Forestry Commission

Trees for Shelter

Edited by

Harriet Palmer, Barry Gardiner,

Max Hislop, Alan Sibbald and Alan Duncan

MACAULAY LAND USE RESEARCH INSTITUTE
MLURI

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Technical Paper 21

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Trees for Shelter

Edited by Harriet Palmer[1], Barry Gardiner[2], Max Hislop[2], Alan Sibbald[3] and Alan Duncan[3]

[1]Scottish Agricultural College, West Mains Road, Edinburgh EH9 3JG
[2]Forestry Commission Research Agency, Roslin EH25 9SY
[3]Macaulay Land Research Institute, Aberdeen AB15 8QH

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Enquiries relating to this publication should be addressed to:

The Research Communications Officer
Forestry Commission Research Agency
Alice Holt Lodge
Wrecclesham, Farnham
Surrey GU10 4LH

Front cover: A well-established upland shelterbelt system near Innerleithen, Peebleshire (Forest Life Picture Library: 1012221020)

Back cover: *top:* Sheep sheltered by trees in Radnor, Powys (40326)
bottom: Shelter trees help to provide wide ranging benefits to this business centre in Washington New Town, Durham (38391)

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List of contributors

John Blyth	*Institute of Ecology and Resource Management, University of Edinburgh, Darwin Building, Mayfield Road, Edinburgh EH9 3JU*
Mark Broadmeadow	*Forestry Commission Research Division, Alice Holt Lodge, Wrecclesham, Farnham, Surrey GU10 4LH*
David Clarke	*David Clarke Associates, Toll House Studio, Cambridge Cottages, Kew Green, Richmond TW9 3AY*
Jenny Dick	*Department of Zoology, University of Aberdeen, Aberdeen AB24 3TZ*
Alan Duncan	*Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen AB15 8QH*
Peter Freer-Smith	*Forestry Commission Research Division, Alice Holt Lodge, Wrecclesham, Farnham, Surrey GU10 4LH*
Barry Gardiner	*Forestry Commission Research Division, Northern Research Station, Roslin, Midlothian EH25 9SY*
Glenn Iason	*Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen AB15 8QH*
Samantha Jackson	*Forestry Commission Research Division, Alice Holt Lodge, Wrecclesham, Farnham, Surrey GU10 4LH*
C. Stuart Lamb	*Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen AB15 8QH*
Bob Mayes	*Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen AB15 8QH*
Alan Sibbald	*Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen AB15 8QH*
Michael Usher	*Scottish Natural Heritage, 2 Anderson Place, Edinburgh EH6 5NP*
John Webster	*Department of Clinical Veterinary Science, University of Bristol, Langford, Bristol BS17 8DU*
Patricia Wilson	*Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen AB15 8QH*
Sheila Young	*Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen AB15 8QH*

Please note that as from 1 April 1997 Forestry Commission Research Division became Forest Research, an Agency of the Forestry Commission.

Introduction: Outline of the seminar

The use of trees for shelter is an international issue which bridges a wide range of disciplines, from the protection of crops and livestock in upland agriculture to the control of energy consumption in urban buildings. A great deal of research and development work continues to be undertaken world-wide into the provision and management of shelter for different objectives. However, there is no forum in the UK for the exchange of information across all the different industries with an interest in the use of shelter.

The Trees for Shelter seminar was organised jointly by representatives of three Scottish-based institutions with an active interest in the use of trees for shelter – the Forestry Commission Research Division (Northern Research Station), the Macaulay Land Use Research Institute (MLURI), and the Scottish Agricultural College (SAC).

All three institutions recognise the importance of collaboration within different areas of contemporary shelter research. The motivation for the seminar stemmed from realisation that there is a need in Britain to raise the profile of the use of trees for shelter as a research and development topic. To this end, the following objectives were set for the day's proceedings:

- To review current research and development in the use of trees for shelter in all relevant industries, both nationally and internationally.
- To increase the awareness of shelter-related research and development work being undertaken in the UK.
- To identify priority areas for future research and development and potential collaborative links between organisations.

The seminar was attended by over 50 people from a variety of professions, including building and landscape design, ecology and conservation, agriculture and forestry. Participants came with experience at all levels in the use of trees for shelter, from fundamental research to practising foresters and farmers.

The day's proceedings and outcomes are presented in the keynote presentations, reports from workshops, and posters, which form the first three sections of this Technical Paper. The final section provides a comprehensive summary with conclusions and recommendations. While there is no doubt that a great deal of information on the use of trees for shelter already exists, the need for decision support for practitioners in the field came out as an overriding conclusion of the day. There also appears to be support for a more regular forum to look at the use of trees for shelter and related topics.

The organisers are now looking at ways to develop the outcomes of the seminar, including the possibility of establishing a Working Group to examine and progress the areas of most urgent need in shelter research and development.

Section 1: Keynote Presentations

1. **Shelter trees for energy conservation**
   David Clarke

   Question and answer session

2. **The uptake of pollutants by trees: benefits to air quality**
   Peter Freer-Smith, Mark Broadmeadow and Samantha Jackson

   Question and answer session

3. **Shelter trees in animal production**
   John Webster

   Question and answer session

4. **Shelter and wildlife**
   Michael Usher

   Question and answer session

5. **The economics of shelter provision on farms**
   John Blyth

   Question and answer session

Chapter 1

Shelter trees for energy conservation

David Clarke

Summary

This paper is based on a research study funded by the Department of the Environment in 1995, in collaboration with Landscape Design Associates. The aim was to review research into urban tree planting as an energy conservation measure and assess the need for further measurements of the impact of tree shelter on energy consumption in buildings. An extensive literature review was carried out and various experts were consulted. Tree planting has a significant effect on the environment at three levels:the regional (macro) scale, the neighbourhood (meso) scale and the scale of individual buildings (micro). Almost all the research is at the micro scale and concerned with the behaviour of shelterbelts. At the neighbourhood scale tree planting can reduce average wind speeds. In summer transpiration creates lower temperatures; in heavily planted urban parks up to 8°C below surrounding built up areas. Shelterbelts for specific groups of buildings can reduce wind speeds by more than 50%; in newer residential buildings resulting annual fuel savings are in the region of 3-5%; in older properties the savings are likely to be twice this. Heating savings for commercial buildings are much less as their larger size makes them less sensitive to reduction in unwanted air infiltration. Shelter planting is generally not cost effective in terms of energy saving alone; however cost benefit analysis, taking only energy savings into account, does not fully reflect the value of tree planting in urban areas because of the many other positive benefits.

Methodology

An extensive review was carried out of existing literature; some of the authors were also consulted. We carried out calculations to estimate the potential savings from sheltering. From the literature review and the experience of our collaborators, planting scenarios and their costs were devised. These figures were combined to estimate the cost benefit of shelter planting for energy conservation in buildings.

Current knowledge

The study by the Property Services Agency (PSA) (Dodd, 1988) clearly identifies three scales of influence of tree planting:

- *Macro environment*: the regional scale where tree planting can affect the climate of a region by transpiration and increasing the surface roughness and therefore reducing average wind speeds near the ground.

- *Meso environment*: planting can affect local conditions in the same ways and create specific pockets of shelter (e.g. Milton Keynes or Warrington neighbourhoods). This is also called the neighbourhood scale.

- *Micro environment*: deals with the influence of specific planting of trees or shelterbelts. This is the area where all the field measurement work has been done and where one can attempt to identify specific benefits for individual buildings.

The study did not deal with macro environment issues as this is the realm of climatology and regional geography. At the meso scale the main benefits of tree planting in a heating dominated climate such as the UK is to decrease the average wind speed near ground level. As far as building energy use is concerned, this will reduce unwanted air infiltration and reduce convective losses. The magnitude of the shelter effects is discussed below. At the micro scale we are dealing with the influence of individual trees or groups of trees on single or blocks of buildings where the majority of research has been directed.

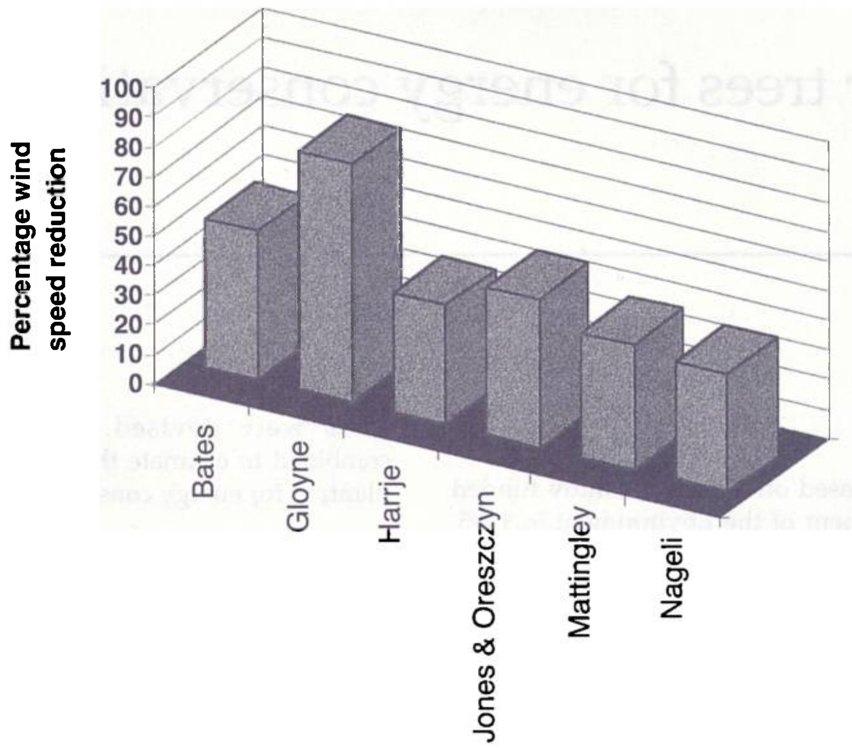

Figure 1.1 Measured wind reduction of shelterbelts from various authors

Research results

Figure 1.1 shows the estimated or measured reduction in wind speed using figures taken from a variety of field and wind tunnel studies fulfilling the following criteria:

- Distance of a sheltering belt from a building of 3 to 4H (where H = height of shelter), which is consistently identified as an optimum separation distance for shelterbelts.
- A reasonably permeable shelterbelt which is identified as the most appropriate form.
- Measurements at a height of 2–3 m from ground level.

The range of figures is explained by the different types of study; some are based on field measurement, some on wind tunnels, and they relate to different regions where the wind profile ahead of the wind break could vary. Despite these differences there is a broad measure of agreement of the size of shelter effects.

Figure 1.2 shows the estimated energy savings achievable from shelterbelts (all for domestic scale buildings). The highest values are for very leaky buildings based on American research in the middle of this century (Bates, 1945). These figures are not at all relevant for modern buildings. More recent studies suggest annual energy saving for heating use in the 3 to 10% range. In the analysis section below, using two calculation methods, we estimated the maximum possible energy savings for different building types.

The high estimates of potential savings in earlier studies seems to have been perpetuated by some researchers including leading figures in the field. One of the papers studied (Heisler, 1977) has detailed corrections made by the author in 1984. In one instance, the text quotes a figure from a paper by Mattingley of a reduction in air infiltration at 60%, which was subsequently changed to 42% (a manuscript annotation corrects this). More significantly the original text quotes potential energy savings in a house for the winter season of 20%. This figure was in fact 14% in the paper quoted and that was a figure *only* for the period when wind

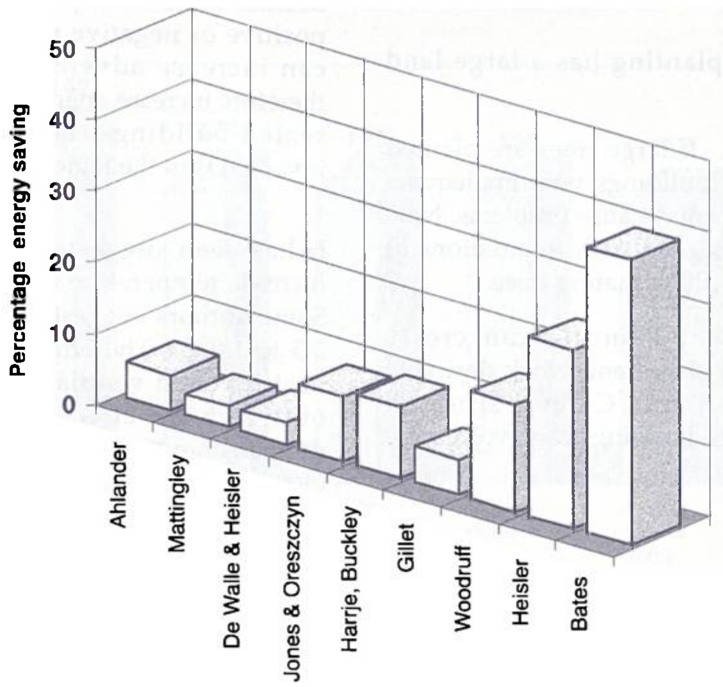

Figure 1.2 Estimates of annual energy savings from shelterbelts by various authors

speeds were high: the *annual* fuel savings were estimated in the original paper at 3%. An annotation corrects this large discrepancy.

Benefits and drawbacks

Windbreaks in urban areas can perform many roles other than that of reducing wind speeds. These additional roles provide benefits to the environment and residents, making shelter planting along with other landscaping a worthwhile investment.

Additional benefits

Providing a sense of place. Shelter planting can help to provide a sense of place in an urban environment that may appear bland and sterile without planting.

Defining the urban edge. Shelter planting at the meso scale can define the urban edge, screen urban development from the countryside, and create a recreational buffer between town and country.

Screening. Wind breaks can also provide visual screening.

Noise control. Planting needs to be as dense and wide as possible to filter noise.

Air purification. It has been shown that planting improves air quality.

Wildlife. Shelter planting can provide wildlife corridors to connect fragmented habitats such as woodland.

Improved outdoor microclimate. Shelter planting can enhance the areas surrounding buildings by creating sheltered sitting areas and transport routes.

CO_2 absorption. Another good reason for tree-planting is for CO_2 absorption. This will reduce the amount of CO_2 contributing to the greenhouse effect. In Australia, for example, mass tree planting is being planned in conjunction with new road building to balance the emissions from vehicles.

Reduced storm water run-off. Trees as part of the soft landscaping will increase the capacity of the soil to absorb water, and therefore reduce run-off of sudden storm water.

Driving rain. Wind-driven rain results in increased wetting of walls leading to greater heat losses; the increased wetting can damage the wall surface by wetting and freezing cycles. Reduced wind speeds due to shelter planting will also reduce driving rain.

Drawbacks

Land use. Shelter planting has a large land requirement.

Damage to buildings. If large trees are planted too close to existing buildings with inadequate foundations the roots may cause problems. New buildings can be designed with foundations to cope with the proximity of mature trees.

Blocking solar gain. Planting can create undesirable areas of shade and block desirable solar gain in buildings. Careful siting of planting in relation to buildings can avoid these problems.

Analysis

The intention of a shelter barrier is to reduce local wind speed. This results in reduced wind infiltration rate, reduced convective cooling of building surfaces, reduced evaporation rate and evaporative cooling of any wet surfaces. For a building with some degree of insulation in the outside skin the change in convective cooling by a reduction in wind speed is insignificant as the boundary layer accounts for a negligible portion of the overall 'U' value. (U value is the rate of heat loss through a building's skin, usually expressed in W m^{-2} K^{-1}.) However, the surface resistance part of the U value can be significantly affected by shelter of glazed surfaces and so the sheltering effect will be more beneficial in highly glazed buildings.

The adventitious infiltration in a building is due to the gaps in the structure not required for normal ventilation purposes. The increase in positive or negative pressure on the building can increase adventitious infiltration and therefore increase energy use. However in well-sealed buildings the percentage of energy involved is in the region of 5%.

