient loss at harvest. In February 2004, all twenty Level II plots were resurveyed and the available data will provide a sound basis for the evaluation of the uptake estimates currently used in the critical loads mapping.

Task 2: Evaluation and development of dynamic models for soils and soil-plant systems
Task 3: Provision of input data sets for the testing and application of dynamic models

It is difficult to differentiate between the provision of input data, the provision of data with which to test the output of the dynamic critical loads models and the interpretation of the outputs and their comparison with measured data. This section therefore reports the data-sets that have been developed and made available for dynamic model calibration and validation, alongside an analysis of observed trends that are relevant to the modelling activities. A full description of the modelling activities is left to the report from the principal contractor for that area of work, although the two sections should be read in conjunction.

The dynamic models that were selected for an assessment of their ability to predict critical loads and their exceedance for acidity and nutrient nitrogen are MAGIC, SAFE and VSD (Very Simple Dynamic Model). The data requirements and availability for running the dynamic models are summarised in Table A1.2, while details of the full suite of measurements made across the UK Level II network is given by Durrant (2000). For testing the output of the dynamic models, both soil solution data (including DOC) and ground vegetation species distribution have been collated. In addition to providing data for testing dynamic models, a number of the data-sets are also relevant to Work Package 7 (Assessment of the long-term effects of enhanced and reduced S and N deposition on UK forest ecosystems), as they clearly indicate trends in response to changing pollution loading. They can thus be used to indicate the success of emissions control policies, and to assess and quantify the dynamics of recovery.

Summary of results from the Intensive Forest Health Monitoring (Level II) network

Soil solution and throughfall chemistry

Soil solution, bulk precipitation and throughfall chemistry have continued to be monitored across the original ten sites (nine in the case of soil solution) of the UK Level II network. These data-sets have now been updated and mean annual values from 1996 to 2002 for throughfall chemistry and soil solution are given in Tables A1.3 and A1.4. Dissolved organic carbon (DOC) data for 2002 and 2003 are now also available from all nine sites for input to MAGIC and SAFE (Table A1.5). Characterisation of the soil chemistry of each site is also an essential requirement for dynamic modelling, and these data are summarised in Table A1.6.

Preliminary analysis of data from the Scots pine Level II plots has revealed significant trends, particularly in soil solution pH. At Thetford there was a significant decrease ($R^2 = 0.41$, $p<0.05$: data not shown) in soil solution pH between 1996 and 2003. However, this decrease cannot be explained either by changes in throughfall NO_3-N and NH_4-N or by soil solution NO_3-N or NH_4–N, which were both highly variable throughout the period of monitoring. Soil solution Al has increased throughout the period of monitoring, and this increase is correlated with the decrease in soil solution pH. 1996 and 1997 were particularly dry years, and drainage has been estimated as zero and 8 mm respectively, resulting in pulses of very low pH during re-wetting in autumn having a disproportionately large effect on the annual mean soil solution pH (Figure 3a, $R^2 = 0.33$). Data have therefore been restricted to winter months in Figure 3b ($R^2 = 0.87$, $p<0.01$) to demonstrate the underlying trend in soil solution chemistry. No relationships were apparent between soil solution pH and NO_3-N or SO_4-S, suggesting that nitrate and sulphate in the soil are not the underlying cause of the acidification.

Other possible causes for the observed trends include:

- A preferential uptake of ammonium compared with nitrate from the soil solution, which would acidify the soil due to the excretion of H^+ by the roots during uptake. Scots pine has shown a preference for ammonium over nitrate as a nitrogen source if both are available. However, the predominant source of nitrogen measured in the soil solution is nitrate, and although this may reflect that ammonium is taken up preferentially, it is unlikely that this mechanism could be responsible for a change of such magnitude as that observed at Thetford.

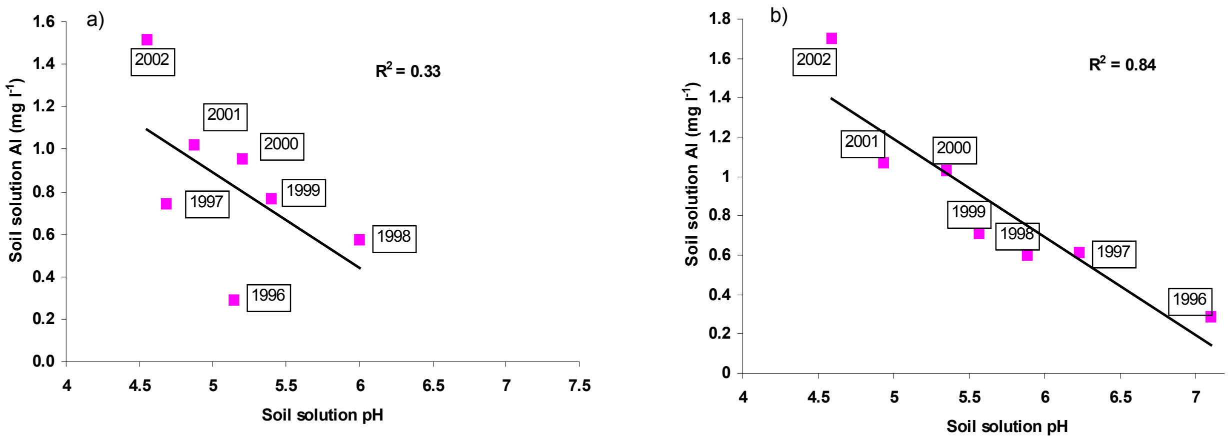

Figure 3. Temporal changes in soil solution pH and [Al] in soil solution at Thetford: (a) all data and (b) data for winter months which exclude acid pulses during autumn re-wetting. Values shown are annual means.

- The establishment of a pig rearing unit within 300 m of the Thetford plot in 2001 represents a significant source of nitrogen and thus acidification. However, the trend towards lower soil solution pH has been apparent since the plot was established in 1996, and this single point source cannot, therefore, explain the underlying trend. No effect of the siting of the pig unit was apparent in throughfall chemistry, although the foliar nitrogen content in 2002 (2.3%: see Table A1.6) was significantly higher than in preceding years. Assuming that the mean foliar N content between 1996 and 2001 represents background deposition in the absence of the pig unit, then the difference between this value and that for 2002 represents an additional 11.2 kg ha^{-1} yr^{-1} deposition on the basis of the mean annual needle fall (3300 kg ha^{-1} yr^{-1}: data not shown). It must be assumed that the majority of the additional deposition is as dry deposition of ammonia through stomatal uptake.
- The installation of lysimeters and the length of their equilibration period in the soil can influence soil solution chemistry (Titus and Mahendrappa, 1996). Data from lysimeters installed in 1996 were compared with pH values from a second set of lysimeters installed, subsequently, in 1997. Agreement between the data-sets was poor (r = -0.26), although the temporal trends were the same in both data-sets with a tendency towards decreasing pH and increasing [Al]. Variability in the second data-set was higher than for the first set of lysimeters, resulting in an exaggerated trend in both pH and [Al] in the latter. The data-set used for testing the dynamic modelling approach using MAGIC (Task 2) was from the first set of lysimeters, and any interpretation of the comparison between modelled and measured soil solution chemistry should consider the discrepancy between these two data-sets.
- Inter-annual variation in rainfall amount and intensity could influence the leaching of elements from the leaves and needles contributing to changes in throughfall and soil solution chemistry.
- The location of the porous cups in the soil profile could, potentially, exaggerate any observed trends towards lower soil solution pH. This might be particularly important at Thetford, where the gradient in soil pH (measured in $CaCl_2$) is large, varying between 4.1 in the O, 4.8 in the Ah (where the shallow porous cups are located), 6.6 in the Bw (where the deep cups are located) and 8.1 in the 2BC horizons. Furthermore, although there are large pieces of chalk below 50 cm, the cation exchange capacity of the profile is low (15 cmol kg^{-1}: Table A1.6), and thus buffering capacity is limited.

- In contrast to the observed acidification of the soil solution at Thetford, a general trend towards higher soil solution pH was observed at the Ladybower Scots pine plot in the south Pennines, and was accompanied by a small decrease in [Al] in both the shallow (R^2 = 0.14) and deep ($R^2 = 0.22$) sets of lysimeters. An opposite trend in the relationship between annual mean soil solution pH and [Al] to that at Thetford was apparent, indicating that during the earlier years (1996, 1998 and 1999, with 1997 an exception), the soil at Ladybower was more acidic than in recent years (2000, 2001 and 2002: Figure 4). Foliar [Al] has shown a significant decrease at Ladybower ($R^2 = 0.87$) as well as at Rannoch ($R^2 = 0.9$) between 1995 and 2002, contrasting with the small increase observed at Thetford (Figure 5). These trends can be explained by changes in pH and thus [Al] in soil solution (Figure 3), and may represent the first evidence of recovery. Further monitoring will reveal whether this phenomenon materialises at all sites, and also the dynamics of the recovery process.

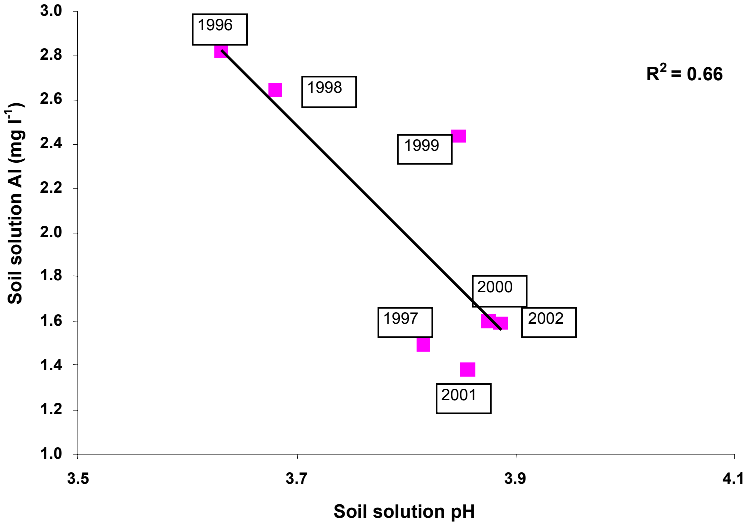

Figure 4. Temporal changes in annual mean soil solution pH and [Al] in soil solution at Ladybower. Data are for the 'shallow' (15 cm) porous cups.