It has been suggested that shelterbelts will increase temperature downwind of the shelter. Some authors suggest a rise in temperature of 0.5 to 1.0°C. The effect of this on conductive heat loss and ventilation heat loss would far outweigh the effect of wind reduction and provide annual savings of around 9% (Jones and Oreszczyn, 1987). However increased sheltering can *reduce* the ambient temperature on nights with clear skies. As most wind measurements are taken in the day, these effects may not have been recorded. We therefore do not extrapolate an increase in daytime air temperature into an annual effect as there will also be adverse effects.

Effect of location and size of building

The infiltration in a building is proportional to the external skin, so the fact that a typical commercial building may have a surface to volume ratio around one-fifth of that of a domestic building means that the variation in adventitious infiltration will be one-fifth as much and therefore much less significant. Figure 1.3 shows the different heating requirement for two sizes of buildings with

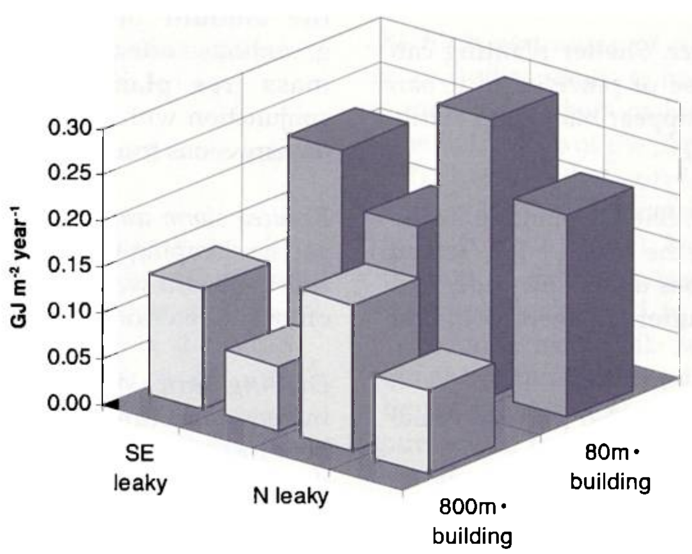

Figure 1.3 Heating requirements for different locations for two sizes of building

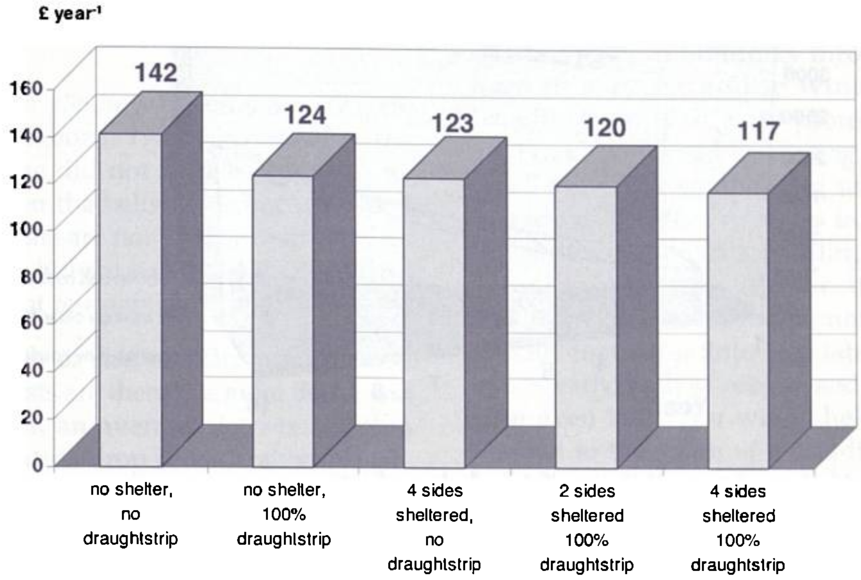

Figure 1.4 Annual cost of heating for different scenarios of sheltering and draughtstripping

different leakage characteristics and locations. These figures are derived from a BREDEM (Building Research Establishment Domestic Energy Model) analysis. They show the effects of building scale on heating requirements and the regional variations possible in the UK. The cases represent the possible extremes of performance. The small building is based on the 1995 Building Regulations example 2 house (Anon., 1995); the Regions are South East and Shetland (to represent the extremes in the UK). The larger building approximates to a medium size commercial building. This is far more efficient due to the different surface to volume ratio. The greater sealing of the buildings reduces the regional effects and therefore the energy saving potential of any shelter.

Possible range of shelter effects

Figure 1.4 shows figures for heating requirements with different shelter and sealing scenarios. These figures come from a SAP analysis using the 1995 Building Regulations example 2 house (SAP: Standard Assessment Procedure, a calculation method for assessing energy use; the method is in Approved document L). The benefit of sheltering four sides for an undraughtstripped house is £19 per year or 13%. For a draughtstripped house the maximum benefit is £5 per year or 4%. Although the calculation method is fairly crude these figures are remarkably similar to those in the literature derived from field measurements. The numbers show that the cost of shelter planting is unlikely to be justified by energy savings in buildings alone. These are extreme cases; typical semi-detached or terraced examples will fall somewhere in between.

Cost comparisons

Figure 1.5 shows cumulative energy savings compared to cumulative costs of a simple shelterbelt. The figures are for a notional shelterbelt 100 m long providing shelter to 14 houses. The two cases are for a badly insulated older house and a modern house. The projections are based on a simple payback basis, and do not take account of land costs. For older buildings a simple payback is well over 10 years; for newer buildings the payback period will be far greater. The graphs show that shelter planting cannot be justified on economic grounds solely from energy savings in buildings.

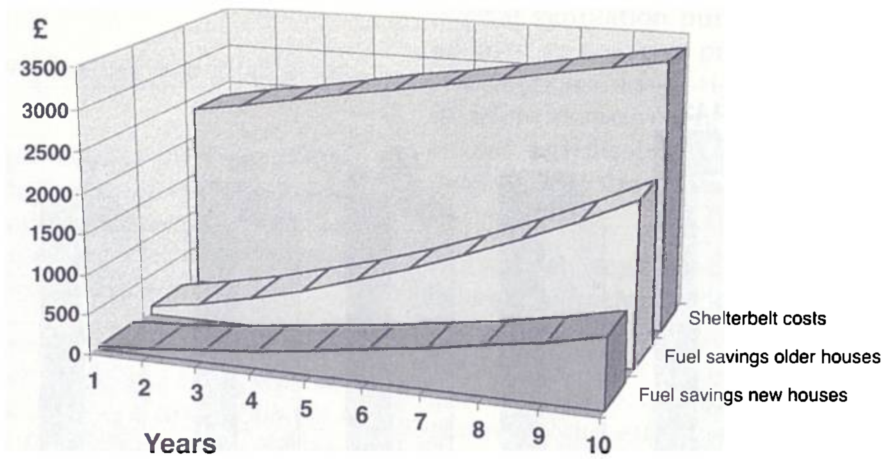

Figure 1.5 Cumulative costs and savings from shelter planting

Character and design of shelter planting

The value of any windbreak in relation to energy conservation in buildings is dependent on the ability of that windbreak to reduce wind speeds, and the distance over which this reduction is sustained. Much of the research has investigated the ability of different windbreaks to achieve this in an agricultural context, but few have considered the contribution to energy conservation in buildings.

The context of the studies varies greatly; biases towards the study of shelterbelts rather than other forms of shelter planting also make it impossible to reach firm conclusions on the benefits of all types of vegetation shelter. Despite these difficulties there are conclusions on the characteristics of windbreaks which are consistent between researchers.

Creating an effective wind shelter

The *porosity* of vegetation is the most influential variable in creating an effective wind shelter. Most research has concluded that dense wind shelter causes the greatest wind speed reductions, and that these reduced wind speeds occur close to the shelter planting on the leeward side and recover quickly to the open wind velocity (Nageli, 1946, cited in Caborn, 1957; Heisler and de Walle, 1983; Jones and Oreszczyn, 1987; Nord, 1991). Very dense windbreaks cause an upward deflection of the airstream, giving rise to an area of low pressure to the leeward of the barrier. The resulting suction draws down air currents and gives rise to turbulence on leeward and windward sides (Caborn, 1957; Baxter, 1986). Thus shelter planting that is too dense and too close to a building may, in fact, increase the infiltration heat loss of a building due to increased turbulence. A number of research projects have concluded that moderately porous windbreaks provide wind velocity reduction over the greatest distance on the leeward side (Nageli, 1946, cited in Caborn, 1957; Heisler and de Walle, 1983; Bean *et al.*, 1975). Several research projects came to the conclusion that open or high porosity windbreaks provide the lowest reductions in wind velocity on the leeward side but that any reduction occurs over a long distance downwind (Nageli, 1946, cited in Caborn, 1957; Heisler and de Walle, 1983).

Although a deciduous shelterbelt is more porous in winter than it is in summer, the research shows the shelter is still significant. Nageli (1946), cited in Nord (1991), remarked that a deciduous shelterbelt will keep about 60% of its sheltering effect when it is leafless. Jones and Oreszczyn (1987) state from field experiments that wind speed reduction in a partially foliated state can be about double that in a defoliated state.

Layout. Most research has revolved around recommendations for planting in rows, but plants can also be arranged in more naturalistic and free-flowing forms. Rows of planting (particularly trees or avenues) have been found to provide some shelter (Nord, 1991), but also found to create significant amounts of turbulence at their base, where the air is forced between the stems of the plants. If plants are arranged in staggered rows (Finbow, 1988; McClenon and Robinette, 1977), then there is less chance for gaps to occur and wind velocities, even in oblique winds, are reduced. It could be assumed that a random mix of species is likely to provide a more even porosity throughout. However, work carried out at Warrington has shown that this type of planting arrangement has affected the establishment of slower growing species due to competition from faster growing species (Tregay and Gustavsson, 1983).

Cumulative shelter planting. Experiments (Nageli, 1946, cited in Caborn, 1957) showed that the free-wind regime did not have a chance to re-establish between the belts. He concluded that as long as the belts are not further than 30 times their common height apart, the free wind regime would not re-establish.

Width. The width of shelter planting can affect its density. Forests are therefore more dense and less porous than an avenue of trees. Within forests, wind speeds drop considerably (Nageli, 1954, cited in Gustavsson, 1994), but also provide a smaller area of shelter in their leeward side when compared to shelterbelts that have a smaller width (Caborn, 1975).

Length. If shelter is required for a given area, it is important to extend the shelter planting beyond the perimeter of this area. This is because wind speed accelerates at the edges of planting to greater than that of the free wind speed. Baxter (1986) suggests that when the wind direction is not constant, the ratio of length to height must be at least 12:1.

Height. For maximum shelter, it is best if the shelter planting is taller than the height of the buildings it is protecting, particularly if the planting is protecting a large area of individual buildings (Bates, 1945; Finbow, 1988). Thus shelter planting 20 m high would protect a house well above its roof ridge of 10 m (Finbow, 1988).

Wind shelter profile shape and edge. Generally, research suggests that a vertical edge to planting is most effective at abating winds. This will not push large gusts of air up over the planting which can then drop on the leeward side creating eddies (Caborn, 1957; Gustavsson, 1994; Glauman and Nord, 1993). Research also indicates the importance of underplanting to prevent gaps at the base where wind speeds may be forced to accelerate.

Distance and orientation in relation to building. The optimum distance and orientation of shelter planting in relation to a building depends upon the type and design of the shelterbelt, the local environmental conditions, and the size of the building or area of buildings to be sheltered. Gillet and Priestnall (1986) recommend a rule of thumb for designers stating that a windbreak should be located at 3H of the windbreak and not further than 6H; beyond this the free wind regime is re-established.

Reduction of solar gain. In Britain, the heating qualities of the sun are valuable in reducing heating costs in buildings through solar gain, both in summer and in winter. Maximum benefits from both wind protection and solar gain can be achieved by placing shelter planting on all except the south facing side of a building. The use of deciduous species in a shelterbelt on the southern side of a building can still allow solar gain in the winter months, while providing shelter in the summer. Deciduous species that come into leaf late and lose their leaves early, such as robinia and ash, block solar gain even less. If a wind shelter needs to be planted to the south of a building it should be located 3 to 4H away from the building to avoid interference with solar gain (Jones and Oreszczyn, 1987).

Structural composition. For shelter planting to perform well in abating wind, the density of planting should be as near uniform as possible with no gaps at the base. In other words shelter planting is often most effective with a combination of upper storey plants as well as an under storey and edge.

Development over time. An uneven age structure is desirable to create an even density of planting throughout the windbreak with few to no gaps and an overlapping and layered structure. Species that can be thinned, coppiced, brashed and pollarded will greatly extend the life expectancy of the shelter planting.

Establishment and management. Windbreaks should be planted ahead of site development in order to reduce infiltration heat loss in buildings from the day construction is finished. Proper management of a shelterbelt can extend the life of the plants within it; hedges have been managed over centuries, full maturity of trees and shrubs in a windbreak may take 100 years to achieve, but they can be managed so the benefits last indefinitely.

Costs. The initial capital costs of planting, followed by establishment and management costs over a five-year period are considered using 1995 prices. Planting capital costs include: purchase of plants, site clearance, planting, mulching. The cost of establishing and managing shelter for a five-year period is calculated as a percentage of the capital costs of the scheme. For the first three years establishment and management is calculated as 7.5% of capital costs, and for the following two years as 5%. These calculations are used on a series of windbreak types: an avenue of trees,

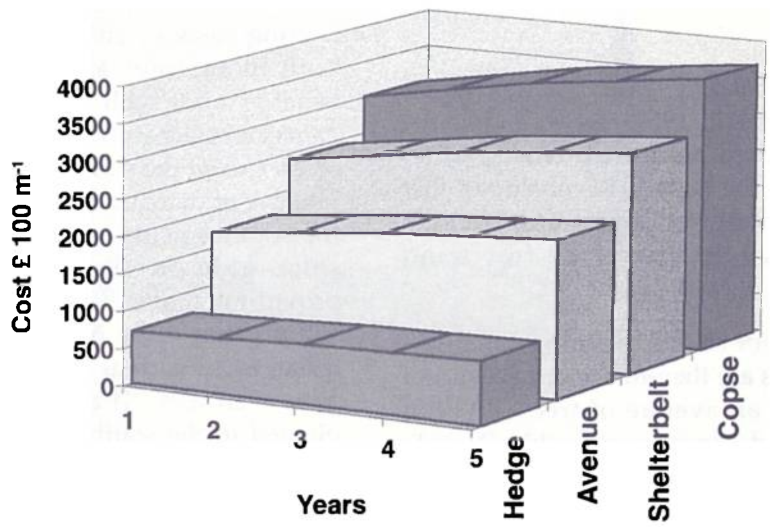

Figure 1.6 Cumulative costs for types of shelter planting

hedge, shelterbelt (5 m wide) and woodland copse (7.5 m wide) (Figure 1.6). The density of planting and the age of plant material have the greatest effect on planting costs. Establishment and management costs will vary depending on the exact situation. In some cases replacement of plants due to wind scorch, or vandalism, may increase costs as will protective fencing.

Conclusions

- Early research suggesting energy savings of 20% or more due to tree planting were based on leaky buildings and are not relevant to current buildings standards.

- Shelterbelts for specific groups of buildings can reduce wind speeds by more than 50%; in newer residential buildings resulting annual fuel savings are in the region of 3-5%; in older properties the savings are likely to be twice this.

- Heating savings for commercial buildings are much less as their larger size makes them less sensitive to reduction in unwanted air infiltration.

- Structures with high leakage rates and high conductive losses such as commercial glasshouses benefit greatly from shelter planting: savings exceeding 30% are possible.

- Shelter planting is generally not cost effective in terms of energy saving alone, having a simple payback of well over 10 years for older properties and more than twice that for modern buildings. However cost–benefit analysis, taking only energy savings into account, does not fully reflect the value of tree planting in urban areas because of the many other positive benefits, and these may be reflected in property values.

- The many benefits from urban tree planting include:

  - providing a sense of place
  - defining the urban edge
  - cooling effects
  - timber production
  - visual screening
  - noise control
  - air purification
  - wildlife
  - improved outdoor microclimate
  - increased food production
  - CO_2 absorption
  - reduced storm water run-off
  - reduced impact of driving rain.

- The few drawbacks to tree planting include:

  - land use
  - damage to buildings
  - leaf litter
  - blocking solar gain
  - reduced natural ventilation.

- At the neighbourhood scale, tree planting can reduce average wind speeds and by transpiration create lower temperatures in summer. In heavily planted urban parks temperatures may be up to 8°C below surrounding built up areas.

- There is a large amount of information about the best ways to carry out tree planting to maximise energy savings over the long term. Because this information is not in an accessible form, we recommend the production of some design guidance material to help implement shelter planting more effectively.

References

Anon. (1995). *The Building Regulations 1991 Approved document L (revised).* HMSO, London.

Bates, C.G. (1945). Shelterbelt influences: The value of shelterbelts in house heating. *Journal of Forestry* **43**, 176-196.

Baxter, S.M. (1986). *Windbreaks for horticulture.* ADAS/MAFF.

Bean, A., Alpern, R. and Federer, C.A. (1975). A method of categorising shelterbelt porosity. *Agricultural Meteorology* **14**, 417-429.

Caborn, J.M. (1957). *Shelterbelts and microclimate.* Forestry Commission Bulletin 29. HMSO, Edinburgh.

Clarke, D. (1996). *Shelter and energy conservation.* In press.

Dodd, J.S. (1988). *Energy saving through landscape planning —the background.* Property Services Agency, Croydon.

Finbow, M. (1988). *Energy saving through landscape planning,* vol. 3, *The contribution of shelter planting.* Property Services Agency, Croydon.

Gillet and Priestnall, M.A. (1986). The benefits of shelter and site planning. In: *The efficient use of energy in buildings, 2nd UK ISES Conference.*

Glauman and Nord, M. (1993). External climate : vegetation as wind shelter. *Stad and Land,* no. 113, *Uteckliimat 1993.* Sidor, Sweden.

Gloyne, R.W. (1954). Some effects of Shelterbelts on local and micro-climate. *Forestry 27.*

Gustavsson, R. and Ingelög, T. (1994). Det nya landskapet. Skogsstyrelsen, Sweden.

Heisler, G.M. (1977). Discussion of 'Amelioration - how trees reduce energy loss in cities' *Proceedings, Society of American Foresters.*

Heisler, G.M. and de Walle, D.R. (1983). Windbreak effects on air infiltration and space heating in a mobile home. *Energy and Buildings* **5**, 279-288.

Jones, B. and Oreszczyn, T. (1987). The effects of shelterbelts on microclimate and on passive solar gains. *Buildings and Environment* **22**, 101-110.

Mattingley, G.E., Harrje, D. and Heisler, G. (1979). The effectiveness of an evergreen windbreak for reducing residential energy consumption. *ASHRAE Transactions* **85**, 428-444.

McClenon, C. and Robinette, G.O. (1977). *Landscape planning for energy conservation.* Environmental Design Press.

Nord, M. (1991). *Shelter effects of vegetation belts – results of field measurements.* The National Swedish Institute for Building Research, Reprint series no. 59.

Tregay, R. and Gustavsson, R. (1983). *Oakwood's new landscape: designing for nature in the residential environment.* Sveriges Lantbruksuniversitet. Stad och land, report no. 15, Ainarp.

Question and answer session

Graham Bell, Earthward

Can the speaker please define 'urban edge'?

In Peterborough, for example, rather than the urban area spreading up to a point where there is the last house, a back garden and a fence and then agricultural land, there is a zone of substantial tree planting between the back garden of the house and the start of agricultural land. This defines the urban edge from a planner's point of view visually but also has a very important effect on the sheltering of the whole district.

Alan Sibbald, MLURI

The results you gave on energy savings were presumably made with deciduous trees. You made the comment about deciduous trees actually losing their leaves at the wrong time. Would that energy saving be increased if evergreen trees were used instead?

We did look at this. The savings we obtained are based on actual shelterbelts in Milton Keynes. The sheltering performance of deciduous trees in winter is about 50 % of the trees in full leaf. It is much better than I expected. The effect of foliated trees is quite good and it would improve the figures, but not very much, because the maximum potential is just not there in money terms. I think our landscape architect colleagues didn't feel that that type of planting would be appropriate in many southern areas.

Ian Cunningham, retired chairman MLURI Board of Management

Could you tell me what the structure of these shelterbelts were. Were they single rows, for example?

In our full study we went into some detail on the optimum construction of the shelterbelt and it is based on multiple rows to create a reasonably dense consistent shelterbelt. The conclusion was that a medium density was the most desirable; this created the greatest shelter effects downwind. The other important considerations were not to create underplanting so that there were gaps at the bottom which can accelerate wind and not to create planting which had a gradual build-up to a high forest in the middle and then going down to shrubs. That's not a good form of shelterbelt for buildings, because it doesn't break up the wind enough. It is better to have a reasonably abrupt edge to it.

John Blyth, Edinburgh University

Could you say how shelter for buildings develops over time? Was the 3-5% saving the maximum? And is this related to a single height, to the height of the building?

That figure relates to the maximum. Studies at Milton Keynes were done on the existing hedgerow-type shelterbelts, already centuries old. For typical housing, optimum shelterbelt height would be around 20 m as a maximum. Within 10 years you are going to having a reasonable affect I would have thought.

If they were mature belts, would they be more effective when they were younger? Had they gone past their best in terms of sheltered effect?

Well, our colleagues are suggesting that it should be possible to design and to manage a shelterbelt that will last forever. Now, I should argue that this is not my field, but we all experience hedgerows that have been managed for several centuries. Whether you could maintain an effective belt for several centuries for sheltering buildings by appropriate management, I am not in a position to say.

Graham Hunt, Forest of Mercia

In your research did you look at the relationship of shelterbelts within a more greatly planted countryside rather than seeing it as an isolated measure as a means to reduce wind speeds?

We did consider that point, and we looked at the reduction in average wind speed by having planted countryside; what that does is to increase the roughness of the surface terrain and reduce the wind speed on average but it is not a huge amount compared to the effect of sheltering for a specific group of buildings. You might be saving less than 1% for a modern building. To achieve up to 5% you have got to be looking at specific sheltering.

Graham Hunt, Forest of Mercia

I was thinking of the wider context as a complementary measure to the specific sheltering. Would the wider context increase the total energy saving above 5%? Would that contribute to a greater saving?

No, not really. At any building within that wider context instead of realising a reduction in free wind of 40 % you would realise a reduction in wind speed by 40 % of the actual wind speed that was 10 % less than free wind speed. So the money you are actually saving is very small. You might also create more turbulence and therefore the shelterbelts might be less effective.

Peter Freer-Smith, Forestry Commission

Thinking back to last year's very hot summer, as well as cooling costs it would seem to me that comfort in the open environment may be a relevant factor. I wonder if you could comment on the cooling effect?

Certainly in climates that are warmer than ours, for example Illinois which has hotter summers than we do and California which is not actually a lot hotter than our summers, but it is warmer all the time, air conditioning is required and then you could save money from the air conditioning. Also trees for shading of open spaces is a very important factor in the use of outdoor spaces in the summer time. I would certainly go along with that as being part of the whole mix of things that you should be trying to address. French canals, for instance, were all planted with trees to create comfort for the horses which pulled the barges.

Bob Agnew, MLURI Institute

The problem of leaf litter in the new towns: has this been something you have investigated in the proximity of trees to houses, roadway drainage, etc?

The distance that you need to have a shelter tree away from the building shouldn't create blockage of gutters because there's going to be at least 3-4 times the height of the shelterbelt between the houses and the trees. The trees in my garden that are far away don't block the gutters. It's the ones that overhang that block the gutters. I don't think that that's a problem. The roadway drainage you mentioned is a drawback.

Chapter 2

The uptake of pollutants by trees: benefits to air quality

Peter Freer-Smith, Mark Broadmeadow and Samantha Jackson

Summary

A critical review of the extensive scientific literature on pollutant uptake by trees conclusively demonstrates that amenity trees, woodlands and forests can be major sinks for a number of important pollutants. Trees facilitate the uptake, transport and assimilation or decomposition of pollutants such as ozone, the oxides of nitrogen, ammonia, nitric acid vapour and dust particles. However, most of the available data are highly site specific, or theoretical considerations, or cover the uptake of pollution by forests in the rural uplands. Data availability is insufficient to accurately quantify the role which trees play in improving air quality in urban and suburban Britain where such effects might be greatest. However, for a few relevant tree species there is sufficient information for a simple model to be developed which predicts the uptake rates of some gaseous pollutants (sulphur dioxide, ozone and the oxides of nitrogen) by urban woodlands. Because data have not been collected with the objective of estimating the benefits to air quality, the estimates of pollutant uptake which are available are preliminary only and research is required if the beneficial effects of trees on air quality are to be quantified accurately. The effects of urban trees and of the new Community Forests in accumulating or decomposing particulates (pm10s), heavy metals, the oxides of nitrogen and ozone are important priorities for future research.

Introduction

During the last 20 years it has become clear that vegetation, soils and the aquatic environment are more important than the atmosphere as sinks for many contemporary pollutants. Many of the compounds which we commonly regard as pollutants are naturally occurring in the atmosphere but concentrations have increased significantly as a result of man's activities. In the northern hemisphere average concentrations of ozone, the oxides of nitrogen and sulphur dioxide have increased some 12, 40 and 400 times, respectively. Such increases are considered significant because they result in concentrations or depositions which have, at times, exceeded the threshold values for damage to the environment (i.e. the critical levels or loads for particular pollutants and target receptors). Pollutants are transferred from the atmosphere to the terrestrial environment by three processes:

1. *Dry deposition*: the movement of particles and gases by molecular diffusion (Brownian motion) and turbulent transfer to wet and dry surfaces.
2. *Wet deposition*: the movement of particles and dissolved gases in rainfall.
3. *Occult deposition*: the movement of particles and dissolved gases in cloudwater, fog and mist.

Trees and other vegetation take up ozone (O_3), nitric acid vapour (HNO_3), nitrogen dioxide (NO_2), ammonia (NH_3), mercury vapour, sulphur dioxide (SO_2) and particles (dust) more efficiently than other land surfaces. This is because plants absorb, transport and assimilate or decompose these pollutants. The effectiveness of trees at taking up gaseous pollutants is linked to the evolution of aerial structures which maximise the uptake of carbon dioxide (CO_2) and the capture of light. The layered nature of woodland canopies gives them a surface area 2 to 12 times greater than the land area which they cover. As well as having greater leaf areas than other types of vegetation, trees also create more turbulent mixing of air passing over the land surface than is created by shorter vegetation. More turbulent mixing significantly increases the uptake or deposition of those pollutants for which surface properties do not limit the uptake rate.

Among the pollutants listed above are those which accelerate the erosion of building materials, acidify the environment and contribute to human health problems, particularly in the urban environment. Consequently, in addition to the shelter, aesthetic and wildlife benefits which forests, woodlands and trees can have, they may also provide significant benefits by taking up pollution and reducing such harmful effects.

Literature review

The literature on pollution uptake by trees was reviewed and the references and synthesis may be found in *Urban woodland and the benefits for local air quality* (Broadmeadow and Freer-Smith, 1996). The review covers pollutant uptake by individual trees and woodland canopies, and an analysis of the likely effects of these pollutants on tree condition. All pollutants for which relevant information was available were covered, but particular attention was paid to major urban pollutants: the oxides of nitrogen (NO_x), particulates (pm10s – particulate matter of diameter less than 10μm), volatile organic compounds (VOCs), carbon monoxide (CO), heavy metals (Cu, Cd, Zn, Pb, and Ni) and sulphur dioxide (SO_2). Since the community and urban forests extend out of town centres into rural areas, the classic rural pollutants (sulphate, nitrate and ammonium in rain and mist, ozone (O_3), nitric acid vapour (HNO_3) and ammonia (NH_3)) were also considered. The review covered some 400 papers which provided a number of laboratory measurements of the rates of uptake of O_3, SO_2, NO_2 by various tree species (Table 2.1). No suitable data on the uptake of NH_3 by trees were found but for herbaceous plants higher uptake rates of NH_3 were larger than for other gaseous pollutants. A wide range of uptake rates are reported for all three pollutants (Table 2.1), although very few measurements of pollutant uptake are available for species planted as street trees or in Community Forests. However, many of the studies demonstrate a close relationship between exposure concentration and uptake rate. Similarly pollutant uptake is greater by foliage with larger stomatal conductance – a measure of the number and degree of opening of leaf stomata.

Table 2.1 The uptake rates by foliage ($\mu g\ m^{-2}\ s^{-1}$) of ozone, sulphur dioxide and nitrogen dioxide by trees and ammonia by some herbaceous species. The exposure concentrations in parts per billion at which each uptake rate was measured are also shown. The individual references from which these data were derived can be found in Broadmeadow and Freer-Smith (1996)

Ozone

Species	Concentration (ppb)	Uptake rate ($\mu g\ m^{-2}\ s^{-1}$)	Reference
Acer platanoides	250	0.10	Elkiey *et al.*, 1982
Sorbus aria	250	0.13	Elkiey *et al.*, 1982
Betula pendula	250	0.16	Elkiey *et al.*, 1982
Pseudotsuga menziesii	250	0.28	Elkiey *et al.*, 1982
Picea abies	250	0.20	Elkiey *et al.*, 1982
Picea abies	-	0.08	Wieser and Havranek, 1993
Picea abies	300	0.72	Freer-Smith and Dobson, 1989
Picea abies	250	0.53	Freer-Smith *et al.*, 1989
Picea sitchensis	300	0.35	Freer-Smith and Dobson, 1989
Picea sitchensis	80	0.31	Freer-Smith *et al.*, 1989
Picea sitchensis	100	0.58	Dobson *et al.*, 1990
Pinus sylvestris	400	0.30	Skarby *et al.*, 1987
Pinus nigra	250	0.17	Elkiey *et al.*, 1982

Sulphur dioxide

Species	Concentration (ppb)	Uptake rate ($\mu g\ m^{-2}\ s^{-1}$)	Reference
Betula pendula	55	0.90	Freer-Smith, 1985
Betula papyrifera	1000	2.39	Roberts, 1974
Betula pendula	400	0.29	Elkiey *et al.*, 1982
Ligustrum vulgare	1000	1.89	Roberts, 1974
Fraxinus americana	1000	1.28	Roberts, 1974
Sorbus aria	400	0.25	Elkiey *et al.*, 1982
Pinus sylvestris	70	0.56	Hallgren *et al.*, 1982
Acer rubrum	1000	2.40	Roberts, 1974
Acer platanoides	400	0.15	Elkiey *et al.*, 1982
Pinus nigra	400	0.29	Elkiey *et al.*, 1982
Pinus nigra	770	0.11	Dasch, 1989
Pseudotsuga menziesii	400	0.24	Elkiey *et al.*, 1982
Picea abies	400	0.36	Elkiey *et al.*, 1982
Quercus palustris	770	0.53	Dasch, 1989
Ulmus americana	770	2.42	Dasch, 1989

Nitrogen dioxide and ammonia

Species	Concentration (ppb)	Uptake rate ($\mu g\ m^{-1}\ s^{-1}$)	Reference
Nitrogen dioxide			
Picea abies	50	0.07	Thoene *et al.*, 1991
Picea abies	400	0.19	Elkiey *et al.*, 1982
Betula pendula	400	0.16	Elkiey *et al.*, 1982
Betula pendula	270	1.70	Freer-Smith, 1983
Acer platanoides	400	0.10	Elkiey *et al.*, 1982
Sorbus aria	400	0.18	Elkiey *et al.*, 1982
Pinus sylvestris (field)	97	0.13	Bengtson *et al.*, 1980
Pinus sylvestris (lab.)	240	0.09	Bengston *et al.*, 1980
Quercus myrsinaefolia	300	0.67	Okano *et al.*, 1989
Pinus taeda	–	0.25	Rogers *et al.*, 1979
Quercus alba	–	0.06	Rogers *et al.*, 1979
Populus nigra	590	3.60	Freer-Smith, 1983
Populus sp.	300	2.00	Okano *et al.*, 1989
Pseudotsuga menziesii	400	0.17	Elkiey *et al.*, 1982
Pinus nigra	400	0.25	Elkiey *et al.*, 1982
Ammonia			
Avena sp.	277	2.95	Rogers and Aneja, 1980
Lycopersicum	148	1.06	Rogers and Aneja, 1980
Zea mays	320	0.80	Rogers and Aneja, 1980
Zea mays	32	0.16	Hutchinson *et al.*, 1972
Helianthus annua	41	0.14	Hutchinson *et al.*, 1982
Lolium multiflorum	21	0.05	Lockyer and Whitehead, 1986
Lolium Multiflorum	155	0.21	Lockyer and Whitehead, 1986
Lolium multiflorum	685	0.81	Lockyer and Whitehead, 1986

Data of a different type are available also in the literature. These are measurements of the total sulphur (S) and nitrogen (N) inputs to forests and woodlands (Table 2.2). These data can be converted to kilogrammes of S or N per hectare per year and are the total elemental inputs to the whole woodland ecosystem by dry deposition to leaf and shoot surfaces and in rain and mist. Values can be very large in polluted areas and location may be more important than woodland type in determining the input values. The data shown in Table 2.2 are all from rural areas and commercial hardwood or coniferous forests. The paper by Fowler *et al.* (1989) is particularly valuable because it puts together inputs of S and N by dry, wet and occult deposition, and also considers gaseous uptake for Kielder Forest, assuming both the current tree cover and also the original moorland land-use. (The forest is taken to be 60 000 ha at 300 m a.s.l. and with annual precipitation of 1500 mm.) The difference which an upland forest makes to the inputs by all three processes is clearly illustrated; moorland gives total inputs of 17.5 kg ha^{-1} yr^{-1} of S and 12.4 kg ha^{-1} yr^{-1} of N and inputs increase to 22.7 kg ha^{-1} yr^{-1} and 23.4 kg ha^{-1} yr^{-1} respectively with forest cover. There are no similar published data for urban or community forests. The studies from which values are quoted in Table 2.2 were intended to evaluate the environmental threat posed by pollutant input rather than to determine the benefits to air quality.