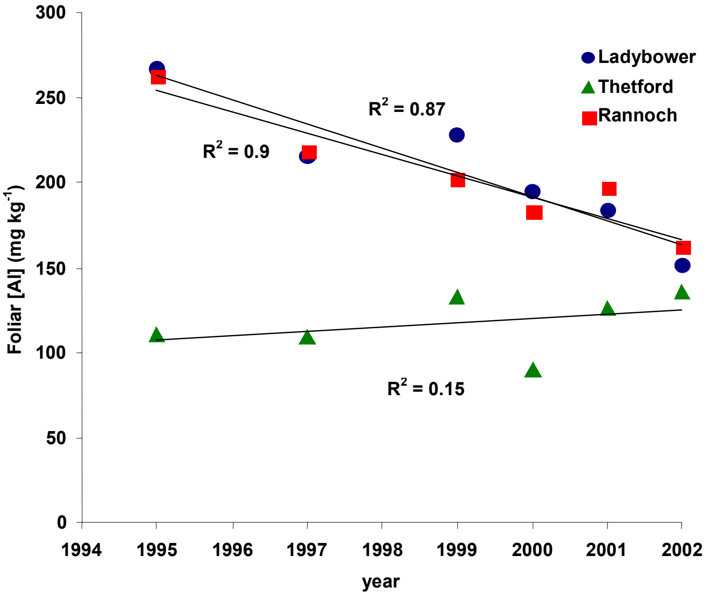

Figure 5. Temporal changes in foliar [Al] at Thetford, Ladybower and Rannoch. The trends are significant ($p<0.01$) for Thetford and Ladybower.

Nitrate concentrations vary greatly between sites, as would be expected given the range of both modelled and measured deposition (see Table A1.3). It should be noted that nitrogen deposition measured as throughfall is lower than modelled values, and does not account for dry deposition via the stomata or leaf cuticle which may be significant, particularly for ammonia. Dynamic models (Task 2) thus rely on modelled nitrogen deposition. $[NO_3^{2-}]$ in soil solution is minimal at Rannoch, relatively high at Ladybower reflecting its historic pollution loading, and very high at Thetford. Equilibrium concentrations predicted by MAGIC cannot account for the scale of nitrate breakthrough at Thetford, and this may reflect that even prior to establishment of the pig rearing unit, local sources of ammonia resulted in higher total nitrogen deposition than that predicted by FRAME. Of the two Sitka spruce plots, high nitrate concentrations in soil solution are apparent at Coalburn and Tummel, with an increasing trend evident at Tummel. At both sites, these high concentrations are at odds with those predicted by MAGIC, assuming the low total nitrogen deposition typical of both areas. One possible explanation for Coalburn is that they may reflect mineralisation of the peat, minimal drainage through the clay underlying the peat and effective uptake by sphagnum in the drains within the plot; nitrogen is thus not leaving the site, and this is confirmed by freshwater chemistry which does not show a significant loss of nitrogen. The high concentrations at Tummel are more difficult to explain, but may have been influenced by the thinning operation that was undertaken in 1996, providing a large nitrogen input from the foliage and brash. However, the long time-frame of the trend excludes this as the sole explanation for the observed trend. The low $[NO_3^{2-}]$ concentrations at Llyn Brianne are much as expected for the location. At both Alice Holt and Grizedale, $[NO_3^{2-}]$ in soil solution is again low, contrasting with Savernake where a large reduction is apparent since establishment of the site. This may reflect either a reduction in deposition as a result of recent changes in local agricultural practices and sources or, alternatively, the release of the canopy by thinning in 1996, thus enhancing the nitrogen demand of the plot.

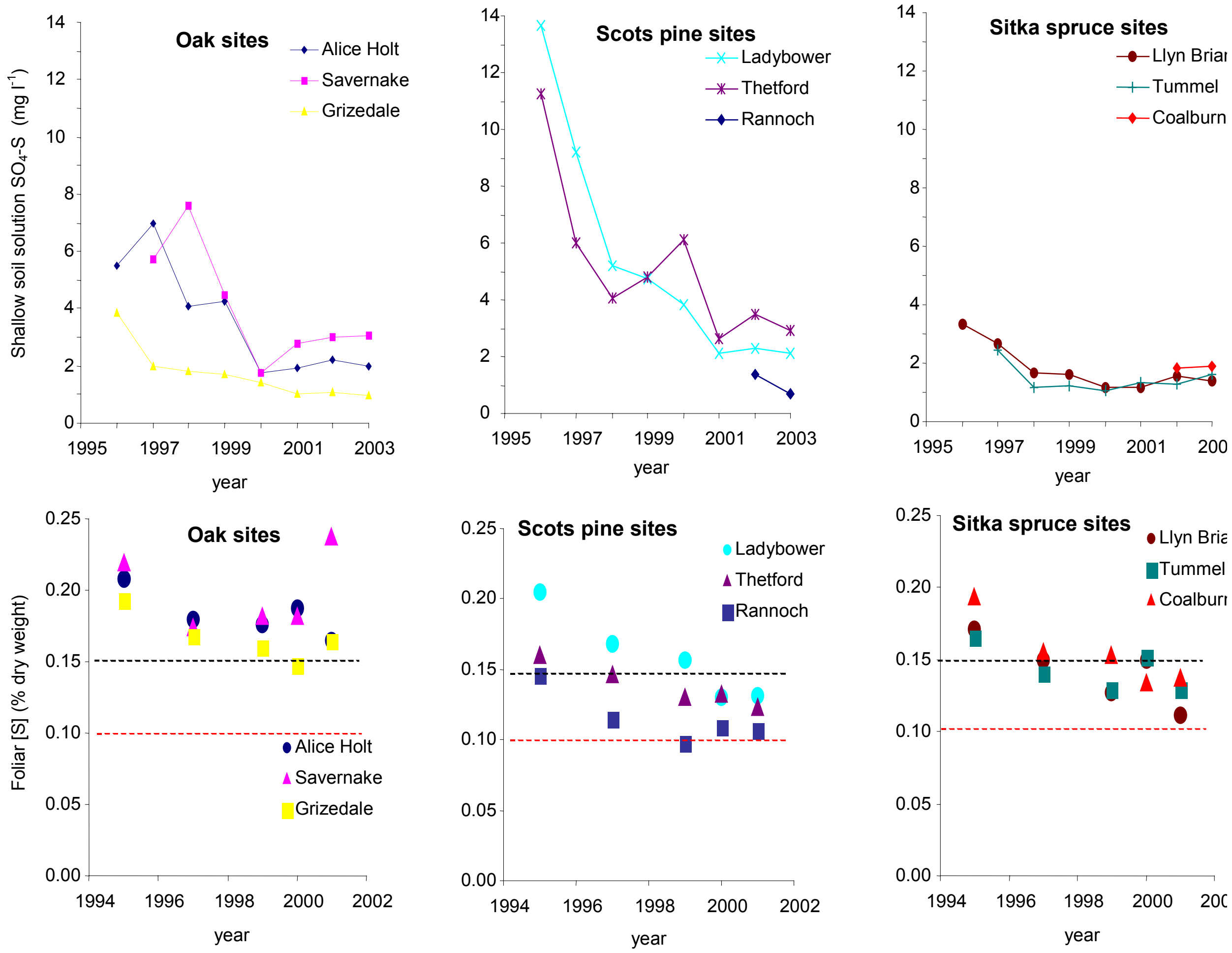

Figure 4. Soil solution SO_4-S and foliar [S] in Level II Oak, Scots pine and Sitka spruce plots between 1996 and 2003. Values shown are annual means with the red line indicating foliar [S] below which deficiency symptoms occur and the black line, optimal foliar [S] according to Van den Burg (1985).

The concentration of SO_4 in soil solution in most of the Level II plots has decreased in recent years which is consistent with the expected response to the reduction in S deposition as a result of emissions control policies (Figure 4). As a result, S uptake has been reduced as indicated by the foliar chemistry data given in Table A1.7 and Figure 4. Values for [S] in foliage are all between the deficient and optimal limits according to Van den Burg (1985), with the lowest values observed for the Scots pine sites particularly at Rannoch, where the values approach the deficiency level of less than 1%: Figure 4). These trends indicate that there is a real possibility that large areas of British woodland could become sulphur deficient in the foreseeable future. Trends at the Sitka spruce plots also indicate that sulphur levels may become deficient at these sites in the foreseeable future.

Soil solution [K^+] has shown a significant, consistent downward trend in the majority of the Level II plots between 1996 and 2003 (Figure 7). This reduction has been most apparent in the oak plots with the observed change smallest in the Sitka spruce plots. Possible causes include either enhanced K leaching immediately after the thinning at establishment of the Level II plots or, alternatively, an increase demand for K uptake in response to the same management intervention. Nevertheless, tree K^+ uptake is unaffected and foliar [K^+] is optimal at all sites according to Taylor (1991) (Table A1.7). It is interesting to note that at Thetford, the decline in soil solution [K^+] between 1996 and 2002 was followed by a large increase in 2003. Soil acidification (Figure 3) could have reduced K^+ uptake as a result of high hydrogen ion availability in soil solution, although this is not manifested as reduced foliar [K^+]. Alternatively, K^+ could have been displaced by H^+ from the soil matrix.

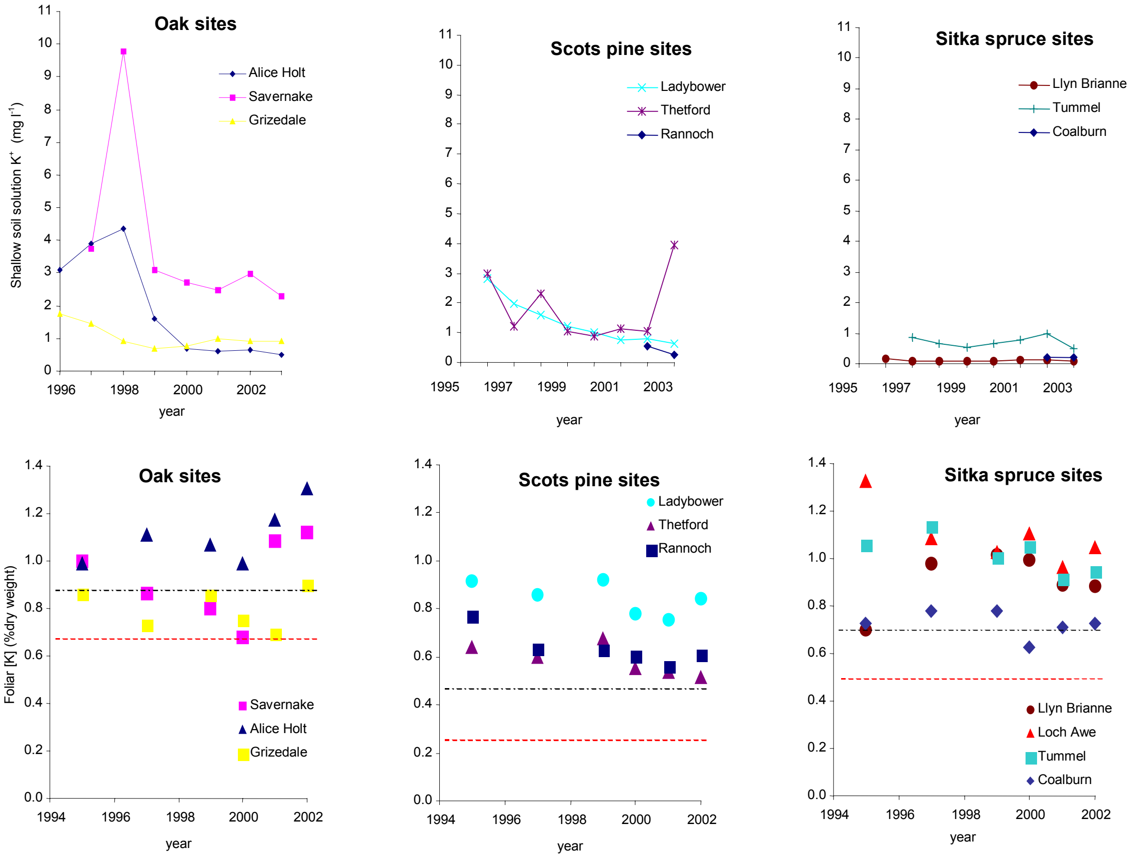

Figure 5. Soil solution [K^+] and foliar [K^+] in Level II Oak, Scots pine and Sitka spruce plots between 1995 and 2003. Values are annual means and the red line indicates foliar [K^+] where deficiency symptoms occur and the black line indicates optimal foliar [K^+] according to Taylor (1991).