Detailed information on the fate of sulphur and nitrogen and other pollutants, such as heavy metals, in the woodland ecosystem would be required before this approach could be used to evaluate the amounts of these compounds which are effectively removed from the environment through retention in the tree biomass, removal at harvest or permanent retention in the soil. For sulphur in the uplands, which can be washed through to streams where it may have detrimental effects, increased uptake by trees may not result in an overall benefit to the environment. For others, such as ozone and nitrogen (from NH_3 and NO_2) which are converted to nontoxic molecules, there may be net and long lasting benefits resulting from tree uptake. Terpene emissions from forests have also been implicated in photochemical ozone production. However, given the climate of the UK, forest stands should still be considered as net sinks for O_3.

Because measurements of wet deposition and mist interception by urban woodlands have not been made, input values, similar to those shown in Table 2.2 for rural forests, cannot be provided for the Community Forests or for urban plantings and street trees.

Tree canopies also intercept greater amounts of heavy metals (Little and Martin, 1972) and dust particles (Freer-Smith *et al.*, 1997) than other vegetation types. For both particles and heavy metals, accumulation or 'sequestration' may also occur through a build-up of organic matter in soils and particularly as a surface organic horizon. Some pollutants may even enhance the rate of accumulation of organic matter in upper soil horizons by inhibiting litter decomposition. The heavy metal content of soils correlates positively with organic matter content and with soil pH; low pH probably causes exchange of metals with H^+ at cation exchange sites and leaching of heavy metals. Trees have recently been shown not to evolve tolerance to heavy metals in the way that herbaceous plants do, but rather to depend on avoidance mechanisms based on soil exploration during root growth (Watmough and Dickinson, 1995).

Conclusions

There are insufficient data to allow an accurate evaluation of the role which trees currently play in improving Britain's air quality. However, the scientific literature conclusively demonstrates that trees and woodlands can act as major sinks for a number of pollutants. Pollutant uptake would be greater with increased planting. In general terms, any planting configuration which maximises leaf area per unit ground area will increase the potential pollutant uptake rate. Additionally, pollutant uptake by trees is larger at the woodland edge and some species are more efficient at taking up pollutants.

Table 2.2 The minimum and maximum values of total sulphur (sulphate plus SO_2) and total nitrogen (NO_x plus NH_3 and NH_4^+) inputs to forests and woodlands

Species or ecosystem	Sulphur ($kg\ ha^{-1}\ yr^{-1}$)	Nitrogen ($kg\ ha^{-1}\ yr^{-1}$)	Reference
Glentress Forest	12	18.9	Sutton and Fowler, 1993
Thetford Forest	20	60.8	
Scots pine *Pinus sylvestris*	28.7	8.5 to 200	Cape, 1986; Pearson and Stewart, 1993
White pine *Pinus strobus*	8.96	7.3	Lindberg, 1992; Lovett and Lindberg, 1992
Loblolly pine *Pinus taeda*	6.86 (Tennessee) to 16.96 (N. Carolina)	9.1 to 14.0	Lindberg, 1992; Lovett and Lindberg, 1992
Douglas fir *Pseudotsuga menziesii*	5.12 (Washington) to 43.27 (The Netherlands)	66.33	Lindberg, 1992; Erisman, 1993
Jeffrey and Ponderosa pine *P. jeffreyi and P. ponderosa*	0.9 to 2.9 (S. Carolina)	6.0 to 30.7	Fenn and Bytnerowicz, 1993
Sitka spruce *Picea sitchensis*	22.7 (Kielder Forest)	23.4	Fowler *et al.*, 1989
Norway spruce *Picea abies*	10.73 (Norway) to 131.4 (Forest edge)	12 to 34.77	Lindberg, 1992; Godt and Mayer, 1988
Red spruce *Picea rubens*	9.28 (Maine) to 18.56 (Gt Smoky mts)	7.6 to 28.0	Lindberg, 1992
Mixed deciduous/coniferous	9.74 to 15.57	16.0	Lindberg, 1992; Rustal *et al.*, 1994
Mixed hardwood	16.93 to 34.1	10.08	Lovell and Lindberg, 1984; Kelly, 1980
Northern hardwood	3.52 (Great Lakes) to 7.84 (New York)	4.8 to 9.6	Leichty *et al.*, 1993; Lindberg, 1992
Red alder *Alnus rubra*	5.12 (Washington)	4.9	Leichty *et al.*, 1993; Lindberg, 1992
Ceanothus crassifolius	0 to 0.18	6.55	Bytnerowiez *et al.*, 1992
Beech *Fagus sylvatica*	36.9 to 50.0 (Germany)	-	Sah and Meiwes, 1993
Mixed conifers	– (Colorado)	3.5	Langford, 1992
Douglas fir *Pseudotsuga menziesii*	– (The Netherlands)	85	Pearson and Stewart, 1993
Loblolly pine *Pinus taeda*	– (Tennessee)	11.42	Lindberg *et al.*, 1990
Oak *Quercus petraea*	–	23	Pearson and Stewart, 1993

Deficiencies exist in our knowledge of the applicability of existing results from work in the uplands to the UK lowlands, and how these deposition processes are affected by species and site specific parameters. Of the processes involved, the importance of mist (or occult) deposition in the lowlands is not known to any degree, while few data are available regarding the deposition of particulates (pm10s) and volatile organic compounds (VOCs) to trees. A number of areas for future research are identified:

1. Models have been developed to estimate pollutant deposition to forests and uptake by individual trees and thus to woodland (Broadmeadow and Freer-Smith, 1996): see, for example, Figure 2.1. Developmental work is required if such models are to be used to estimate the benefits to air quality.

2. Examinations of total pollutant budgets (inputs, storage and loss to groundwater and at harvesting) would be valuable in order to identify the fate in the terrestrial environment of those pollutants of particular concern.

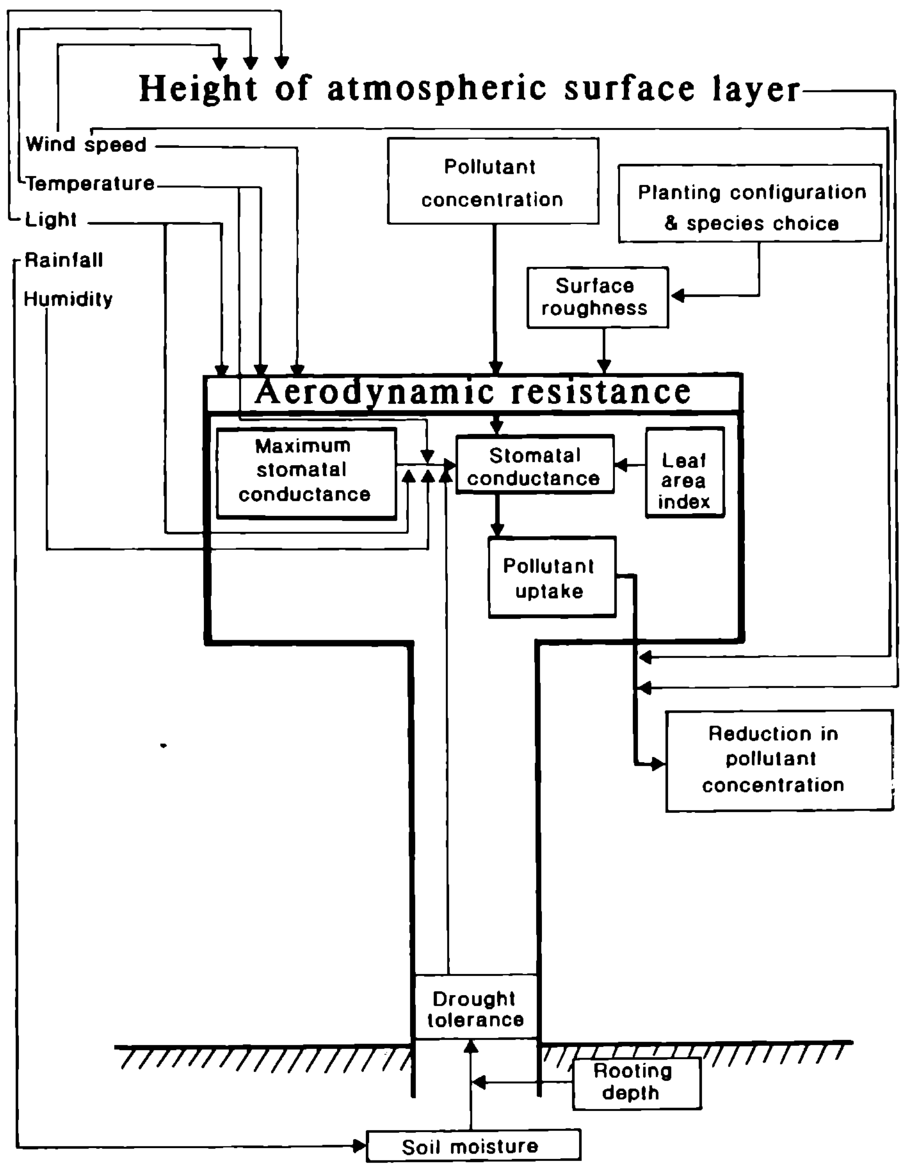

Figure 2.1 Schematic diagram of a model for estimating pollutant uptake by trees

3. Measurements of occult or mist deposition in the UK lowlands are required.

4. It is known that the presence of ammonia can increase sulphur deposition (an interaction known as co-deposition). The co-deposition of the various pollutant gases in the UK urban environment needs investigation.

5. Measurements of variations in particulate (pm10s) and hydrocarbon (VOC) deposition to urban woodland at both the spatial and temporal level.

6. Analysis of uptake of the major urban pollutants by the tree species in use in the Community Forests and urban areas, paying particular attention to differences in leaf morphology. These data are needed in order to scale up from existing models of pollution uptake by individual trees.

7. The application of micrometeorological approaches (flux gradient, eddy correlation and relaxed eddy accumulation technique) to measure pollutant depositions to urban and community woodlands.

References

Broadmeadow, M.S.J. and Freer-Smith, P.H. (1996). *Urban woodland and the benefits for local air quality.* Department of the Environment, Research for Amenity Trees No. 5 . The Stationery Office, London.

Fowler, D., Cape, J.N. and Unsworth,M.H. (1989). Deposition of atmospheric pollutants on forests. *Philosophical Transactions of the Royal Society of London* **324 B**, 247-265.

Freer-Smith, P.H. and Broadmeadow, M.S.J. (1996). *The improvement of urban air quality by trees.* Arboriculture Research and Information Note 135/ERB/96. AAIS, Farnham, Surrey.

Freer-Smith, P.H., Holloway, S. and Goodman, A. (1997). The uptake of particulates by urban woodland. *Environmental Pollution* **95**, 27-35.

Little, P. and Martin, M.H. (1972). A survey of zinc, lead and cadmium in soils and natural vegetation around a smelting complex. *Environmental Pollution* **3**, 241-254.

Watmough, S.A. and Dickinson, N.M. (1995). Dispersal and mobility of heavy metals in relation to tree survival in an aerially contaminated woodland soil. *Environmental Pollution* **90**, 135-142.

Question and answer session

Jeff Maxwell, MLURI

You mentioned site characteristics as an element of concern in relation to some of the data. Could you expand a little on that? Are you referring to size of plantation, soil type, soil depth, etc?

The size of the plantation, the species on the site and the leaf area index of the species will all be critical factors but this wasn't what I had in mind when I mentioned site characteristics, although they are very important. I was more concerned about the characteristics that will effect growth rate, the size of the tree and the ability of the soil to supply nutrients. Soil moisture is important in that it determines stomatal aperture and therefore the amount of uptake of pollutants. So it was more the classic site factors that I had in mind when mentioning site characteristics.

Michael Usher, SNH

You mentioned individual tree species. Has there been any work on mixtures because this will affect the shape of the canopy which will modify the efficiency of pollutant capture from clouds or mist?

Some of the studies of pollution input to woodland ecosystems I mentioned were studies of mixed species woodland. The way we have dealt with mixtures in our model of forest pollutant uptake is by calculating a species specific value and then integrating the separate contributions by the different species.

Michael Usher, SNH

How realistic is that approach, because mixtures have a very different canopy structure from mono-cultures?

We have made some very simplistic assumptions about canopy height in our model. For example, we have a uniform single value for canopy height and canopy height is the only parameter in the model which describes the canopy structure, so that is clearly inadequate. These are exactly the kind of things that we would like to follow up and improve.

Jacques-Eric Bergez, MLURI

Did you measure the gradient of air pollutant within the canopy?

No we didn't, but it will be an important factor. It is certainly the case that at woodland edges pollution uptake is substantially greater than in the interior.

Graham Hunt, Forest of Mercia

In your presentation you showed pictures of Rough Wood in Walsall where we are currently carrying out thinning operations for the local authority. In view of what you've said about the role of woodlands in taking up pollutants should we change our management operations plan and restrict our thinning?

The DoE would like us to produce an Arboriculture Research and Information Note [ARIN 135/ERB/96: see Freer-Smith and Broadmeadow, 1996] to provide a prescriptive recommendation on how those responsible for community and urban forests can improve pollution uptake in those situations. It is clear from what I've said that intuitively leaving more trees in the wood should maximise the pollution uptake. However, as David Clarke suggested in his talk we need to balance all the different benefits from woodlands. The reduction in pollution uptake by thinning is unlikely to be large enough to merit putting on one side your other important management objectives, which are the primary reason for carrying out the thinning operations.

Chapter 3

Shelter trees in animal production

John Webster

Summary

The practical importance of shelter trees depends not only on the extent to which they can modify heat loss by convection and radiation but also on the extent to which large grazing/browsing herbivores 'need' shelter. This chapter briefly reviews the factors that determine heat exchanges of animals in outdoor environments by evaporation, convection, conduction and radiation. Large herbivores are shown to have a wide thermoneutral range and a high degree of cold tolerance as defined by the lower critical temperature. Forest environments can provide sufficient shelter from convective and radiant heat losses to minimise direct stresses of cold on cattle and sheep in good condition. Red deer are much more susceptible to the chronic stresses of winter because of their limited energy reserves. The final section deals with the methodology necessary for a new study of the impact of shelter trees on the winter energetics of large herbivores.

Introduction

A full investigation of the topic 'Shelter trees in animal production' should include:

- Effects of trees on animals: energy exchanges and thermal stress.
- Effects of trees on availability and quality of food for animals.
- Effects of grazing/browsing animals on trees.

This chapter deals only with the first topic.

Shelter trees, by definition, modify heat losses from animals. In the cool temperate and boreal regions of the globe, this usually implies an amelioration of the environment by a reduction in heat loss, although trees can, of course, provide shelter from excessive heat load by solar radiation. The practical importance of shelter trees depends on:

1. The extent to which shelter can modify heat loss by convection and radiation.
2. The extent to which grazing/browsing animals 'need' shelter.

Heat exchanges of animals

To achieve homeothermy, an animal must balance the heat it produces in metabolism (H_p) against the heat it loses to the environment (H_l). The heat balance equation may be written as follows:

$$H_p \pm H_s = H_l = H_n + H_e$$

H_s = heat storage within the body.
H_n = heat exchange (usually loss) by convection, conduction and radiation, defined as sensible or 'Newtonian' heat loss.
H_e = heat loss by evaporation of water from the skin and respiratory tract.

Figure 3.1 illustrates heat exchanges of a sheep standing in the sun (Webster, 1995, after MacFarlane, 1968). Heat is exchanged firstly by convection, between the heat sources in the body, at deep body temperature (T_b) and the surface of the skin (T_s), then by convection between skin and air or by conduction between the surface of the body and other surfaces, usually the ground. In most circumstances the skin is warmer than the air or ground and heat is lost, e.g. by convection, at a rate proportional to the temperature gradient between the skin and the air (T_s - T_a). Increasing air movement increases the rate of convective heat loss relative to (T_s - T_a). Radiant heat exchanges are more complex. There is exchange of radiant heat within the infrared spectrum between the

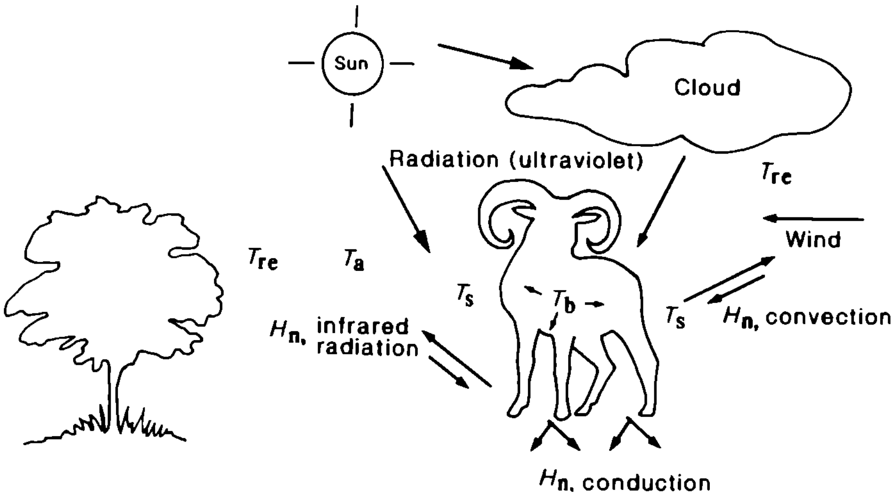

Figure 3.1 Heat balance of a sheep standing in the sun

surface of the animal and other surfaces in the environment (T_{re}), which may be walls, trees or even the sky. Once again this is proportional to temperature gradient although, in this case, defined by (T_s^4 -T_{re}^4). There is also, during the hours of daylight, incoming solar radiation whether direct or diffused through cloud, which always constitutes a heat gain. An animal that shelters *behind* a wind break of trees reduces heat loss by convection. When an animal shelters *within* a clump of trees, the effective radiant temperature of the environment is similar to air temperature.

The sensible heat exchanges of an animal at a given (T_b - T_a) are determined by its physical form, in particular the thickness and thermal insulation of its coat. Size is not very important. Sensible heat exchange at a given (T_s - T_a) is also affected by features of the environment such as wind and rain, both of which reduce the insulation of the coat. Free-living animals can usually act to modify H_n by seeking shelter from wind, rain and sun, by huddling together for warmth or by spreading their limbs to cool down. A particular species of animal may be adapted, largely by virtue of its anatomy, to life in hot or cold climates but, in the short term, it has limited physiological ability to prevent H_n from varying with air temperature. If it cannot maintain homeothermy by behavioural means, it must adjust those elements of the heat balance equation which can be regulated physiologically, namely metabolic heat production (H_p) and evaporative heat loss (H_e).

Homeothermic animals may be divided, somewhat arbitrarily, into two categories: those that in their natural environment normally regulate heat production to keep body temperature *up* to the set point on their thermostat and those that normally regulate evaporative heat loss to keep body temperature *down* to the set point. The heat exchanges of these two categories of homeotherms are illustrated in Figure 3.2. Type I (regulators of H_p) is by far the bigger category since it appears to include all the birds, small mammals (under 5 kg), such as rodents and rabbits, and many larger mammals including the well-studied pig and probably most of the carnivores. An animal loses heat by evaporation when water on the surface of the body vaporises on exposure to air. All animals lose some heat by continuous evaporation of water from the skin surface and from the respiratory tract as they exhale warmed, moistened air. However they differ greatly in their ability to regulate H_e either by active secretion of sweat or by thermal panting. Type I homeotherms are those with a limited ability to regulate H_e. This means that environmentally induced changes in H_n must be accommodated by physiologically induced changes in H_p.

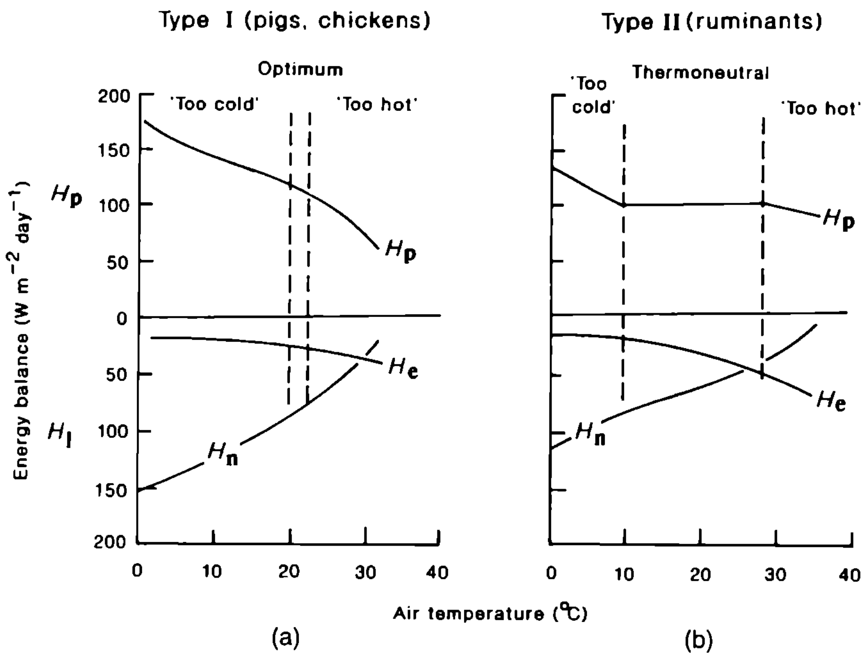

Figure 3.2 Effect of air temperature on different classes of homeotherms: (a) Type I, (b) Type II

Type II homeotherms include man, the higher primates and most of the large grazing animals. Man and the horse are excellent sweaters. The woolly sheep cannot sweat effectively but has an exquisite mechanism for regulating heat loss by rapid shallow respiration over the turbinate or scroll bones within the nose which act as highly efficient heat exchangers. Cattle and wild deer rely on a combination of sweating and thermal panting. As a result of their ability to regulate H_e over a wide range at negligible metabolic cost, Type II homeotherms (with the notable exception of civilised man) have a wide *thermoneutral zone* wherein their metabolic heat production is independent of air temperature (Figure 3.2(b)).

Below the thermoneutral zone an animal must increase H_p to maintain homeothermy. If ample food is available, this can be achieved without discomfort by a simple increase in food intake. If not, the animal will need to recruit cold thermogenesis. For a grazing animal this means it will have to shiver in order to maintain body temperature. The animal is now stressed by cold. Unless more food can be provided it will lose condition because H_p has increased but metabolisable energy (ME) intake has remained the same. The long-term effect of this is that it will become increasingly susceptible to cold as it loses its energy reserves and the insulating properties of body fat.

Small changes in the intensity of heat or cold can be accommodated without distress but as the intensity of heat or cold is increased the cost of thermoregulation increases to the point where the animal exceeds the threshold of suffering from:

- direct unpleasant sensations of heat or cold;
- acute hypo- or hyperthermia;
- exhaustion of energy reserves following prolonged shivering, or inadequate ME intake; exhaustion of water and electrolyte reserves following prolonged sweating or thermal panting.

Several important welfare issues emerge from inspection of Figure 3.2. For Type I animals there is no true thermoneutral zone (i.e. in Figure 3.2(a) the slope of the line relating H_p to T_a is never horizontal). This is a direct consequence of their limited ability to regulate H_e. In moderately cold environments Type I animals (e.g. a pig in a forest) can maintain comfort and welfare by eating more (given the chance). In hot environments they must eat less in order to reduce H_p. This may be incompatible with welfare and there is a basal level below which H_p cannot fall if life is to be sustained. Given their limited ability to regulate H_e, Type I animals are therefore also more susceptible than Type II animals to heat stress.

Table 3.1 Lower critical temperatures of ruminants in still air and in a moderate draught (from Webster, 1983)

	Weight (kg)	LCT (°C)	
		$V = 0.2$ m s^{-1}	$V = 2.0$ m s^{-1}
Cattle			
newborn calf	40	9	20
beef cow, maintenance	450	-17	-9
dairy cow, 22 l milk day^{-1}	600	-26	-13
Sheep			
ewe, full fleece	50	-11	-4
ewe, shorn	50	17	20
newborn lamb	4	19	24
Red deer calf	45	-7	3

Cold tolerance of grazing animals

Table 3.1 illustrates the cold tolerance of different classes of ruminants in terms of values for their lower critical temperatures (LCT, °C) in still air and in a moderate draught (V= 2 m s^{-1}) in a roofed yard, i.e. when T_{re} is similar to T_a. For the newborn, dry calf and lamb, still-air LCT is 9°C, rising to approximately 20°C in a draught. The still-air LCT of adult beef cattle in good condition and sheep in full fleece is below -10°C, which implies that, when dry and in the shelter of a forest, they are never likely to be seriously stressed by cold under UK conditions.

The red deer calf is less tolerant of acute cold than either cattle or sheep; the external insulation provided by the deer calf's coat is obviously less than that of a sheep in full fleece and the tissue insulation provided by the skin and subcutaneous fat is less than that of cattle. From first principles, the thermal insulation of goats would be estimated to be similar to that of red deer. The very high apparent cold tolerance (i.e. low LCT) of the high yielding dairy cow reflects her large food intake and thus high thermoneutral H_p. However this illustrates the point that LCT is not a sufficient descriptor of cold tolerance. Temperatures below 0°C reduce milk yield primarily via reduced blood flow to the udder.

Table 3.2 (from Webster, 1974) illustrates the extent to which variations in air movement, net radiation (solar and infrared) and precipitation can modify the sensation of cold experienced by a beef cow at a given air temperature. The data on which this summary table is based were derived from studies in Western Canada involving exposure of young beef cattle and a heat loss simulator (Moocow = Model ox observing cold outdoor environments: Webster, 1971). For this typical beef cow in still air conditions under a roof, overcast skies, or in thick forest cover, LCT is -13°C. If it could come out to get 8 h winter sun, even at low solar altitude (Clapperton *et al.*, 1965) but retire under a roof, or into a forest at night, LCT (averaged over 24 h) would fall to -21°C. If, on the other hand, it received 6 h solar gain during the day but had to stand out under a cloudless winter night sky when T_{re} can be 40°C below T_a (Swinbank, 1963), the increase in sensible heat loss would be equivalent to raising LCT to -6°C.

Table 3.2 also illustrates effects of wind and rain on heat loss. A wet windy day at +2°C is effectively as cold as a still, sunny day at -21°C. This much simplified table provides convincing evidence that a microclimate such as a forest, which can greatly reduce air movement , allow animals to stay reasonably dry, and provide shelter from excessively high infrared radiant

Table 3.2 Lower critical temperatures of a beef cow out of doors

	Wind ($m\ s^{-1}$)	Net radiation ($W\ m^{-2}$)	LCT (°C)
Dry, calm			
overcast	0.4	-10	-13
8 h sun	0.4	+63	-21
8 h sun, 16 h clear night	0.4	-68	-6
Dry, overcast, windy	4.5	-10	-3
Overcast, wind and rain	4.5	-10	+2

heat loss to the winter night sky, can practically eliminate cold stress for cattle and sheep that are adequately fed and so can sustain a normal thermoneutral metabolic rate. Pigs too would not be severely cold stressed provided that they could increase food intake to approximately 150 % of their thermoneutral requirement. This would obviously have greater resource costs than for cattle or sheep.

The biggest problem faced by grazing/browsing animals exposed to long, cold winters is not so much the acute severity of cold stress but the chronic duration of the period during which energy expenditure (for cold thermogenesis) is increased but food energy availability is reduced. One of the major determinants of an animal's ability to withstand the winter is the extent of its energy reserves laid down as fat by the end of the summer. Table 3.3 summarises data obtained at the Rowett Institute (Simpson *et al.*, 1978) to compare the fat and energy reserves of lambs, beef calves and red deer calves at the end of their first summer. Red deer typically carry much less fat than the other two species. Using classic rules for scaling energy metabolism according to metabolic body size, one can predict the extent to which the three species could withstand chronic, moderate cold exposure, namely when H_p is 20% greater than metabolisable energy requirement for maintenance at thermoneutrality. Table 3.3 shows that both cattle and sheep will normally go into winter with substantial energy reserves, whereas the red deer calf is quite unable to stand a prolonged period of cold weather. These figures provide a sufficient explanation for the general knowledge that winter mortality in deer calves can be very high on the Scottish moors.

Tables 3.2 and 3.3, taken together, also provide a partial explanation for the successful evolution of the red deer in the forest of northern Europe and the successful strategy of the North American caribou which migrates between the treeless Arctic tundra during the summer and the boreal forest (for food and shelter) during the winter.

Table 3.3 Fat and energy reserves of beef cattle, sheep and red deer at 8 months of age

	Cattle	Sheep	Red deer
Body weight (kg)	220	36	46
Body fat (kg)	30–40	4.4–5.2	0.5–1.9
Energy stored as fat (MJ)	900–1400	220–280	20–75
Energy reserve (days) when H = 1.2 ME maintenance	180–270	230–290	13–52

Monitoring effects of shelter on herbivores

Any realistic field study or computer model of the effects of tree shelter on the ecology of large grazing herbivores ('large'= too big to build nests) must provide quantitative information concerning the two critical questions defined at the outset. These are:

1. The extent to which shelter can modify heat loss by convection and radiation.

2. The extent to which grazing/browsing animals 'need' shelter.

In winter conditions the thermal demand of the environment is determined almost entirely by sensible heat loss. In these circumstances it is possible to integrate thermal demand using heat loss simulators which measure the heat required to maintain an object with dimensions and thermal insulation similar to the animal being simulated at a typical deep body temperature of 39°C. If air movement and air temperature are recorded at the same time, it is then possible to partition heat loss approximately according to convection and radiation (Webster, 1971; Webster *et al.*, 1993). This approach will not distinguish solar and infrared radiation but this is not a serious omission under Scottish conditions.