Litter analysis

Litterfall is required as an input to SAFE. Measurements began at Alice Holt and Grizedale in 1998, while litterfall in conifer stands (Coalburn, Tummel, Rannoch, Thetford and Ladybower) was established as part of the UK Level II protocol (at selected sites) during the course of 2001. Litter is collected in 0.33 m^2 fibreglass funnels using cotton bags, with 10 replicate collectors per site. Collection is over a period of one month, except for autumn (October-December) at the broadleaf sites, where the collection period is reduced to two weeks. Total litterfall is broken down into foliage, wood, flower/bud and seed components.

Routine litter analysis has undergone chemical analysis to provide estimates of nutrient inputs for dynamic models. Chemical analysis has only been carried out for the foliage component of litter from Alice Holt and Grizedale in 2000 and all components (foliage, wood, flower/bud, fruit) from seven of the original Level II plots together with four of the recently established beech plots for 2002 and 2003. Foliage litter chemistry is compared for all sites and presented in Table A1.8. Comparing nutrient concentrations in litter with those in foliage (Table A1.7) provides an indication of the proportion of nutrients recycled. There is little difference between species and sites apparent in the 2002 data, and average values are given for all sites as a general indication of the level of recycling for individual elements. Nitrogen, phosphorus and potassium are recycled relatively efficiently (49%, 62% and 74% of nutrients retained, respectively) while 80% of magnesium is lost in litter. Calcium appears not to be recycled, with an increase in concentration apparent at most sites as a result of the retention of other elements. Input of individual elements from all litter components are given for 2002 and 2003 in Table A1.9, by combining the biomass of individual components with their chemical composition. The contribution to the nitrogen pool in the soil from overstorey litter is significantly larger at all sites than the contribution from total atmospheric deposition, varying between 22 Kg ha^{-1} at Rannoch in 2003 and 93 kg ha^{-1} in 2002 at Alice Holt. In most cases, the ranking between sites is similar for the two years for which data are available. However, total litter N input at Covet Wood in 2003 was only 37 kg ha^{-1}, compared with 83 kg ha^{-1} in 2002. The difference is a result of 2002 being a mast year, and indicates the important role that seed production can play, particularly in a species such as beech which fruits infrequently. Variation in P input is greater than for nitrogen, and may reflect the extent of P-deficiency. Nearly all P is recycled at Ardtornish (west coast of Scotland) with an annual input of less than 1 kg ha^{-1} from litter contrasting with over 7 kg ha^{-1} at Alice Holt, both in 2002. Base cation input from litter is very consistent between sites, varying between 15 kg ha^{-1} at Ladybower in 2003 and 114 kg ha^{-1} at Alice Holt in 2002. None of these estimates account for the contribution from the ground vegetation, which can be significant, amounting to 1017 Kg ha^{-1} from foliage biomass alone at Alice Holt in 1999 (Pitman and Broadmeadow, 2001).

Vegetation

Ground vegetation community structure is used for testing the output of dynamic critical load models as it is a good bio-indicator of site fertility and environmental change. Woody species in the shrub layer were assessed in ten 10 m x 10 m plots, laid out randomly over the area of the Level II plots. A smaller 2 m x 2 m sub-plot at the southwest corner of the 10 m x 10 m was used to assess ground and field layer (herbaceous) vegetation. In both the 10 m x 10 m and 2 m x 2 m plots cover for individual species is estimated visually using the Braun-Blanquet scale, coded as follows: **r** - rare (0.01%); + - few (<1% cover); **1** (1-5% cover); **2** (6 – 25% cover); **3** (26 – 50% cover); **4** (51 – 75% cover) and **5** (76 – 100% cover). Assessments are carried out at 3-yearly intervals, with additional assessments being made prior to any substantial management disturbance such as thinning. Once the assessment of the individual species has been recorded, a global cover estimate of the plot (%) is made using the general categories shown in Table A1.10.

Records of individual species cover in each vegetation layer are also available (data not shown). Changes in the occurrence of individual species in each plot can thus be assessed for different vegetation surveys in comparison with the data for 1998 given in Table A1.10. Data are also available for 2001 with the next survey due in 2004.

It is clear that the three species represented in the original Level II network have very different ground vegetation communities associated with them. The lack of ground vegetation in the Sitka spruce plots is expected, although the 11% moss cover at Llyn Brianne is of interest. The Scots pine plots all have high moss cover associated with them, but are dominated by either grasses at the upland sites or a combination of herbs and ferns/sedges at Thetford. All three oak sites have vegetation cover exceeding 100% as is also the case for the Scots pine plot at Thetford. Oak is the only species with a well developed secondary canopy (hazel at Alice Holt, *Rubus* and *Prunus* at Savernake and Alice Holt). The ground vegetation communities are markedly different in the three oak plots with *Vaccinium* and grass species dominating at Grizedale which is typical of upland oak. At Alice Holt, the ground vegetation is dominated by herbaceous species, which are largely replaced by grasses and *Rubus* at Savernake, possibly reflecting the high nitrate levels in soil solution (see Table A1.4).

5. Outputs/Deliverables

The key deliverables of Forest Research in this contract were:

- Provision of expert advice on woodland ecosystems;
- characterisation of candidate sites and regions for the modelling work;
- an assessment of the availability of input data for the dynamic models for each of the candidate sites;
- a recommended short-list of sites suitable for the application of dynamic models
- compatible, quality controlled data-sets of driving, state and response variables for the selected study sites.

In the first year of the contract, the sites for modelling work were characterised and the availability of input data for the dynamic models for each of the sites identified. A short-list of sites across a distinct gradient in N deposition were subsequently selected for evaluating the dynamic models (Kennedy, 2002). The provision of compatible, quality controlled data-sets and response variables for the selected intensive monitoring plots has been achieved, with summaries of the relevant data-sets given in Appendix 1. The input data have continually been updated and evaluated over the duration of the contract. A brief summary of observed trends is given in this report, which will provide a future test of the ability of the dynamic models to replicate the dynamics of ecosystem recovery. In addition, more sites have been established within the monitoring programme providing the potential for contributing to the development of the critical loads methodology and evaluation.

FR staff have also been closely involved with the updating of national critical loads exceedance maps for the UK, including the provision of woodland cover maps accounting for woodland type and management at a basic level. Details are given elsewhere in this report.

Publications arising from this and associated work since the beginning of this contract are as follows:

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6. Recommendations for future work

- An ongoing analysis of the level II data-sets will provide information on the long-term dynamics of ecosystem recovery as emissions control measures are implemented. It is essential that these long-term data-sets are maintained, and that discontinuities are not introduced as a result of changing protocols, sampling periods, management practices or sample sites.
- Data presented in this report indicate that at one Level II site, foliar sulphur concentrations are already borderline deficient and that, certainly in the uplands, this may become widespread in the near future as a result of emissions reductions. An assessment of sulphur stocks in soils and biomass and their inclusion in dynamic nutrient models should be considered. This may become pertinent for freshwaters critical loads if sulphur fertilisation of forests was to become common practice.
- Soil solution data from the Level II plot at Thetford indicates recent, rapid acidification, possibly including a contribution from a pig rearing unit from 2001-2003. Other research indicates a trend towards more nitrogen demanding species in beech stands close to forest edges (Kennedy, 2003; Pitman and Kennedy, 2004). Critical loads maps indicate that the majority (>90%) of broadleaf woodland in the UK currently exceeds the critical load for nutrient nitrogen (Hall *et al*., 2003), although widespread effects of excess nitrogen deposition are not evident outside woodland edges (Moffat, 2002). Spatial variation in nitrogen deposition, particularly of reduced nitrogen, together with deposition being mapped at a 5 km resolution may contribute to an overestimate of the proportion of UK woodland affected by excess nitrogen deposition. Comparisons should be made between mapped critical load exceedance and measured deposition in an area with large spatial variability in

deposition. This research could also evaluate the applicability of exceedance maps at a site level and, also, the proportion of woodland where critical loads are exceeded in an area with highly variable deposition.

- Trees are generally one of the more robust elements of woodland ecosystems, and as such, are likely to be the last to show effects of excess pollution. Fine root distribution and, possibly, ectomycorrhizal infection or morphotype identity may prove to be a more responsive measure. This hypothesis should be tested at sites with well characterised and changing pollutant inputs.
- Rainfall patterns appear to have an important bearing on the ability of woodland ecosystems to withstand pollution deposition, largely through dilution and leaching. An investigation of the effects of predicted climate change should be undertaken though a dynamic, process-based modelling approach incorporating the most recent climate change scenarios.
- The current value of the uptake term for base cations and nutrient nitrogen in the simple mass balance equation includes a contribution from branchwood for broadleaf species. The branchwood component is currently calculated assuming a fixed proportion of stemwood (18.5%) based on existing allometric relationships. The chemical composition of branchwood is also based on a single published value. There are concerns that uptake in branchwood is underestimated, particularly if small-diameter branchwood is taken off-site as firewood. This may become an increasingly common practice, particularly if the use of woodfuel becomes more common in small-scale power generation and CHP facilities. A quantification of the contribution that branchwood makes to total biomass removed at harvest during routine thinning operations across the Level II network would provide information compatible with the current methodology for assessing the uptake term.
- It is assumed that branchwood is not taken off-site during harvesting activities in conifer stands. However, whole-tree harvesting is practised in some regions and on some sites. Various options are available for whole tree harvesting of conifer species, and the implications of each of these for critical load exceedance and management and long-term site sustainability will differ. Further information is required on the chemical composition of branchwood so that increases in whole tree harvesting for bioenergy can be accounted for. In addition, together with research into broadleaf branchwood biomass and chemistry described above this work would provide valuable information on methods to manage nitrogen sensitive woodland, as is currently undertaken on some heathland sites.

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Appendix 1

Table A1.1. Updated calculated uptake rates for nutrient nitrogen and base cations for the individual sites comprising the UK Level II network.

Site Name	**Alice Holt**	**Savernake**	**Grizedale**	**Thetford**	**Ladybower**	**Rannoch**	**Coalburn**	**Tummel**	**Loch Awe**	**LlynBrianne**
Species	oak	oak	oak	scots pine	scots pine	scots pine	sitka spruce	sitka spruce	sitka spruce	sitka spruce
Planting year	1935	1950	1920	1967	1952	1965	1974	1969	1971	1973
Age of stand	66	51	80	33	48	35	26	31	29	27
Date of last mensuration field survey	Mar 2001	Mar 2000	Nov 1999	Mar 2000	Feb 2000	Nov 1999	Mar 2000	Nov 1999	Nov 1999	Mar 2000
MEAN TOP HEIGHT (m)	19.9	15.9	17.4	14.9	16.4	10.4	14.5			12.3
MEAN DBH (cm)	24.5	21.8	34.9	20.4	21.9	14.4	20.7			19.1
MAIN CROP BASAL AREA (m2/ha)	23.4	20.8	22	31.9	42.5	37	62	59.7	64.8	58
GYC	6	6	4	12	12	8	18			16
LYC		5	4	12	9	9	21	18?	24?	18
MAIN CROP OVERBARK VOLUME (m3/ha)		*155*	*186*	*219*	*347*	*192*	*379*			*347*
Initial Crop Spacing (within/between rows)	[1.2] ?	[1.2] 1/1.7	[1.2] ?	[1.8] 1.7/1.8	[3.0] 3.2/3.7	[1.8] ?	[1.7] ?	[1.7] 1.8/1.6	[1.7] ?	[2.0] ?/2.1
BARK (% OB Volume)	18	18	17	15	15	17	10	10	10	10
basic density (kg/m3)	560	560	560	420	420	420	330	330	330	330
predicted rotation duration	120	140	140	69	75	75	49	55	48	51
age of max MAI	79	85	90	69	75	75	49	55	50	52
Overbark Volume CP at final harvest (m3/ha)	664	609.5	495	811	573	663	905.5	877	1029	811
stem wood CP at final harvest (m3/ha)	***544***	***500***	***411***	***689***	***487***	***550***	***815***	***789***	***926***	***730***
CP = CUMULATIVE PRODUCTION at final harvest										
Biomass proportions										
stem wood	66.3	66.3	66.3	63.0	63.0	63.0	65.8	65.8	65.8	65.8
stem bark	7.7	7.7	7.7	4.8	4.8	4.8	5.3	5.3	5.3	5.3
branches	18.5	18.5	18.5	8.1	8.1	8.1	12.5	12.5	12.5	12.5
estimation of biomass at harvest (including yield from thinings) t/ha										
stem wood	305	280	230	290	205	231	269	260	306	241
stem bark	36	33	27	22	16	18	22	21	25	19
branches	85	78	64	37	26	30	51	49	58	46
total	426	391	321	349	247	279	342	331	388	306
average growth rate over the duration of the rotation kg/ha/yr										
stem wood	2541	1999	1643	4196	2727	3082	5488	4736	6367	4723
stem bark	296	233	192	321	209	236	444	383	515	382
branches	709	558	459	540	351	396	1042	899	1209	896
total	3546	2790	2294	5057	3287	3714	6974	6018	8091	6001
estimated N uptake Kg/ha	**10.8**	**9.9**	**6.8**	**3.8**	**2.6**	**2.8**	**5.1**	**5.5**	**4.0**	**4.4**
stem wood	2.3	2.8	2.0	2.9	1.9	2.2	3.3	2.8	1.9	3.3
stem bark	2.0	2.1	1.1	0.9	0.6	0.6	1.8	2.7	2.1	1.1
branches	6.6	5.0	3.7							
estimated P uptake Kg/ha	**0.93**	**0.59**	**0.47**	**0.16**	**0.10**	**0.14**	**1.87**	**0.82**	**0.84**	**0.63**
stem wood	0.25	0.06	0.05	0.13	0.08	0.09	1.65	0.47	0.64	0.47
stem bark	0.09	0.07	0.04	0.03	0.02	0.05	0.22	0.34	0.21	0.15
branches	0.59	0.46	0.38							
estimated K uptake Kg/ha	**6.00**	**4.67**	**3.60**	**2.16**	**1.43**	**1.99**	**3.77**	**4.37**	**3.94**	**4.06**
stem wood	2.03	1.60	1.15	2.10	1.36	1.85	2.74	2.84	2.55	2.83
stem bark	0.56	0.40	0.25	0.06	0.06	0.14	1.02	1.53	1.39	1.22
branches	3.40	2.68	2.20							
estimated Ca uptake Kg/ha	**10.7**	**9.1**	**4.9**	**4.7**	**3.4**	**3.4**	**6.4**	**5.1**	**4.6**	**3.2**
stem wood	2.0	2.0	1.0	3.8	1.9	3.1	3.8	3.3	2.5	1.9
stem bark	5.9	4.9	2.1	0.9	1.5	0.3	2.6	1.8	2.0	1.3
branches	2.8	2.2	1.8							
estimated Mg uptake Kg/ha	**1.15**	**0.81**	**0.70**	**0.87**	**0.40**	**0.97**	**0.85**	**0.70**	**0.83**	**0.93**
stem wood	0.25	0.14	0.12	0.84	0.38	0.92	0.60	0.43	0.57	0.61
stem bark	0.21	0.13	0.14	0.03	0.02	0.05	0.25	0.28	0.26	0.31
branches	0.69	0.54	0.44							
N uptake (moles/ha/yr)	774	705	482	274	183	200	362	395	284	313
(Ca+Mg+K) (eq/ha/yr)	784	640	394	362	238	301	487	426	396	339
Ca uptake (eq/ha/yr)	536	454	244	235	168	170	320	257	227	159
[N]										
stem wood	0.09	0.14	0.12	0.07	0.07	0.07	0.06	0.06	0.03	0.07
stem bark	0.66	0.88	0.58	0.28	0.31	0.27	0.4	0.7	0.4	0.28
branches	0.93	0.9	0.8							
[P]										
stem wood	0.01	0.003	0.003	0.003	0.003	0.003	0.03	0.01	0.01	0.01
stem bark	0.03	0.03	0.02	0.01	0.01	0.02	0.05	0.09	0.04	0.04
branches	0.083	0.083	0.083							
[K]										
stem wood	0.08	0.08	0.07	0.05	0.05	0.06	0.05	0.06	0.04	0.06
stem bark	0.19	0.17	0.13	0.02	0.03	0.06	0.23	0.4	0.27	0.32
branches	0.48	0.48	0.48							
[Ca]										
stem wood	0.08	0.1	0.06	0.09	0.07	0.1	0.07	0.07	0.04	0.04

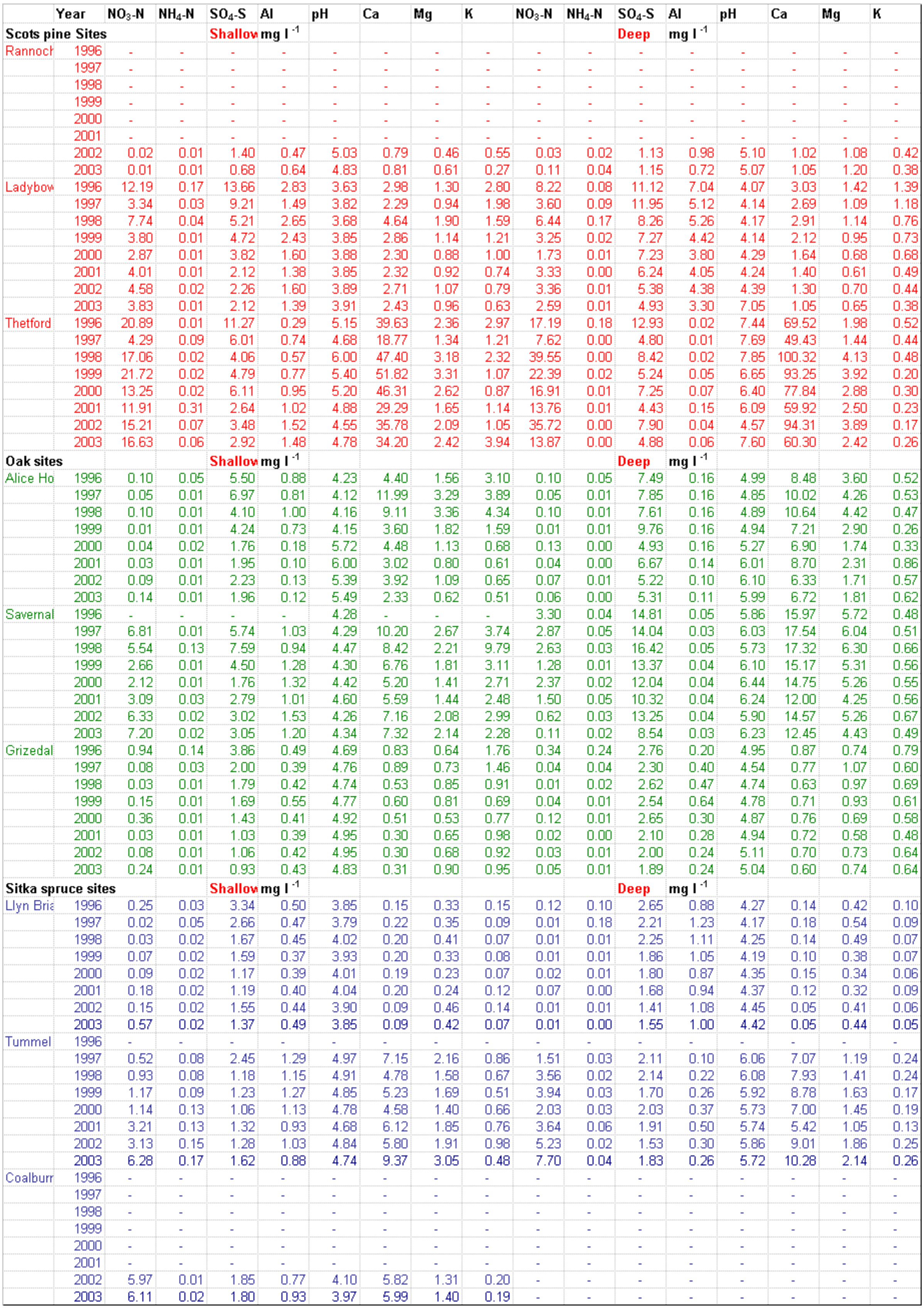
Table A1.2. Data requirements and availability for running dynamic models at the UK Level II sites.