To estimate the extent to which grazing herbivores 'need' shelter it is necessary to estimate at least two of the three elements of energy exchange:

ME intake (I_{ME}) = Heat production (H_p) ± Energy retention (E_R)

There have been many attempts to devise acceptable, more or less dynamic methods for estimation of the energy expenditure of free ranging animals. These include (in approximate chronological order) measurement of heart rate, carbon dioxide entry rate, and the doubly labelled water technique (for review see McLean and Tobin, 1987). Telemetry of heart rate is unlikely ever to carry sufficient precision, although telemetry of cardiac output would inherently be as precise as any other technique because of the limited extent of variation in the oxygen carrying capacity of blood. The carbon dioxide entry rate (CERT: Sahlu *et al.*, 1988) and doubly labelled water techniques (Prentice, 1990) are satisfactory provided that animals are regularly accessible for administration of labels and collection of body fluids.

The theoretical attraction of telemetry of cardiac output or CERT is that the measurements are dynamic and can be correlated with recordings of thermal demand. However the real problems of the winter, thus the real benefits of shelter, are defined by the chronic effects on the ability of animals to sustain body condition. To investigate this it becomes more appropriate to use long-term integrative indicators of energy exchange, i.e. indicators of changes in body mass and energy, an approach already adopted with success by Wright and Russell (1984). If it is also possible to obtain long-term estimates of ME intake, e.g. using techniques developed by Dove and Mayes (1991), this is even better.

Much of this chapter has been based on studies carried out more than 20 years ago. They are none the worse for that. However, my final comment must be that many of the questions relating to the effects of tree shelter on the winter ecology of herbivores could be resolved for most practical purposes by 'research' in its most precise definition, i.e. 'looking again' at existing data, probably using the strength of new techniques for computer modelling. This should, at least, form the initial approach before embarking on expensive studies in the field.

References

Clapperton, J.L., Joyce, J.P. and Blaxter, K.L. (1965). Estimates of the contribution of solar radiation to the thermal exchanges of sheep at a latitude of 55° north. *Journal of Agricultural Science* **64**, 37-49.

Dove, H. and Mayes, R.W. (1991). The use of plant wax alkanes as marker substances in the nutrition of herbivores: a review. *Australian Journal of Agricultural Research* **42**, 913-952.

McLean, J.A. and Tobin, G. (1987). *Animal and human calorimetry*. Cambridge, Cambridge University Press.

McFarlane, W.V. (1968). Adaptation of ruminants to tropics and deserts. In: E.S.E. Hafez, ed. *Adaptation of domestic animals*. Lea & Febiger, Philadelphia, 164-183.

Prentice, A.M., ed. (1990). *The doubly-labelled water method of measuring energy expenditure.* International Atomic Energy Agency, Vienna.

Sahlu T., Jung, H.G., Nienaber, J.A. and Morris, J.G. (1988). Development and validation of a prediction equation estimating heat production by carbon dioxide entry rate technique. *Journal of Animal Science* **66**, 2036-2043.

Simpson, A. Webster, A.J.F., Smith, J.S. and Simpson, C.A. (1978). Energy and nitrogen metabolism of red deer *(Cervus elaphus)* in cold environments; a comparison with cattle and sheep. *Comparative Biochemistry and Physiology* **60**, 251-256.

Swinbank, W.C. (1963). Long wave radiation from clear skies. *Quarterly Journal of the Royal Meteorological Society* **89**, 339-348.

Webster, A.J.F. (1971). Prediction of heat losses from cattle exposed to cold outdoor environments. *Journal of Applied Physiology* **30**, 684-690.

Webster, A.J.F. (1974). Heat losses from cattle with particular emphasis on the effects of cold. In: J. Monteith and L.E. Mount, eds. *Heat losses from animals.* Butterworths, London, 205-231.

Webster, A.J.F. (1983). Nutrition and the thermal environment. In: J.A.F. Rook and P.C. Thomas, eds. *Nutritional physiology of farm animals.* Longman, London, 639-669.

Webster, A.J.F. (1995). *Animal welfare: a cool eye towards Eden.* Blackwell Scientific Publications, Oxford.

Webster, A.J.F, Tuddenham, A., Saville, C. and Scott, G. (1993). Thermal stresses on poultry in transit. *British Poultry Science* **34**, 267-277.

Wright, I.A. and Russell, A.J.F. (1984). Partition of fat, body composition and body condition score in mature cows. *Animal Production* **38**, 23-32.

Question and answer session

Graham Bell, Earthward

You mentioned this very wide band of thermoneutral comfort. Presumably as you move towards the extremities of that wide band the animal is either eating more food or it is consuming more of its own energy store?

Actually, the nature of thermal neutrality, which is not the same thing as thermal comfort, is that heat production does not alter. Rather, it is a straight line and that is because within that wide range the animal is able to maintain homeothermy by some slight manipulation in sensible heat loss by vasoconstriction, vasodilation, huddling and things of this nature, but much more by its extreme capacity to regulate evaporative heat loss.

Graham Bell, Earthward

So within that band it neither needs more food nor consumes its own body weight?

Exactly that. Of course, one wonders why is it that only relatively few species that have evolved this mechanism. Well, they are the big herbivores, the animals that are too big to make nests. Most animals adapt in a behavioural way. These animals we are talking about are too big to adapt in a behavioural way. They are the ones who have to slug it out and Darwinism has worked very nicely for them. They slug it out at minimal energy cost.

John King, West Linton, Peebleshire

The question of what we mean by shelter is important. I came to this meeting thinking that shelter meant protecting from prevailing wind and rain. Having listened now to your talk with great interest, I get the idea that it ought to be protection against the sky, as it were, the open sky. It is much more important to be able to creep under some cover and stop the radiation at night time than perhaps to actually be sheltering from the wind.

Not so much in Scotland but in Canada the effect of woodland shelter for things like the woodland caribou is far more through effect on radiant exchanges than it is through effect of precipitation, which is very minor. Just after I left Canada a group actually started rearing beef cattle in a forest on the Yukon river on the Arctic Circle and they had a controlled environment building. There was no significant difference in growth rate or food conversion efficiency between the two. You couldn't do it on the barren lands but there is a massive effect of a forest in ameliorating radiant exchange, and the ability of an animal to choose its micro-environment is hugely beneficial. There are good micro-environments for lambs on the Scottish moorland, where, if there is a straw bale or a tussock or something like that you'll often see the lamb lying upwind of the tussock and initially you think it strange. Then you realise it's exactly like a modern car; the wind goes over the top and comes in the back. It's much warmer upwind of the tussock than it is downwind, but the potential of forest to create a micro-environment is huge and the real message here is that radiant effects in a Canadian environment are more important than the effect of precipitation.

Alan Sibbald, MLURI

Presumably the effect on lower critical temperature of cold, wet, windy climates is on the insulating properties of the fleece. I draw your attention to our poster where we did a preliminary study of behaviour of sheep in an agroforestry area where trees are of wide spacing. We found that animals seem to move away from trees on wet days and move towards trees on dry windy days. Is that an attempt by the animal to avoid drips?

If it's wet and not windy and they're in full fleece, the rain will probably not penetrate the fleece, and actually if you have a little bit of rain one must consider the thermic reaction of the fleece. If you get a little bit of rain on the outside of the fleece it actually gets warmer. Goats will get out of the rain and again there are perfectly logical, physical reasons for that.

Alan Sibbald, MLURI

I was wondering if there's any evidence for your hypothesis?

I bet you they'll be motivated by thermal comfort. I'll go and look at your poster and maybe we'll come back to that in the afternoon, but I expect in both cases they are motivated by thermal comfort. A lot of dairy cows go outdoors at night, if they can, on a cold clear night. But when you realise what their metabolic rate is you're not likely to be surprised.

Alan Sibbald, MLURI

And they may not as I thought be avoiding big drips from canopies?

Well, that is a possibility because again big drips will penetrate the fleece, and the reason that cows in the rain stand with their backs into the rain and their heads down, is exactly the same reason as why when I'm in an oilskin in a boat I sit very still to stop the rain going down the back of my neck. It is minimising the penetration of the coat by big drips.

Ian Cunningham, retired chairman, MLURI Board of Management

I'm intrigued John. How do ptarmigan cope on the top of the Cairngorms in the winter time? Is it superb insulation or what?

Yes, and I'm not going to suggest wool for them. Pigs, for example, classically adapt to forests quite well and the outdoor pig does require more fat. It also requires pigmented skin to prevent sunburn and things of this nature, and the modern blue outdoor hybrids have more external fat and more insulation. You can argue that the most optimal welfare strategies for pigs compatible with production of lean meat are that you have your female hybrids with more fat and pigmented skin but then you actually give growth promoters to their offspring in order to get the leanness back into the growth generation. With a sufficient degree of fat and an energy reserve they exist quite well. The capacity of pigs to adapt to cold is actually mind-boggling provided they are allowed to, and much of this adaptation comes back to a time when it's in peripheral circulation and not vasoconstriction. It's cold-induced vasodilation to stop freezing. I was called out by nutritionists who thought there was a nutritional problem in some pigs in Canada. The air temperature was -45°C there were 16 pigs; I picked up 13 claws which had fallen off because of frostbite and 11 of the pigs had saddled frostbite across their backs. It was a grotesque piece of welfare abuse, and they were outdoors with a hut but going outside at -45°C. In the next pen were another 16 pigs in which there wasn't a single case of frostbite, although the temperature and environment were the same.

The pigs with frostbite had been weaned 5 days before the weather turned cold so they'd only been active 3 days before the weather changed and their feet started dropping off. The others had been out for 16 days. In that 16 days their peripheral circulation had adapted to the point where none of them got frostbite.

John Milne, MLURI

I would like to follow-up your suggested idea that animals seek thermal comfort. Now in terms of trying to keep warm, would they actually eat more and therefore leave shelter to go and eat more, or alternatively go and seek shelter and eat less?

There are two responses to the problem of being cold. There is the stoic response and there is the hedonic response. If there's food aplenty you can go for the hedonic response where you eat a huge amount and you keep warm. The Eskimo is a classic example of that. He eats huge amounts of food and so has enough energy to keep warm and allow his bare fingers to hold ice, and fish in the snow. Classically the Australian aborigines or the Tierra del Fuego Indians went for the true stoic response. They would sit around and conserve energy. Keeping warm is a comfort thing and conserving energy is a survival thing. In our deer in the early days we had some fairly good evidence that the deer were adopting one or other strategy; if they were reasonably well covered they went for a hedonic response, their tissue insulation was low and the heat production was high; if they were very thin then the tissue insulation went up because they were conserving energy and the heat loss was lower. I genuinely believe that in outwintered animals you will see either response. Either you burn up the fuel or you put on more clothes and huddle. Those are the two strategies. If they can they would like to use the high fuel strategy and so would we. That can be modelled too.

Chapter 4

Shelter and wildlife

Michael Usher

Summary

The axiom 'trees are good for wildlife' is analysed at three hierarchical scales: the tree, the woodland and the landscape. The species of tree used to provide shelter is important in its potential to support species-rich assemblages of arthropods. Consideration of the size of woodlands in agricultural landscapes indicates that they should be larger rather than smaller, more compact rather than long and thin, surrounded by 'stepping stones' of habitat fragments and, where possible, incorporate habitat fragments. Riparian zones have a special role to play. Mosaic landscapes are visually attractive, and appear to be capable of supporting a considerable species richness, though larger blocks in the mosaic are required to support characteristic woodland species.

Introduction

Trees are good for wildlife. This tends to be taken as axiomatic, but as a statement it leads to many other questions. Are all trees good? Are there benefits for all wildlife? Is it true in all locations, lowland or upland, on acidic or basic soils, etc? These are the sorts of questions that need to be asked if the countryside, and not just protected areas, is to contribute to the conservation of Britain's biodiversity. The Countryside Commission's Demonstration Farms Project in England and Wales (Matthews, 1987) investigated the non-farmed parts of agricultural land – ponds, wetlands, woodlands, hedgerows, unimproved pasture and heather. The case studies of woodlands point to a variety of benefits: tangibly to the wildlife and, less tangibly, to the landscape. There seems, therefore, to be truth in the axiom that 'trees are good for wildlife', at least as far as trees in an agricultural setting are concerned.

The aim of this chapter is to explore aspects of shelter, wildlife and landscape at three hierarchical levels:

- the tree
- the woodland
- the landscape.

Individual trees provide food and shelter for animal, plant and microbial life. The woodland affects the local climate, providing a structured environment for wildlife. The mosaic of trees, woodlands, fields, streams and other features provides a landscape within which the wildlife lives and moves. The next three sections look at these three levels in the hierarchy.

The tree

The classic paper by Southwood (1961) indicates that the actual species of tree is important. Some species support very few species of invertebrates, whereas others, such as oak (*Quercus* spp.), willow (*Salix* spp.) and birch (*Betula* spp.), support large numbers of species (Table 4.1). Although there are few general rules that have predictive power, the one that is often accepted is that native tree species support more species of invertebrates than non-native tree species. This rule is not universally true as lime, hornbeam and holly support fewer insects than some non-native coniferous species, for example spruce.

Table 4.1 The number of insect species associated with forest trees in Britain (data from Southwood, 1961)

Tree species	Number of insect species
Abies: fir	16
Alnus: alder	90
Betula: birch	229
Carpinus: hornbeam	28
Corylus: hazel	73
Crataegus: hawthorn	149
Fagus: beech	64
Fraxinus: ash	41
Ilex: holly	7
Larix: larch	17
Malus: apple	93
Populus: poplar	97
Picea: spruce	37
Pinus: pine	91
Quercus: oak	284
Salix: willow	266
Tilia: lime	31
Ulmus: elm	82

The number of phytophagous invertebrates is not necessarily the best indicator of wildlife. For animals that are less specialised feeders, does it matter if the insect food comprises many individuals of one or two species, or few individuals of many species, provided that there are sufficient prey items to sustain the predator and its family? A number of research questions have direct relevance to biodiversity considerations, for example:

- Do native tree species support a richer bird community than non-native species?
- Are there differences in the soil and litter fauna (and microbial assemblages) under native and non-native tree species?
- How does the management of an individual tree affect its ability to support a diverse fauna?

Trees provide structure to the environment. One of the features of the bird surveys associated with the Demonstration Farms Project (Matthews, 1987) was the location of bird territories. For many of the farmland birds, e.g. blackbird and dunnock, the hedgerows provided a focus for their territories. However, small woodlands had a much greater density of territories, and also a greater range of species, including great tit, blue tit and tree sparrow. The hypothesis is that the structural diversity of trees and shrubs is an important feature of woodlands, copses, shelterbelts and hedgerows, leading to a greater diversity of wildlife.

It is perhaps too often uncritically assumed that structural diversity is important. It is easy to advocate it, as does Goldstein-Golding (1991), without proving its effectiveness. Intuitively it seems correct, and certainly the censusing of birds on farmland tends to indicate that intuition is appropriate. However, if we are asking questions for which research measures are needed, perhaps woodland and shelterbelt structures need to be considered. The following kinds of questions could provide a starting point for further research.

1. Do woods of different tree species, or mixtures of tree species (or tree and shrub species), have different wildlife assemblages?

2. How does the wildlife in hedgerow trees, woods or shelterbelts change as the trees age?

3. How is the diversity of wildlife, or particular groups of wildlife (e.g. birds or butterflies), related to the structural complexity of woodlands and shelterbelts?

All of these questions are tree-centred. The species of tree, its age, its management, and the presence of the other tree or shrub species are all important. Intuitively it seems as if the locally native species are likely to host the greatest number of herbivorous invertebrates, but does this relationship hold for all groups of wildlife, the thousands of species in the soil, the plants that provide ground cover, and the vertebrates that are more capable than the invertebrates of moving around the countryside?

The woodland

A large number of questions were addressed in the Farm Forestry Research Programme (Parr, 1992), which ran from 1988 to 1992. A wealth of information was collected on a variety of groups of wild animals and plants, but unfortunately

Table 4.2 Equations derived for multiple regression analyses of species richness (S) as a function of the number of individuals caught (N), woodland area (A), woodland isolation (I) and woodland shape (H). Only those coefficients that were significant are included (from Usher *et al.*, 1993)

Taxon	**Equation**	$F_{2,25}$	**Probability (p)**
All ground beetles	$S = -1.07 + 2.43 \ln N + 2.99 H$	18.30	<0.001
Woodland ground beetles	$S = 3.11 + 0.68 \ln N + 0.43 \ln A$	7.72	<0.01
Spiders	$S = -7.60 + 6.86 \ln N - 1.59 I$	9.42	<0.001

these studies were geographically separated and hence it is difficult to determine patterns that can be generally true of different types of woodland, in different geographical locations, and for the different groups of species that have been investigated. A broadly based and interdisciplinary study on a single set of woodlands may have allowed for general patterns to be discovered, but this would have required a large, multidisciplinary research team.