	MODELS **M (MAGIC)** **S (SAFE)** **V (VSD)**	**Alice Holt**	**Savernake**	**Grizedale**	**Thetford**	**Ladybower**	**Rannoch**	**Coalburn**	**Llyn Brianne**	**Tummel**	**Loch Awe**
Deposition											
Wet deposition	MSV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dry deposition	MSV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Throughfall	S	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Historic sequences	MS		6 years								
Soil properties											
Soil depth	MSV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CEC	MSV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Field moist bulk density	MSV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Base saturation	MV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Exchangeable Ca, Mg, Na, K	M	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Porosity	S										
Litter layer/O horizon C:N	MV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Litter layer/O horizon C pool	MV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
S adsorption half saturation	(M)										
S adsorption max capacity	(M)										
Soil moisture content	SV	✓			✓			✓			
Soil solution DOC	MS	Since April 02									
Soil solution major ions	M	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Soil solution pCO$_2$	MSV										
Soil solution pH	M										
Soil temperature	MSV	✓			✓			✓		✓	
(Apparent) $K_{GIBBSITE}$	MSV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Al and H selectivity constants	V										
Particle size distribution	S	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mineralogy	S	✓	✓	✓	✓	✓	%	%	✓	%	%
Base cation weathering rates	V	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hydrology											
Precipitation	MS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Evapotranspiration	MS	✓		✓	✓			✓			
Lateral flow by horizon	(M)										
Evapotranspiration by hzn.	S	✓		✓	✓			✓			
Percolation	V	✓		✓	✓			✓			
Vegetation											
Forest cover	MS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Base cation uptake	MSV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
NO$_3$ and NH$_4$ uptake	MSV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nitrification	M								✓		
Denitrification	MV								✓		
N imobilisation	V								✓		
Compartment biomass	S	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Compartment Ca, Mg, N	S	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Deciduous canopy ratio	S	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Litterfall	S	✓		✓	✓		✓	✓		✓	
Mineralisation rate (litter)	S								✓		
Mineralisation rate (brash)	S										
Growth curves/sequences	SM										
Planting/harvesting info	SM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Compartment removal	S										

Table A1.3. Total deposition to the ten Level II plots between 1996 and 2002. Values given are annual means, and include wet deposition measured in bulk precipitation and dry deposition measured in throughfall.

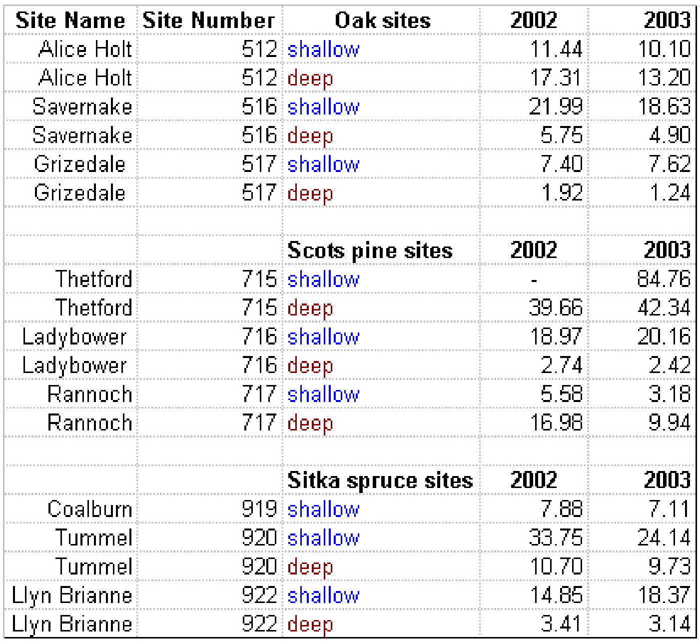
Site name	Tree species	Year	H	K	Ca	Mg	Na	Cl	S	N
						kg ha^{-1} yr^{-1}				
Alice Holt	**Oak**	1996	0.64	2.59	4.93	2.43	19.02	32.70	11.06	9.74
		1997	0.54	3.99	5.73	2.56	18.40	32.29	9.79	7.94
		1998	0.58	3.66	5.92	3.91	29.63	50.72	16.24	13.27
		1999	0.92	2.34	4.45	2.48	19.04	34.57	11.13	13.93
		2000	1.10	3.08	5.72	2.82	22.68	42.31	13.13	15.59
		2001	0.73	1.82	3.72	1.94	16.59	27.01	9.77	12.17
		2002	0.66	4.04	4.73	3.06	27.59	44.39	11.85	13.19
Savernake	**Oak**	1996	0.25	2.92	5.68	1.84	12.79	22.77	9.26	14.43
		1997	0.38	3.36	8.01	3.54	25.45	47.72	11.00	14.38
		1998	0.32	9.50	4.04	13.16	11.73	9.00	9.83	16.99
		1999	0.49	3.08	7.43	2.39	16.64	30.39	11.21	16.94
		2000	0.56	3.43	10.11	2.87	21.79	41.83	14.96	18.32
		2001	0.31	6.75	5.99	1.53	13.09	22.28	11.97	14.85
		2002	0.47	2.73	10.34	2.82	25.20	40.85	12.45	14.02
Grizedale	**Oak**	1996	0.64	3.27	4.88	5.38	46.02	86.11	16.43	20.87
		1997	0.57	6.27	9.00	8.88	71.60	138.17	18.54	20.43
		1998	0.63	4.34	7.26	7.76	63.98	119.89	18.02	15.29
		1999	0.51	3.88	6.00	7.45	59.80	110.45	14.17	15.54
		2000	0.42	4.43	8.37	6.85	55.18	98.98	15.20	12.89
		2001	0.53	3.83	4.02	3.78	36.43	59.86	11.87	12.21
		2002	0.57	4.79	4.91	7.00	64.91	105.25	13.55	14.80
Thetford	**Scots pine**	1996	0.21	5.26	6.38	2.75	21.27	40.39	11.69	19.28
		1997	0.28	2.51	7.34	2.29	17.15	29.85	10.94	14.90
		1998	0.36	2.60	4.90	2.05	16.09	27.44	13.96	14.90
		1999	0.33	2.58	5.52	2.01	16.17	28.69	12.98	21.30
		2000	0.28	3.44	5.42	1.81	16.34	26.89	12.55	14.71
		2001	0.31	2.43	4.01	1.62	15.33	24.37	10.18	12.76
		2002	0.26	2.82	5.41	1.85	18.95	28.29	12.29	14.09
Ladybower	**Scots pine**	1996	0.74	3.43	10.85	4.58	35.83	69.03	16.73	16.51
		1997	0.78	3.17	10.96	4.29	34.31	64.89	18.40	11.49
		1998	0.78	5.55	9.86	5.25	41.43	74.96	26.06	17.69
		1999	0.57	3.88	11.24	5.32	43.30	81.47	22.68	15.29
		2000	0.56	5.29	11.86	4.00	32.54	59.19	23.44	15.90
		2001	0.54	5.38	6.71	2.77	25.20	39.72	16.12	15.85
		2002	0.40	8.24	8.27	5.14	44.21	73.90	17.51	25.32
Rannoch	**Scots pine**	1996	0.31	2.42	2.74	3.42	26.48	52.59	9.00	7.26
		1997	0.29	4.32	5.25	3.54	26.31	45.60	6.34	8.17
		1998	0.31	2.34	4.15	3.50	30.79	51.24	7.02	5.47
		1999	0.30	2.20	3.75	4.23	34.85	64.70	6.60	4.50
		2000	0.19	3.38	5.37	3.07	24.87	44.59	5.93	4.48
		2001	0.19	1.89	1.81	1.51	16.90	23.36	4.70	4.85
		2002	0.28	3.34	2.68	3.92	38.99	60.78	8.35	4.88
Coalburn	**Sitka spruce**	1996	0.64	3.13	2.85	3.36	25.50	46.29	13.57	12.73
		1997	0.51	3.41	6.26	3.76	26.82	48.27	11.70	10.93
		1998	0.64	5.87	5.90	8.30	67.65	122.64	14.37	17.79
		1999	0.67	2.70	4.17	3.53	28.90	53.44	10.89	11.34
		2000	0.50	3.28	5.55	3.24	26.86	49.89	10.82	11.44
		2001	0.70	5.04	2.64	1.95	19.32	27.14	11.07	18.54
		2002	0.59	4.18	3.63	3.84	35.89	57.52	12.09	12.58
Tummel	**Sitka spruce**	1996	0.44	2.63	1.98	2.31	18.28	31.65	7.92	7.07
		1997	0.33	2.61	3.96	2.91	20.84	37.70	6.43	5.57
		1998	0.30	2.22	2.78	2.66	22.39	38.11	6.48	4.23
		1999	0.32	2.64	2.64	2.85	23.93	48.84	5.42	5.27
		2000	0.37	3.01	4.44	2.95	23.57	42.97	7.43	6.53
		2001	0.34	2.32	1.84	1.17	12.30	17.71	5.71	5.95
		2002	0.39	2.96	2.62	2.91	29.46	47.18	10.18	7.30
Loch Awe	**Sitka spruce**	1996	0.53	6.46	5.60	11.80	101.01	193.98	13.90	12.79
		1997	0.35	6.56	6.35	7.00	57.15	98.84	11.01	7.79
		1998	0.34	15.82	13.14	17.53	9.43	11.49	11.26	14.00
		1999	0.72	6.86	6.89	13.08	109.14	206.91	13.93	10.77
		2000	0.54	7.03	8.13	13.56	107.43	205.27	13.28	7.64
		2001	0.45	3.75	3.85	4.50	43.91	70.37	8.37	5.09
		2002	0.34	5.94	5.64	11.12	100.78	175.54	12.87	5.58
Llyn Brianne	**Sitka spruce**	1996	0.72	4.56	4.84	5.58	44.47	80.94	16.99	15.00
		1997	0.77	6.20	9.50	8.25	66.57	122.02	18.18	13.37
		1998	0.94	3.92	6.46	8.77	71.90	126.58	27.64	13.98
		1999	0.66	4.52	7.94	7.85	65.12	117.68	18.13	10.27
		2000	0.77	5.10	9.86	7.94	65.67	122.35	20.14	8.90
		2001	0.76	5.67	9.18	4.97	47.08	73.96	18.35	10.29
		2002	0.70	7.07	6.94	11.65	106.83	179.87	25.81	15.38

Table A1.4. Soil solution concentrations of selected elements for nine all Level II plots. Values (mg l^{-1}) are annual means for both shallow (15 cm) and deep (50 cm) porous cups.



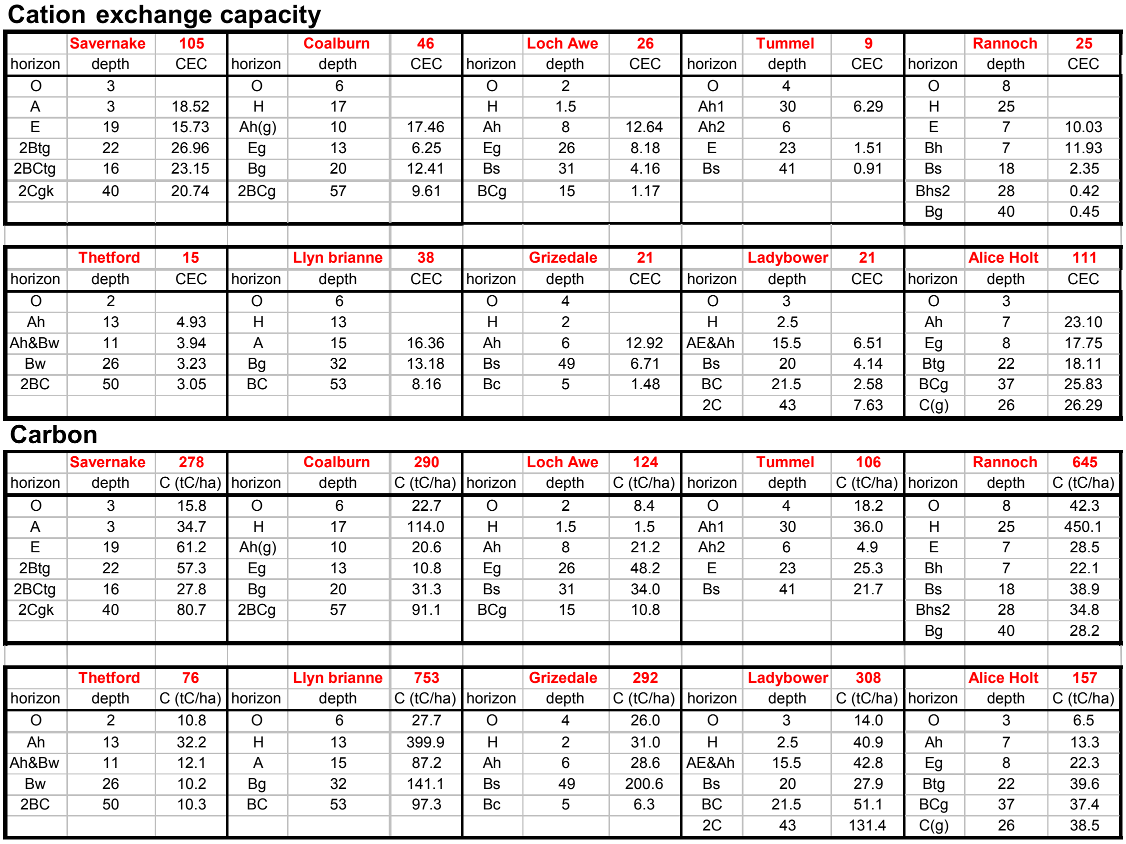
	Year	NO_3-N	NH_4-N	SO_4-S	Al	pH	Ca	Mg	K	NO_3-N	NH_4-N	SO_4-S	Al	pH	Ca	Mg	K
Scots pine Sites				**Shallow**	**mg l^{-1}**							**Deep**	**mg l^{-1}**				
Rannoch	1996	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1997	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1998	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1999	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2002	0.02	0.01	1.40	0.47	5.03	0.79	0.46	0.55	0.03	0.02	1.13	0.98	5.10	1.02	1.08	0.42
	2003	0.01	0.01	0.68	0.64	4.83	0.81	0.61	0.27	0.11	0.04	1.15	0.72	5.07	1.05	1.20	0.38
Ladybow	1996	12.19	0.17	13.66	2.83	3.63	2.98	1.30	2.80	8.22	0.08	11.12	7.04	4.07	3.03	1.42	1.39
	1997	3.34	0.03	9.21	1.49	3.82	2.29	0.94	1.98	3.60	0.09	11.95	5.12	4.14	2.69	1.09	1.18
	1998	7.74	0.04	5.21	2.65	3.68	4.64	1.90	1.59	6.44	0.17	8.26	5.26	4.17	2.91	1.14	0.76
	1999	3.80	0.01	4.72	2.43	3.85	2.86	1.14	1.21	3.25	0.02	7.27	4.42	4.14	2.12	0.95	0.73
	2000	2.87	0.01	3.82	1.60	3.88	2.30	0.88	1.00	1.73	0.01	7.23	3.80	4.29	1.64	0.68	0.68
	2001	4.01	0.01	2.12	1.38	3.85	2.32	0.92	0.74	3.33	0.00	6.24	4.05	4.24	1.40	0.61	0.49
	2002	4.58	0.02	2.26	1.60	3.89	2.71	1.07	0.79	3.36	0.01	5.38	4.38	4.39	1.30	0.70	0.44
	2003	3.83	0.01	2.12	1.39	3.91	2.43	0.96	0.63	2.59	0.01	4.93	3.30	7.05	1.05	0.65	0.38
Thetford	1996	20.89	0.01	11.27	0.29	5.15	39.63	2.36	2.97	17.19	0.18	12.93	0.02	7.44	69.52	1.98	0.52
	1997	4.29	0.09	6.01	0.74	4.68	18.77	1.34	1.21	7.62	0.00	4.80	0.01	7.69	49.43	1.44	0.44
	1998	17.06	0.02	4.06	0.57	6.00	47.40	3.18	2.32	39.55	0.00	8.42	0.02	7.85	100.32	4.13	0.48
	1999	21.72	0.02	4.79	0.77	5.40	51.82	3.31	1.07	22.39	0.02	5.24	0.05	6.65	93.25	3.92	0.20
	2000	13.25	0.02	6.11	0.95	5.20	46.31	2.62	0.87	16.91	0.01	7.25	0.07	6.40	77.84	2.88	0.30
	2001	11.91	0.31	2.64	1.02	4.88	29.29	1.65	1.14	13.76	0.01	4.43	0.15	6.09	59.92	2.50	0.23
	2002	15.21	0.07	3.48	1.52	4.55	35.78	2.09	1.05	35.72	0.00	7.90	0.04	4.57	94.31	3.89	0.17
	2003	16.63	0.06	2.92	1.48	4.78	34.20	2.42	3.94	13.87	0.00	4.88	0.06	7.60	60.30	2.42	0.26
Oak sites				**Shallow**	**mg l^{-1}**							**Deep**	**mg l^{-1}**				
Alice Ho	1996	0.10	0.05	5.50	0.88	4.23	4.40	1.56	3.10	0.10	0.05	7.49	0.16	4.99	8.48	3.60	0.52
	1997	0.05	0.01	6.97	0.81	4.12	11.99	3.29	3.89	0.05	0.01	7.85	0.16	4.85	10.02	4.26	0.53
	1998	0.10	0.01	4.10	1.00	4.16	9.11	3.36	4.34	0.10	0.01	7.61	0.16	4.89	10.64	4.42	0.47
	1999	0.01	0.01	4.24	0.73	4.15	3.60	1.82	1.59	0.01	0.01	9.76	0.16	4.94	7.21	2.90	0.26
	2000	0.04	0.02	1.76	0.18	5.72	4.48	1.13	0.68	0.13	0.00	4.93	0.16	5.27	6.90	1.74	0.33
	2001	0.03	0.01	1.95	0.10	6.00	3.02	0.80	0.61	0.04	0.00	6.67	0.14	6.01	8.70	2.31	0.86
	2002	0.09	0.01	2.23	0.13	5.39	3.92	1.09	0.65	0.07	0.01	5.22	0.10	6.10	6.33	1.71	0.57
	2003	0.14	0.01	1.96	0.12	5.49	2.33	0.62	0.51	0.06	0.00	5.31	0.11	5.99	6.72	1.81	0.62
Savernal	1996	-	-	-	-	4.28	-	-	-	3.30	0.04	14.81	0.05	5.86	15.97	5.72	0.48
	1997	6.81	0.01	5.74	1.03	4.29	10.20	2.67	3.74	2.87	0.05	14.04	0.03	6.03	17.54	6.04	0.51
	1998	5.54	0.13	7.59	0.94	4.47	8.42	2.21	9.79	2.63	0.03	16.42	0.05	5.73	17.32	6.30	0.66
	1999	2.66	0.01	4.50	1.28	4.30	6.76	1.81	3.11	1.28	0.01	13.37	0.04	6.10	15.17	5.31	0.56
	2000	2.12	0.01	1.76	1.32	4.42	5.20	1.41	2.71	2.37	0.02	12.04	0.04	6.44	14.75	5.26	0.55
	2001	3.09	0.03	2.79	1.01	4.60	5.59	1.44	2.48	1.50	0.05	10.32	0.04	6.24	12.00	4.25	0.56
	2002	6.33	0.02	3.02	1.53	4.26	7.16	2.08	2.99	0.62	0.03	13.25	0.04	5.90	14.57	5.26	0.67
	2003	7.20	0.02	3.05	1.20	4.34	7.32	2.14	2.28	0.11	0.02	8.54	0.03	6.23	12.45	4.43	0.49
Grizedal	1996	0.94	0.14	3.86	0.49	4.69	0.83	0.64	1.76	0.34	0.24	2.76	0.20	4.95	0.87	0.74	0.79
	1997	0.08	0.03	2.00	0.39	4.76	0.89	0.73	1.46	0.04	0.04	2.30	0.40	4.54	0.77	1.07	0.60
	1998	0.03	0.01	1.79	0.42	4.74	0.53	0.85	0.91	0.01	0.02	2.62	0.47	4.74	0.63	0.97	0.69
	1999	0.15	0.01	1.69	0.55	4.77	0.60	0.81	0.69	0.04	0.01	2.54	0.64	4.78	0.71	0.93	0.61
	2000	0.36	0.01	1.43	0.41	4.92	0.51	0.53	0.77	0.12	0.01	2.65	0.30	4.87	0.76	0.69	0.58
	2001	0.03	0.01	1.03	0.39	4.95	0.30	0.65	0.98	0.02	0.00	2.10	0.28	4.94	0.72	0.58	0.48
	2002	0.08	0.01	1.06	0.42	4.95	0.30	0.68	0.92	0.03	0.01	2.00	0.24	5.11	0.70	0.73	0.64
	2003	0.24	0.01	0.93	0.43	4.83	0.31	0.90	0.95	0.05	0.01	1.89	0.24	5.04	0.60	0.74	0.64
Sitka spruce sites				**Shallow**	**mg l^{-1}**							**Deep**	**mg l^{-1}**				
Llyn Bria	1996	0.25	0.03	3.34	0.50	3.85	0.15	0.33	0.15	0.12	0.10	2.65	0.88	4.27	0.14	0.42	0.10
	1997	0.02	0.05	2.66	0.47	3.79	0.22	0.35	0.09	0.01	0.18	2.21	1.23	4.17	0.18	0.54	0.09
	1998	0.03	0.02	1.67	0.45	4.02	0.20	0.41	0.07	0.01	0.01	2.25	1.11	4.25	0.14	0.49	0.07
	1999	0.07	0.02	1.59	0.37	3.93	0.20	0.33	0.08	0.01	0.01	1.86	1.05	4.19	0.10	0.38	0.07
	2000	0.09	0.02	1.17	0.39	4.01	0.19	0.23	0.07	0.02	0.01	1.80	0.87	4.35	0.15	0.34	0.06
	2001	0.18	0.02	1.19	0.40	4.04	0.20	0.24	0.12	0.07	0.00	1.68	0.94	4.37	0.12	0.32	0.09
	2002	0.15	0.02	1.55	0.44	3.90	0.09	0.46	0.14	0.01	0.01	1.41	1.08	4.45	0.05	0.41	0.06
	2003	0.57	0.02	1.37	0.49	3.85	0.09	0.42	0.07	0.01	0.00	1.55	1.00	4.42	0.05	0.44	0.05
Tummel	1996	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1997	0.52	0.08	2.45	1.29	4.97	7.15	2.16	0.86	1.51	0.03	2.11	0.10	6.06	7.07	1.19	0.24
	1998	0.93	0.08	1.18	1.15	4.91	4.78	1.58	0.67	3.56	0.02	2.14	0.22	6.08	7.93	1.41	0.24
	1999	1.17	0.09	1.23	1.27	4.85	5.23	1.69	0.51	3.94	0.03	1.70	0.26	5.92	8.78	1.63	0.17
	2000	1.14	0.13	1.06	1.13	4.78	4.58	1.40	0.66	2.03	0.03	2.03	0.37	5.73	7.00	1.45	0.19
	2001	3.21	0.13	1.32	0.93	4.68	6.12	1.85	0.76	3.64	0.06	1.91	0.50	5.74	5.42	1.05	0.13
	2002	3.13	0.15	1.28	1.03	4.84	5.80	1.91	0.98	5.23	0.02	1.53	0.30	5.86	9.01	1.86	0.25
	2003	6.28	0.17	1.62	0.88	4.74	9.37	3.05	0.48	7.70	0.04	1.83	0.26	5.72	10.28	2.14	0.26
Coalburn	1996	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1997	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1998	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1999	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2002	5.97	0.01	1.85	0.77	4.10	5.82	1.31	0.20	-	-	-	-	-	-	-	-
	2003	6.11	0.02	1.80	0.93	3.97	5.99	1.40	0.19	-	-	-	-	-	-	-	-