Studies in the Vale of York aimed to investigate a variety of wildlife groups. For the herbaceous plants in a series of over 30 farm woodlands, there was the expected species–area relationship (Usher *et al.*, 1992). Woodlands of 0.1 ha had an average of about 13 species, while for woodlands of 1 and 10 ha this increased to about 25 and 48 species respectively. The most surprising finding of this study was that neither species richness nor the approximate doubling of the number of species with a 10-fold increase in area was influenced by the type of woodland – deciduous, coniferous or mixed. The sample farm woodlands used were all between 20 and 90 years of age, which was not apparently a factor affecting species richness.

In the litter layer of these woodlands, pitfall traps were used to trap the ground beetles (Carabidae) and spiders. Although ever-lengthening the trapping period tends to increase the number of species caught, the trapping was designed to avoid this problem by having constant effort (Usher *et al.*, 1993). Trapping yielded 4422 ground beetles of 47 species and 3476 spiders of 97 species. In all cases the number of species was positively related to the number of individuals trapped (an expected result), but it is also instructive to look at other variables that influenced species richness (Table 4.2). For the ground beetles, the shape of the woodland was important; long, thin shelterbelts had more species than more rounded woods. Was this due to the fact that shelterbelts 'trap' insects moving across an agricultural environment? If the subset of woodland ground beetles, as defined in the habitat descriptions by Lindroth (1974), was analysed, shape was no longer important, but area was; larger woodlands have larger numbers of woodland species, a result similar to that for plants. For spiders, neither shape nor size appeared to be important, but isolation from other woodland blocks decreased the numbers of spider species. It was not possible to determine a subset of woodland spiders, and hence it remains an open question as to whether there would be more species in larger woods.

Studies across these farm woodland boundaries have indicated interesting effects on species richness. Bedford and Usher (1994) indicated that species richness of both ground beetles and spiders was greater near the margin of the two farm woodlands that they studied. This increase in species richness near woodland margins has also been demonstrated by Downie *et al.* (1996) for grass pasture/coniferous woodland transitions in the north of England. Despite these results for litter and surface dwelling arthropods, there is a different pattern for the soil arthropods. Sgardelis and Usher (1994) showed that there were few species (5-10) of Cryptostigmata (moss mites) in an arable field, but that within 1 m of the boundary to a shelterbelt this number had increased to over 30 species, a diversity that was maintained in samples across the shelterbelt. It is possible that soil disturbance and the use of agrochemicals had adversely affected the species richness of mites in the arable field, but the relatively uniform species richness and diversity index across the shelterbelt (from within 1 m of its boundary) indicates the importance of even narrow shelterbelts for the soil fauna.

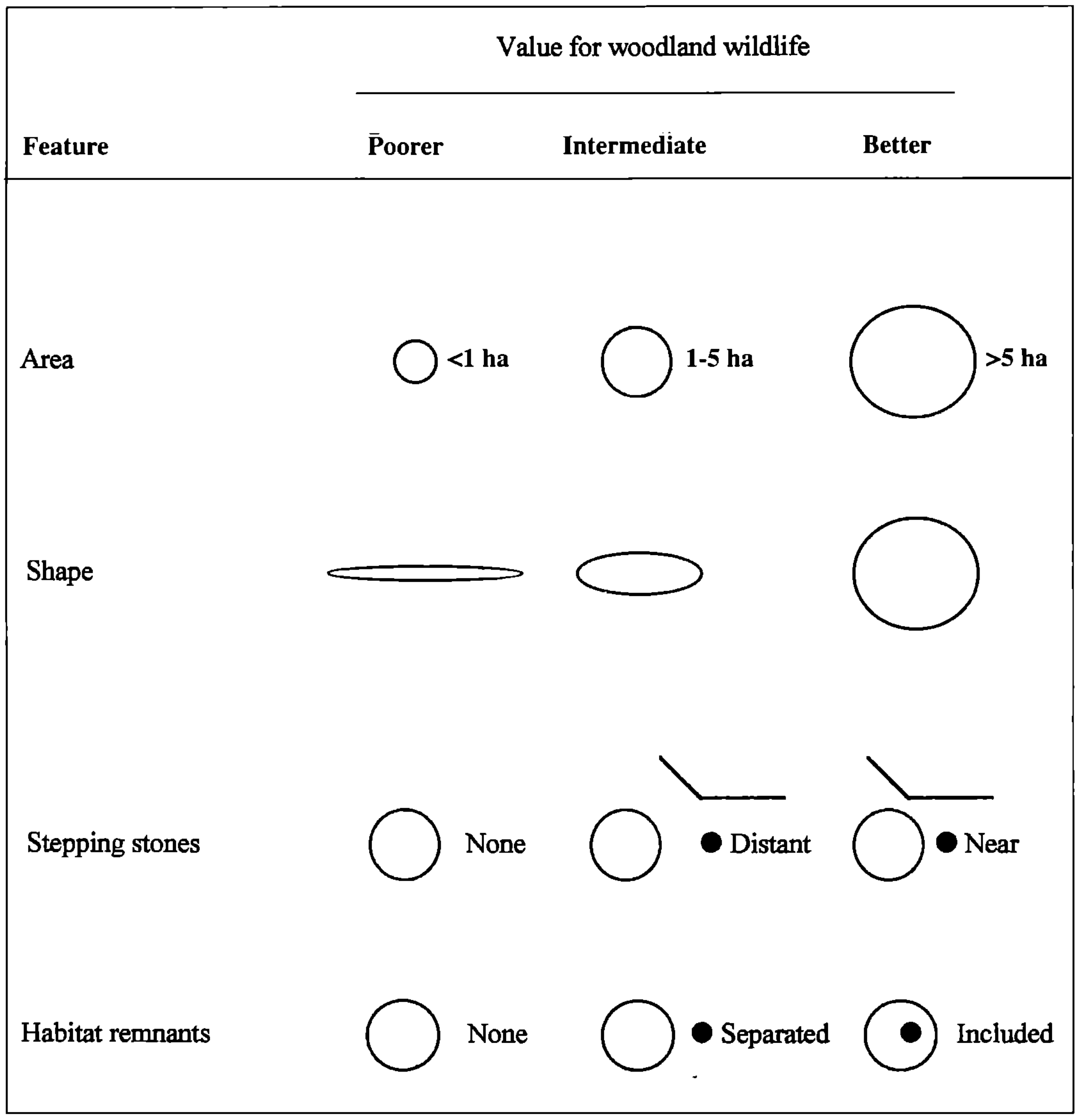

Figure 4.1 Tentative proposals for the design of farm woodlands that will increase the diversity of woodland arthropod species. Habitat remnants are shown as small black circles, and hedgerows by lines (adapted from Usher, 1995)

Such studies have led Usher (1995) to put forward tentative proposals for the design of farm woodlands (see Figure 4.1), assuming that the woodland wildlife value should be maximised. Four 'rules' are:

- The larger the better.
- The more compact the better.
- The more 'stepping stones' in the landscape the better.
- The more habitat remnants incorporated the better.

These concepts need more thorough testing, but they do provide initial guidance when new shelterbelts or farm woodlands are being planned. There may be a fifth 'rule', that one woodland should not be over-isolated from other woodlands, but there is less evidence to support this, and no evidence to suggest what the maximum separation should be.

The landscape

In a sense, the 'rules' shown in Figure 4.1 move from the wood itself to the position of the wood in the landscape. Many species of wildlife use many of the components of the landscape, whether they are woods, hedges, fields, or streams. The study by Zhang and Usher (1991) of wood mice and bank voles demonstrated the ability of these species to move large distances within the mosaic environment of lowland Britain. Shelter is important for this movement, with hedgerows being the main conduit of small mammals from one woodland to another. Plenty of other studies, such as that by FitzGibbon (1993) on grey squirrels, have shown the importance of the juxtaposition of woodlands and potential corridors within agricultural landscapes. Although it is difficult to prove that invertebrate animals use these corridors, there is now ample evidence both in the UK and Australia (see Saunders and Hobbs, 1991) to demonstrate that vertebrate animals are common users of corridors.

As well as woody vegetation in the landscape, there are also streams, which are commonly associated with the development of trees and shrubs in the riparian zone. There is increasing interest in this zone, not just as a buffer against pollution in the water, but also as part of the 'health' of fish stocks, especially salmonids. For example, the Tweed Foundation (Glen, 1995) are advocating active management of river and stream margins, focusing on these being 'planted up with a mixture of mature broadleaf trees, concentrating on various species of willow close to the water's edge'. Besides the stabilisation of banks and the eventual re-creation of deeper water, these bankside woodlands/scrublands are said to provide 'fish with shelter from predators and a large amount of insect food falling from leaves which themselves provide food for stream invertebrates'. The importance of dead wood within rivers and streams must also not be forgotten (Gregory *et al.*, 1995).

Such research has now been incorporated into guidelines (Forestry Commission, 1993), which include eight clear messages:

- Establish some broadleaf trees near watercourses.
- Maintain about half the stream surface in sunlight, the rest in dapple shade.
- Stop cultivation well short of watercourses.
- Do not plough unnecessarily.
- Maintain protective unplanted strips (buffers).
- Keep 'slash' out of the stream and the riparian zone.
- Stack timber away from the riparian zone.
- Design streamside edges in harmony with the landscape.

Again, it is a kind of mosaic structure that is being created, with both broadleaf species and open areas beside the streams. Indeed many of the 20th century landscapes are based on mosaics, which inevitably have large numbers of edges or boundaries. Are these artificially increasing the overall species richness of the countryside? Alternatively, are species that require large tracts of similar habitat being disadvantaged by the more generalist species that can survive in a variety of habitat types or along the edges?

Discussion

Can the axiom that 'trees are good for wildlife' be maintained? Most, if not all, studies indicate that the introduction of woody vegetation into a landscape without trees is going to increase the species richness of that landscape. However, there are some landscapes which, by their very open nature, may not benefit from this increased species richness. This may be true of peatlands, coastal areas, etc., where trees are unlikely to be a natural feature, and the species of these environments may decline if forests or woodlands are planted.

However, trees for shelter are most likely to be considered in urban environments or agricultural landscapes which, before the advent of agriculture, were likely to have carried woodland. If the visual appearance of those landscapes is to be enhanced then low density planting (or regeneration) is required with a well-dispersed tree cover. If the woodland wildlife value of those landscapes is to be enhanced, then what is required is small (>0.5 ha) to medium (>5.0 ha) blocks of woodland, with appropriate interconnections. At first glance these two requirements might not seem compatible.

The available evidence suggests that the axiom is true. The presence of trees in an agricultural landscape does have the capacity to enhance species richness. If woodland species are required, a real woodland environment has to be created, which means blocks of more than 5 ha in extent are required. These may not contribute greatly to the visual appearance of that landscape, which is improved by a more diffuse pattern of trees. However, these diffuse trees, or small groups of trees, can act as 'stepping stones' for wildlife species, especially when they are integrated with linear features, such as hedgerows and streamside plantings. Does this mean that, to achieve both wildlife and landscape objectives, blocks of woodland *and* diffuse planting of trees is required?

The evidence is still patchy and is derived from the examination of existing woods. Ecological research really requires a more experimental approach, monitoring the development of patches of woodland and the speed with which they recruit both generalist and woodland species. The kind of techniques used by Simberloff and Wilson (1969), monitoring the colonisation of empty 'islands', and those of Margules (1992) in creating islands' from pre-existing forests, are potential research tools. Landscape research will need to explore the perceptions of people living in or using the countryside, exploring the ways that trees contribute to the visual attractiveness of an area in which to live, or the desirability of an area in which outdoor recreation is appealing. Economic research can focus on the balance sheet of ecological and social benefits of a diverse environment, while looking at the costs associated with its creation and the possible loss of agricultural production. All of these ideas lead to interdisciplinary and multidisciplinary research. On the ground we have created mosaics: the 20th century landscape. Is this what future generations will thank us for?

References

Bedford, S.E. and Usher, M.B. (1994). Distribution of arthropod species across the margins of farm woodlands. *Agriculture, Ecosystems and Environment* **48**, 295-305.

Downie, I.S., Coulson, J.C. and Butterfield, J.E.L. (1996). Distribution and dynamics of surface-dwelling spiders across a pasture-plantation ecotone. *Ecography* **19**, 29-40.

FitzGibbon, C.D. (1993). The distribution of grey squirrel dreys in farm woodland: the influence of wood area, isolation and management. *Journal of Applied Ecology* **30**, 736-742.

Forestry Commission (1993). *Forests and water guidelines*, 3rd edition. HMSO, London.

Glen, D. (1995). Spawning habitat – the fences go up. *Tweed Foundation Newsletter* **11**, 2.

Goldstein-Golding, E.L. (1991). The ecology and structure of urban greenspaces. In: S.S. Bell, E.D. McCoy and H.R. Mushinsky, eds. *Habitat structure: the physical arrangement of objects in space.* Chapman and Hall, London, 392-411.

Gregory, K.J., Gurnell, A.M. and Petts, G.E. (1995). The role of dead wood in aquatic habitats in forests. In: I.R. Brown, ed. *Forests and water.* Institute of Chartered Foresters, Edinburgh, 158-193.

Lindroth, C.H. (1974). *Handbook for the identification of British insects. Coleoptera, Carabidae.* Royal Entomological Society, London.

Margules, C.R. (1992). The Wog Wog habitat fragmentation experiment. *Environmental Conservation* **19**, 316-325.

Matthews, R., ed. (1987). *Conservation monitoring and management: a report on the monitoring and management of wildlife habitats on demonstration farms.* Countryside Commission, Cheltenham.

Parr, T.W., ed. (1992). *Farm forestry research.* Research Information Note No. 225. Forestry Commission, Farnham, Surrey.

Saunders, D.A. and Hobbs, R.J., eds. (1991). *Nature conservation 2. The role of corridors.* Surrey Beatty, Chipping Norton, New South Wales, Australia.

Sgardelis, S.P. and Usher, M.B. (1994). Responses of soil Cryptostigmata across the boundary between a farm woodland and an arable field. *Pedobiologia* **38**, 36-49.

Simberloff, D.S. and Wilson, E.O. (1969). Experimental zoogeography of islands. The colonization of empty islands. *Ecology* **50**, 278-296.

Southwood, T.R.E. (1961). The number of species of insect associated with various trees. *Journal of Animal Ecology* **30**, 1-8.

Usher, M.B. (1995). A world of change: land-use patterns and arthropod communities. In: R. Harrington and N.E. Stork, eds. *Insects in a changing environment.* Academic Press, London, 371-397.

Usher, M.B., Brown, A.C. and Bedford, S.E. (1992). Plant species richness in farm woodlands. *Forestry* **65**, 1-13.

Usher, M.B., Field, J.P. and Bedford, S.E. (1993). Biogeography and diversity of ground-dwelling arthropods in farm woodlands. *Biodiversity Letters* **1**, 59-62.

Zhang, Z. and Usher, M.B. (1991). Dispersal of wood mice and bank voles in an agricultural landscape. *Acta Theriologica* **36**, 239-245.

Question and answer session

David Clarke, David Clarke Associates

In reviewing the literature we found conflicting suggestions on the question of whether sheltering should connect patches of woodland. The biodiversity argument suggests that this will create wildlife corridors but elsewhere we had suggestions that this would create opportunity for diseases and pests to spread. What is your opinion of these two points of view?