Table A1.5. Soil solution mean dissolved organic carbon (DOC: mg l^{-1}) for the years 2002 and 2003 at nine of the UK Level II plots. Shallow porous cups are located 15 cm and deep porous cups, 50 cm below the soil surface.



Site Name	Site Number	Oak sites	2002	2003
Alice Holt	512	shallow	11.44	10.10
Alice Holt	512	deep	17.31	13.20
Savernake	516	shallow	21.99	18.63
Savernake	516	deep	5.75	4.90
Grizedale	517	shallow	7.40	7.62
Grizedale	517	deep	1.92	1.24
		Scots pine sites	**2002**	**2003**
Thetford	715	shallow	-	84.76
Thetford	715	deep	39.66	42.34
Ladybower	716	shallow	18.97	20.16
Ladybower	716	deep	2.74	2.42
Rannoch	717	shallow	5.58	3.18
Rannoch	717	deep	16.98	9.94
		Sitka spruce sites	**2002**	**2003**
Coalburn	919	shallow	7.88	7.11
Tummel	920	shallow	33.75	24.14
Tummel	920	deep	10.70	9.73
Llyn Brianne	922	shallow	14.85	18.37
Llyn Brianne	922	deep	3.41	3.14

Table A1.6. Soil cation exchange capacity and organic carbon content (measured as loss on ignition) for the ten (original) Level II sites. Data are expressed by horizon for a single representative soil pit, based on descriptive soil profiles for 30 sample points arranged in a grid across the ~0.3 ha plot. Except where measured, the O horizon was assumed a bulk density of 100 kg m^{-3}, and the H horizon, a value of 350 kg m^{-3}. Where the stone content was not assessed gravimetrically, the profile description was used to derive stone content, based on the mid-range values of Hodgson (1974). All depths are to 100 cm or to bedrock.



Cation exchange capacity

	Savernake	105		Coalburn	46		Loch Awe	26		Tummel	9		Rannoch	25
horizon	depth	CEC	horizon	depth	CEC	horizon	depth	CEC	horizon	depth	CEC	horizon	depth	CEC
O	3		O	6		O	2		O	4		O	8	
A	3	18.52	H	17		H	1.5		Ah1	30	6.29	H	25	
E	19	15.73	Ah(g)	10	17.46	Ah	8	12.64	Ah2	6		E	7	10.03
2Btg	22	26.96	Eg	13	6.25	Eg	26	8.18	E	23	1.51	Bh	7	11.93
2BCtg	16	23.15	Bg	20	12.41	Bs	31	4.16	Bs	41	0.91	Bs	18	2.35
2Cgk	40	20.74	2BCg	57	9.61	BCg	15	1.17				Bhs2	28	0.42
												Bg	40	0.45

	Thetford	15		Llyn brianne	38		Grizedale	21		Ladybower	21		Alice Holt	111
horizon	depth	CEC	horizon	depth	CEC	horizon	depth	CEC	horizon	depth	CEC	horizon	depth	CEC
O	2		O	6		O	4		O	3		O	3	
Ah	13	4.93	H	13		H	2		H	2.5		Ah	7	23.10
Ah&Bw	11	3.94	A	15	16.36	Ah	6	12.92	AE&Ah	15.5	6.51	Eg	8	17.75
Bw	26	3.23	Bg	32	13.18	Bs	49	6.71	Bs	20	4.14	Btg	22	18.11
2BC	50	3.05	BC	53	8.16	Bc	5	1.48	BC	21.5	2.58	BCg	37	25.83
									2C	43	7.63	C(g)	26	26.29

Carbon

	Savernake	278		Coalburn	290		Loch Awe	124		Tummel	106		Rannoch	645
horizon	depth	C (tC/ha)	horizon	depth	C (tC/ha)	horizon	depth	C (tC/ha)	horizon	depth	C (tC/ha)	horizon	depth	C (tC/ha)
O	3	15.8	O	6	22.7	O	2	8.4	O	4	18.2	O	8	42.3
A	3	34.7	H	17	114.0	H	1.5	1.5	Ah1	30	36.0	H	25	450.1
E	19	61.2	Ah(g)	10	20.6	Ah	8	21.2	Ah2	6	4.9	E	7	28.5
2Btg	22	57.3	Eg	13	10.8	Eg	26	48.2	E	23	25.3	Bh	7	22.1
2BCtg	16	27.8	Bg	20	31.3	Bs	31	34.0	Bs	41	21.7	Bs	18	38.9
2Cgk	40	80.7	2BCg	57	91.1	BCg	15	10.8				Bhs2	28	34.8
												Bg	40	28.2

	Thetford	76		Llyn brianne	753		Grizedale	292		Ladybower	308		Alice Holt	157
horizon	depth	C (tC/ha)	horizon	depth	C (tC/ha)	horizon	depth	C (tC/ha)	horizon	depth	C (tC/ha)	horizon	depth	C (tC/ha)
O	2	10.8	O	6	27.7	O	4	26.0	O	3	14.0	O	3	6.5
Ah	13	32.2	H	13	399.9	H	2	31.0	H	2.5	40.9	Ah	7	13.3
Ah&Bw	11	12.1	A	15	87.2	Ah	6	28.6	AE&Ah	15.5	42.8	Eg	8	22.3
Bw	26	10.2	Bg	32	141.1	Bs	49	200.6	Bs	20	27.9	Btg	22	39.6
2BC	50	10.3	BC	53	97.3	Bc	5	6.3	BC	21.5	51.1	BCg	37	37.4
									2C	43	131.4	C(g)	26	38.5

Table A1.7. Foliar chemistry for all original Level II sites between 1995 and 2002. The foliar concentrations represent the mean value of samples collected from the upper canopy of four trees, with one sample from the north, south, east and west aspect.

		Foliar current year							Foliar one year						
Site	Year	N	S	P	Ca	Mg	K	Al	N	S	P	Ca	Mg	K	Al
		% dw	% dw	% dw	% dw	% dw	% dw	mg kg^{-1}	% dw	% dw	% dw	% dw	% dw	% dw	mg kg^{-1}
Rannoch	1995	1.61	0.15	0.17	0.30	0.10	0.77	263	1.51	0.15	0.16	0.34	0.09	0.78	250
	1997	1.54	0.12	0.19	0.21	0.10	0.64	219	1.55	0.11	0.16	0.35	0.08	0.63	275
	1999	1.50	0.10	0.18	0.21	0.10	0.63	202	1.57	0.11	0.16	0.33	0.08	0.61	251
	2000	1.62	0.11	0.20	0.23	0.09	0.61	182	1.71	0.11	0.17	0.39	0.09	0.64	236
	2001	1.54	0.11	0.17	0.24	0.10	0.56	197	1.57	0.12	0.16	0.36	0.08	0.60	227
	2002	1.64		0.19	0.24	0.10	0.61	162	1.61		0.16	0.37	0.08	0.58	231
Ladybower	1995	2.06	0.21	0.17	0.20	0.08	0.92	267	1.99	0.23	0.15	0.30	0.06	0.81	286
	1997	1.85	0.17	0.17	0.18	0.08	0.86	216	1.84	0.17	0.15	0.27	0.06	0.72	256
	1999	1.90	0.16	0.19	0.19	0.08	0.92	228	1.99	0.17	0.18	0.29	0.06	0.84	250
	2000	1.75	0.13	0.17	0.15	0.06	0.78	194	1.91	0.16	0.16	0.22	0.05	0.72	219
	2001	1.68	0.13	0.15	0.17	0.06	0.75	184	1.78	0.15	0.15	0.26	0.05	0.70	203
	2002	1.66		0.15	0.18	0.07	0.84	151	1.92		0.15	0.24	0.05	0.72	195
Thetford	1995	1.84	0.16	0.16	0.40	0.10	0.64	111	1.82	0.17	0.14	0.71	0.09	0.53	123
	1997	1.88	0.15	0.17	0.35	0.09	0.60	109	1.93	0.15	0.15	0.67	0.08	0.48	120
	1999	1.96	0.13	0.19	0.45	0.10	0.67	133	1.88	0.13	0.16	0.75	0.09	0.53	110
	2000	1.93	0.13	0.16	0.44	0.09	0.55	90	1.94	0.14	0.15	0.66	0.08	0.50	111
	2001	1.72	0.12	0.16	0.40	0.10	0.54	126	1.78	0.13	0.14	0.65	0.08	0.48	116
	2002	2.20		0.18	0.35	0.11	0.51	135	2.09		0.14	0.53	0.07	0.44	159
Llyn Brianne	1995	1.32	0.17	0.13	0.13	0.09	0.70	113	1.30	0.18	0.11	0.18	0.07	0.59	170
	1997	1.28	0.15	0.16	0.12	0.12	0.98	119	1.13	0.15	0.12	0.09	0.07	0.70	179
	1999	1.64	0.13	0.18	0.14	0.11	1.02	124	1.53	0.12	0.14	0.20	0.09	0.81	211
	2000	1.60	0.15	0.17	0.13	0.11	1.00	111	1.66	0.15	0.14	0.25	0.09	0.73	233
	2001	1.27	0.11	0.16	0.10	0.10	0.89	114	1.31	0.11	0.13	0.14	0.09	0.74	159
	2002	1.52		0.15	0.12	0.11	0.88	169	1.73		0.13	0.15	0.08	0.77	209
Loch Awe	1995	1.45	0.18	0.25	0.30	0.15	1.32	156	1.38	0.19	0.22	0.34	0.11	1.09	246
	1997	1.33	0.13	0.24	0.26	0.12	1.08	126	1.30	0.14	0.23	0.42	0.12	0.88	216
	1999	1.65	0.13	0.28	0.41	0.15	1.03	161	1.66	0.15	0.28	0.44	0.12	1.01	204
	2000	1.74	0.15	0.28	0.23	0.13	1.11	141	1.71	0.16	0.28	0.29	0.08	1.07	269
	2001	1.45	0.12	0.22	0.24	0.12	0.96	132	1.46	0.13	0.21	0.25	0.08	0.89	197
	2002	1.68		0.26	0.26	0.11	1.05	145	1.72		0.25	0.30	0.09	1.00	220
Tummel	1995	1.41	0.17	0.18	0.35	0.10	1.06	61	1.29	0.17	0.14	0.50	0.07	0.75	176
	1997	1.34	0.14	0.20	0.40	0.12	1.13	60	1.34	0.13	0.16	0.46	0.06	0.82	89
	1999	1.71	0.13	0.21	0.52	0.12	1.00	75	1.66	0.12	0.17	0.59	0.07	0.79	87
	2000	1.75	0.15	0.21	0.40	0.10	1.05	78	1.68	0.14	0.17	0.53	0.07	0.79	88
	2001	1.43	0.13	0.17	0.43	0.10	0.92	70	1.51	0.15	0.15	0.49	0.06	0.78	98
	2002	1.69		0.18	0.45	0.10	0.95	72	1.63		0.14	0.59	0.07	0.77	95
Coalburn	1995	1.31	0.19	0.19	0.34	0.10	0.73	96	1.22	0.19	0.18	0.52	0.08	0.72	195
	1997	1.39	0.16	0.22	0.37	0.09	0.78	102	1.33	0.15	0.18	0.54	0.08	0.73	138
	1999	1.74	0.15	0.24	0.45	0.11	0.78	146	1.64	0.13	0.18	0.62	0.08	0.65	164
	2000	1.63	0.13	0.21	0.32	0.09	0.63	92	1.65	0.15	0.18	0.51	0.06	0.59	197
	2001	1.39	0.14	0.20	0.30	0.09	0.71	99	1.47	0.15	0.17	0.43	0.06	0.69	150
	2002	1.71		0.19	0.32	0.09	0.73	93	1.80		0.19	0.41	0.06	0.78	167
Alice Holt	1995	2.62	0.21	0.15	0.79	0.20	0.99	50							
	1997	2.62	0.18	0.18	0.67	0.17	1.11	55							
	1999	2.42	0.18	0.18	0.71	0.14	1.07	57							
	2000	2.69	0.19	0.19	0.66	0.17	0.99	60							
	2001	2.52	0.16	0.18	1.08	0.24	1.17	50							
	2002	2.59		0.22	1.18	0.24	1.31	62							
Savernake	1995	2.67	0.22	0.11	0.76	0.17	1.00	75							
	1997	2.46	0.17	0.11	0.59	0.14	0.86	48							
	1999	2.42	0.18	0.13	0.65	0.12	0.80	40							
	2000	2.58	0.18	0.12	0.51	0.14	0.68	92							
	2001	2.63	0.24	0.13	0.90	0.22	1.08	57							
	2002	2.53		0.14	0.74	0.21	1.12	70							
Grizedale	1995	2.34	0.19	0.11	0.59	0.14	0.86	78							
	1997	2.26	0.17	0.11	0.47	0.14	0.73	55							
	1999	2.26	0.16	0.14	0.54	0.14	0.86	28							
	2000	2.17	0.15	0.13	0.42	0.18	0.75	68							
	2001	2.21	0.16	0.12	0.57	0.17	0.69	73							
	2002	2.25		0.15	0.53	0.13	0.90	83							

Table A1.8. Comparison of foliage litter chemistry at 12 of the Level II plots for 2002 and 2003. Foliage litter chemistry data for 2000 is also available for Alice Holt and Grizedale. The values given are means of ten samples from the individual collectors for 2000 and of five samples (each pooled from two collectors) for 2002 and 2003. Samples from all sample periods were bulked prior to sub-sampling.

Site	Species	Year	N %dw	P% dw	K%dw	Mg%dw	Ca%dw	BC%dw
Alice Holt	Oak	2000	1.61	0.14	0.54	0.18	1.15	1.87
		2002	1.38	0.12	0.57	0.15	1.09	1.82
		2003	1.06	0.10	0.58	0.20	1.16	1.95
Grizedale	Oak	2000	1.04	0.05	0.27	0.15	0.71	1.13
		2002	1.15	0.06	0.26	0.14	0.76	1.15
		2003	1.02	0.05	0.35	0.15	0.73	1.22
Ardtornish	Oak	2002	0.94	0.03	0.28	0.16	0.96	1.40
		2003	0.96	0.04	0.34	0.17	0.96	1.46
Covet wood	Beech	2002	1.31	0.10	0.36	0.15	1.22	1.72
		2003	0.91	0.06	0.41	0.15	1.32	1.89
Cannonteign	Beech	2002	1.34	0.08	0.46	0.10	0.52	1.09
		2003	1.25	0.08	0.66	0.09	0.52	1.27
Brechfa	Beech	2002	1.58	0.09	0.36	0.13	0.54	1.03
		2003	1.18	0.07	0.43	0.12	0.53	1.08
Wykeham	Beech	2002	1.24	0.07	0.43	0.12	0.88	1.43
		2003	1.01	0.05	0.53	0.13	0.91	1.57
Ladybower	Scots pine	2002	0.93	0.05	0.16	0.05	0.27	0.47
		2003	0.92	0.06	0.29	0.05	0.26	0.59
Thetford	Scots pine	2002	0.79	0.04	0.15	0.08	0.89	1.12
		2003	0.82	0.05	0.18	0.08	0.83	1.09
Rannoch	Scots pine	2002	0.71	0.05	0.12	0.07	0.55	0.75
		2003	0.74	0.07	0.15	0.07	0.49	0.71
Tummel	Sitka spruce	2002	0.87	0.07	0.15	0.08	1.03	1.26
		2003	0.66	0.07	0.24	0.07	0.89	1.20
Coalburn	Sitka spruce	2002	1.10	0.10	0.19	0.09	0.78	1.06
		2003	1.00	0.09	0.22	0.08	0.72	1.02

Table A1.9. Comparison of individual element inputs from litter to the Level II plots for 2002 and 2003. The values given represent the sum of all litter components.

Site	Species	Litter Components	Year	N kg/ha	P kg/ha	K kg/ha	Mg kg/ha	Ca kg/ha	BC kg/ha	Biomass kg/ha
Alice Holt	Oak	leaf+acorns+twig+flower/buds	2002	92.92	7.63	40.19	9.73	63.84	113.76	7120
Grizedale		leaf+acorns+twig+flower/buds		52.83	2.90	11.42	5.17	27.20	43.78	4103
Ardtornish		leaf+acorns+twig		26.15	0.93	7.82	4.40	25.69	37.91	2732
Alice Holt	Oak	leaf+flowers/buds+twig	2003	70.09	6.40	35.22	10.94	65.95	112.11	6123
Grizedale		leaf+flower/buds+twig		68.39	4.18	17.88	6.97	32.09	56.94	5237
Ardtornish		leaf+flower/buds+twig		40.14	2.06	11.71	5.74	33.68	51.12	3801
Covet wood	Beech	leaf+nuts+cases+twig	2002	82.85	7.61	19.50	6.79	43.89	70.18	4595
Cannonteign		leaf+twig		39.61	2.39	12.99	3.20	15.75	31.94	3470
Brechfa		leaf+nuts+cases+twig		46.19	2.82	10.42	3.97	15.88	30.28	3024
Wykeham		leaf+nuts+cases+twig		36.93	2.28	13.41	3.84	26.26	43.51	3061
Covet wood	Beech	leaf+bud scales+twig+cases	2003	36.92	2.60	15.99	5.86	51.54	73.39	3853
Cannonteign		leaf+bud scales+twig		54.10	3.24	25.67	4.06	22.11	51.84	4176
Brechfa		leaf+bud scales+twig		43.18	2.50	14.34	4.57	19.32	38.22	5395
Wykeham		leaf+bud scales+twig		37.01	2.08	15.57	4.28	29.93	49.78	3977
Ladybower	Scots pine	needle+flower/buds+cones+twig	2002	42.47	2.50	6.94	2.28	10.37	19.59	4714
Thetford		needls+cones+flower/buds+twig		51.57	3.30	9.93	4.84	47.86	62.63	6246
Rannoch		needles+cones+twig+flower/buds		31.91	2.42	5.40	3.27	21.53	30.19	4421
Ladtbower	Scots pine	needle+flower/buds+cones+twig	2003	26.34	1.71	7.41	1.31	6.73	15.45	2926
Thetford		needles+cones+twig+flower/buds		56.80	3.62	12.17	5.19	35.67	53.03	4726
Rannoch		needles+cones+twig+flower/buds		**21.88**	1.93	4.45	2.03	14.10	20.58	5831
Tummel	Sitka spruce	needle+twig+cones+budscales	2002	23.35	1.86	3.94	2.12	26.18	32.25	2716
Coalburn		needle+twig+budscales+flowers/buds		51.65	4.60	8.75	4.07	34.54	47.35	4664
Tummel	Sitka spruce	needles+twig+budscales	2003	35.46	3.82	12.40	3.43	44.78	60.61	5268
Coalburn		needles+twig+budscales		55.39	5.08	11.52	4.36	38.18	54.07	5880

Table A1.10. Ground vegetation percentage cover for individual plant groups at nine of the original Level II plots in 1998. Individual species data are also available, based on a vegetation survey which adopted the Braun-Blanquet scoring system. The site at Loch Awe was not assessed as no ground vegetation was present.

Site Name	Tree species	Woody sh and saplings	Climbers	Herbs	Grasses	Sedges, R and Ferns	Mosses
			COVER EXTENT (%)				
Alice Holt	Oak	41	22	30	10	2	1
Savernake	Oak	32	44	1	52	0	2
Grizedale	Oak	53	1	3	64	1	61
Thetford	Scots pine	1	2	42	20	49	50
Ladybower	Scots pine	3	0	2	70	18	26
Rannoch	Scots pine	3	0	1	51	0	29
Coalburn	Sutka spruce	0	0	0	0	0	2
Tummel	Sutka spruce	0	0	1	0	0	1
Llyn Brianne	Sutka spruce	0	0	0	0	1	11