This is a very difficult question. The Australians have probably done more work than anyone on wildlife corridors in the wheat belt of Western Australia. They are very concerned about corridors allowing invasive species to move into remnants of semi-natural vegetation. We do know that many species move very slowly along corridors and it is well proven for small mammals and for some of the larger mammals that they move around the landscape by using these corridors. This is true of shrews which we have released by traps and recaptured 300 m along the hedgerow. They certainly move around. Yet if you take a bank vole it won't go more than about 5 m beyond the hedge because it's balancing the risks of predation against access to food. I think much much less is proven for anything other than vertebrates. If you look at George Peterken's ideas of the movements of woodland plants it was reckoned that they move only centimetres a year along hedges. My overall feeling is that very little is proven on the value of corridors but much more is proven about the value of the remnants of semi-natural vegetation still harbouring native species. These species can then expand into environments after you create them around the remnant.

Ian Wright, MLURI

You showed for several groups a positive relationship between the area of woodland and the number of species present. To what extent is that a sort of functional relationship because the bigger the area you sample the more species you are bound to find?

I think there is something in what you say. When I'm working with insects I always include the total number of individuals because we know that the bigger the number of individuals the greater the number of species. The regression for number of species is a function of the number of individuals plus, in the case of the woodland ground beetles, a function also of the area. With spiders area is no longer important but rather the number of species is a negative function of the wood's isolation. I guess that spiders, which don't have wings, have that much more difficulty moving from wood to wood than some of these ground beetles, most of which are alate and can fly.

Jeff Maxwell, MLURI

Did you incorporate any analysis of woodland age in that set of data you showed us?

Yes, but we didn't find an effect, which surprised me. All the woods were between 20 and 90 years old, so far as we knew, but age is a difficult thing to be precise about because people hadn't got records of when the woods were planted and age was usually inferred from different editions of OS maps.

John Blyth, University of Edinburgh

The low numbers of insects on holly intrigues me. Is that more to do with its shade tolerance or to its leaf chemistry and structure?

This is an interesting point. A lot of people, including Sir Richard Southwood himself, put it down to the chemistry of the species. Holly and yew make sense from this point of view but the species that really is surprising is hazel because the hazel is in the group of trees with birches, oaks and beeches which have large numbers of insect species. On any rational basis I would have expected hazel to have a lot of species. But the point you made about shade tolerance and the fact that hazel is growing under the canopy is a good one and one I hadn't thought of, although we do know that the dwarf shrub, *Vaccinium myrtillus*, often growing in considerable shade, has a very species-rich fauna associated with it.

Chapter 5

The economics of shelter provision on farms

John Blyth

Summary

The economic benefit of tree shelter on British farms is generally perceived as 'not proven'. Early 20th century research in North America and Russia indicated substantial benefits but examples of systematic shelter provision in Britain established in that period are now often neglected. An economic assessment of four contrasting farm types suggests that tree shelter can be a viable proposition, particularly on better land. Reasons for the current lack of interest include poorly focused management objectives and cultural heritage which still divides farming and forestry interests. Further investigation is recommended with regard to productivity, design, grant aid, amenity/conservation value and area coordination aspects.

Introduction

The physical influence of shelter is related to changes in microclimate, of both soil and atmosphere; important factors include light, temperature, moisture and gas exchange. The economic influence of shelter on farms is related to land resource allocation by individual farmers based on comparative costs and benefits of different farming systems (with and without shelter) and the capital value of farm property. If suitably planned in an appropriate locality, it may extend to benefit the whole rural economy. Early 20th century data from North America, Russia and Europe reviewed by Caborn (1957) record yield increases in the order of 10-20% for root crops, cereals and grass as a result of shelter (Figure 5.1). In terms of quantity, yield increases exceeded reductions (due to land occupied by shelter trees and edge effects) by a factor of about four (Andersen, 1943).

Other factors influenced by shelter include:

Crop quality	• e.g. raspberries in Fife, kiwi fruit in New Zealand
Grazing quality	• pasture composition
Timing of production	• extension of growing season and earlier ripening
	• an 'early bite' valuable to lambing ewes
	• extended grazing on uplands conserving lower fields for winter fodder
Health	• disease resistance of crops and livestock
Miscellaneous	• reduced losses from soil erosion
	• reduced losses in occasional very bad weather conditions.

The general conclusion from early research was that net agricultural productivity is increased if shelter is incorporated into farming systems. This still leaves the question: 'Is the value of increased production greater than the cost of providing shelter?'

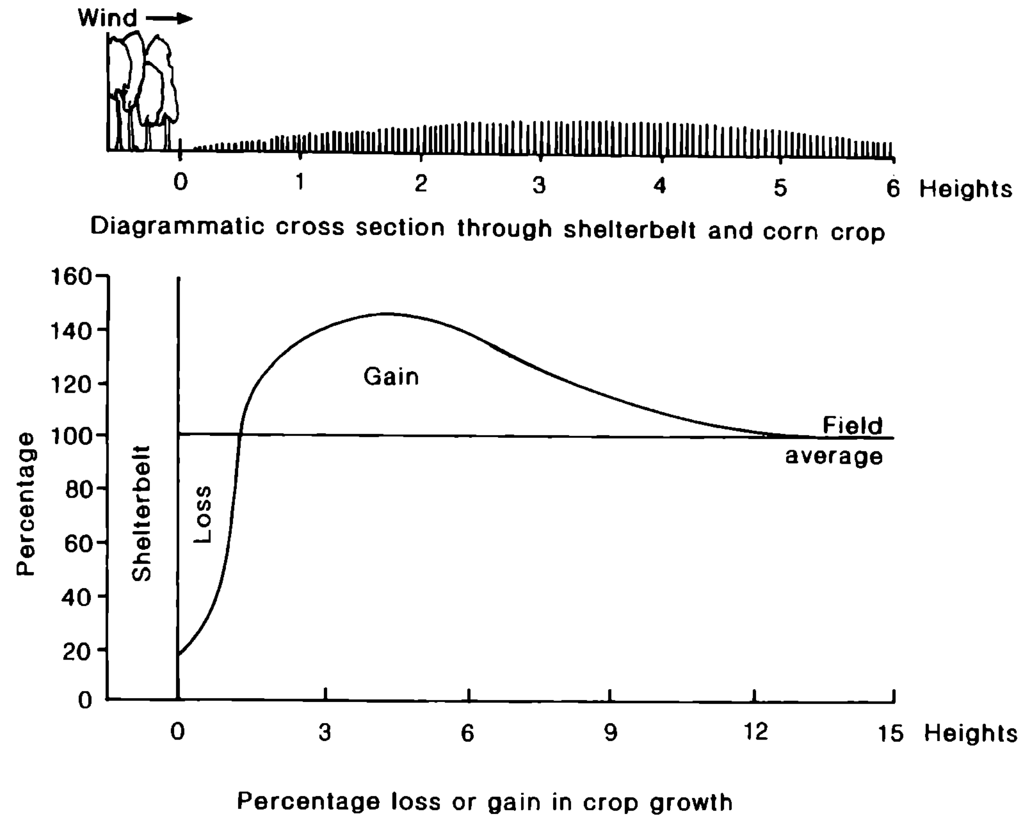

Figure 5.1 Effect of a shelterbelt on crop yields (after Bates, in Caborn, 1957). The distances given below each diagram (0–6 and 0–15) are multiples of shelterbelt height

Background – UK

British site conditions are typically more variable than the areas used for early research including, importantly, wind direction. A general statement as above is therefore 'not proven' although considered opinions generally agree that benefits of shelter can exceed costs in specific locations. A positive benefit/cost relationship may be enhanced where substantial areas of land are managed for shelter in a consistent way (as originally planned near West Calder, Central Scotland, for example). Such planned landscapes involving, for example, systematic shelterbelt patterns established in the 19th century have generally become neglected and thus unable to demonstrate their shelter value to agricultural production as distinct from amenity, sport and conservation values. The latter were given higher priority than shelter by farmers joining the Farm Woodland Scheme in Scotland (Appleton and Crabtree, 1991).

A contributory factor in the neglect of existing shelterbelts has been their management for multiple objectives. This has resulted in poor achievement of any single objective; for example, tree belts have been wider than necessary for shelter provision to accommodate sporting interests. Conversely, narrower tree strips designed primarily for shelter may be too narrow to attract Forestry Commission grants. Another factor contributing to shelterbelt neglect has been the cultural heritage of conflict between agriculture and forestry (Mutch and Hutchison, 1980). Current developments are aimed at reconciliation and partnership but it is worth noting that a recent Scottish Office White Paper (HMSO, 1995) makes no mention of the value of tree shelter to agricultural production.

Types and effects of tree shelter

The main types of tree shelter are listed in Table 5.1, with an outline of shelter effects – both positive and negative – on crops and livestock. In any evaluation it is essential to identify the disadvantages of trees for shelter, as well as their benefits.

In addition to trees and woodland designed primarily to afford shelter it should be noted that woodland blocks (area 0.5 ha – 5 ha), located for optimum benefit to agricultural and forestry components in an integrated land use system, can benefit crops, livestock, property and people. In such a situation, shelter is a secondary objective included along with amenity, conservation, sport and timber (as at Glenlivet in the Scottish Highlands, for example).

Financial implications

Most of the factors generating costs and benefits of tree shelter on farms have already been identified in Table 5.1. The accuracy of specific costings and values is always open to criticism: it is more important to ensure their relative accuracy and to consider the effects of possible changes in input costs and output values. This is particularly important in the context of land resource management generally where individual owner's circumstances vary so much that general statements can be misleading.

In Table 5.2 an attempt is made to compare the costs and benefits of shelter in financial terms for four contrasting farm types. In each case it is assumed that shelter trees occupy 5% of the land area: this figure is based on a tree belt system with 5-10 m wide belts spaced 300 m apart (approximately 15-20 times mature tree height) and includes allowance for a

Table 5.1 Tree shelter on farms: main types and effects

Types of shelter	Effects of shelter	
	positive	negative
Crops		
tree belts (width ≤ 5 m)	yield quality	edge competition, crop damage from turbulence, lodging, woody debris
field boundary trees	harvest period	varies across field
hedgerow intercropping (silvoarable agroforestry)	health/vigour crop pest predators	pests and pathogens
Livestock		
tree belts (width 5-10 m)	improved survival of newborn lambs	increased management input required
woodland blocks (area 0.5 - 5 ha)	shelter from different wind directions	'poaching'
severe weather shelter *within* open woodland or well-thinned plantation	reduced feed and/or conserved forage (grazing rent)	damage to trees
	health	insect pests, e.g. flies
widely spaced trees or tree groups (silvopastoral agroforestry)	grazing quality live weight gain	reduced visibility for shepherd

Table 5.2 Estimated financial implications of tree shelter on farms

Farm example		**Annual gross margin** [a]		**Tree shelter value** [b] **+10% productivity**	**Area of tree shelter**	**Annual cost of maintaining tree shelter** [c]		**Changes in agricultural income due to land re-allocation**	
Type	area (ha)	£ $ewe^{-1}yr^{-1}$	£ ha^{-1} yr^{-1} (A)	£ ha^{-1} yr^{-1}	ha (B)	£ ha^{-1} (woodland) yr^{-1}	£ ha^{-1} (farmland) yr^{-1}	Agricultural revenue foregone £ yr^{-1} (A) x (B)	Farm value of additional productivity £ yr^{-1} [d]
Hill sheep (1000 ewes)	5 000	40	8	0.8	250	10	0.5	2 000	3 800
Upland	500	60	120	12	50	20	2	6 000	5 400
Lowland (arable or livestock)	200		600	60	10	30 + (30 to 70)	5(10)	6 000	11 400
Lowland (raspberries)	50		2 900	290	2.5	40 + (40)	4(8)	7 250	13 775

[a] *Farm management handbook* (Scottish Agricultural College, 1995).

[b] Increased productivity and reduced costs are combined in this value since it is based on a gross margin.

[c] *For hill and upland farms* it is assumed that planting grants equal establishment costs, i.e. annual costs of tree shelter represent maintenance only (FWPS payments would provide net income). *For lowland farms* it is assumed that planting grants are not available: tree belts are too narrow for Forestry Commission grants and the new Scottish Countryside Premium Scheme does not include grants for tree shelter. The figures in parentheses are estimated additional establishment costs (annuitised at 5%): the range of establishment costs in lowland farms relates to whether or not fencing is required.

[d] Calculated by multiplying the total farm area, *minus* the woodland area, by the marginal additional value of tree shelter.

Note No allowance has been made for *capital value*: any reduction in land value due to planting agricultural land might be considered balanced by the increased value (about 5%) of farms including managed woodland.

'one-height' zone immediately adjacent to the belt where crop yields are significantly reduced. Agricultural gross margins are taken from the *Farm management handbook* (Scottish Agricultural College, 1995). Tree costings are based on personal experience at Edinburgh University's Bush Woodlands: it is worth noting that unit costs may be lower for purpose-designed shelterbelts than for farm woodlands in general (particularly on lowland farms) because of better access and greater mechanisation, including the use of farm machinery.

The figures suggest an increasing level of financial benefit from tree shelter on farms as land quality improves from hill to lowland enterprises. In *hill farms*, both costs and benefits are relatively small, and benefits are estimated to exceed costs by a total of £1800 on a 5000 ha farm: this sum is so small that it can be concluded that the decision to have a woodland component is unlikely to be made on an economic analysis of the direct costs and benefits of shelter provision. In *lowland farms*, however, the financial value of tree shelter clearly exceeds the direct cost of providing it despite the lack of grant aid for tree planting. Losses and gains in agricultural income due to change in land use appear to balance at approximately a 5% productivity increase.

For *upland farms* costs and benefits figures are intermediate; in the example given in Table 5.2, the provision of shelter results in a marginal cost to the farm. This result concurs with a financial assessment of silvopastoral proposals for the lower slopes of the Pentland Hills (Kittel and Blyth, 1997), which shows the current upland farming system to be more viable than an agroforestry alternative (19% higher NPV at 4% discount rate). The findings also broadly agree with those of a SAC Report on the potential financial effects of woodland planting on a typical livestock farm in Central Scotland (McLean *et al.*, 1989) which indicated little change in long-term profitability with a 5% woodland component.

In conclusion, the estimates of net financial benefit appear to support the use of shelter on farms, particularly on better land. Since farmers are of necessity economically aware individuals, why have they neglected or removed tree shelter in recent decades? Conflicting objectives and cultural heritage have already been mentioned as possible reasons; two factors which have not been considered in this assessment are the potential reduction in operational costs from field enlargement and the time lag after tree planting for shelter benefit to develop. With current changes in public perception and Government policy concerning the management of our land resource, perhaps it is time to reassess the value of tree shelter on farms. Suggestions for further research are listed below.

Suggestions for further research

1. The productivity benefits of shelter, for both crops and livestock: higher potential returns favour priority consideration of lowland enterprises such as soft fruit.

2. Optimal design of tree shelter on farms with respect to enhanced productivity (quantity and quality) and cost effectiveness.

3. The sensitivity of farmers' choice to provide tree shelter on farms to grants and subsidies for both agriculture and forestry. Would other types of incentive be more acceptable?

4. Recreation, amenity and conservation values (or disbenefits) of shelter trees on farms.

5. The potential cumulative effect of coordinated shelter planting in a given area (as compared with individual farms, or fields). Due to the range of interacting factors involved a modelling approach would be valuable.

6. The apparently 'missing link' between physiological research and management practice.

References

Andersen, P.Chr. (1943). *Laeplantnings-Bogen*, 5th edition. Danish Heath Society, Viborg.

Appleton, Z. and Crabtree, R. (1991). *The Farm Woodland Scheme in Scotland - an economic appraisal.* SAC Economic Report No. 27.

Caborn, J.M. (1957). *Shelterbelts and microclimate.* Forestry Commission Bulletin 29. HMSO, London.

HMSO (1995). *Rural Scotland: people, prosperity and partnership.* Scottish Office White Paper.

Kittel, W. and Blyth J. (1997). An assessment of silvopastoral proposals in the Pentland Hills. *Scottish Forestry* (in press).

McLean, J., Palmer, H., Somerville, S. and Todd, E. (1989). *The potential financial effects upon a typical livestock farm within the core area of the Central Scotland woodlands area of different levels of woodland planting.* SAC Report.

Mutch, W.E.S. and Hutchison A.R. (1980). *The integration of forestry and farming.* ESCA Report.

Scottish Agricultural College (1995). *Farm management handbook, 1995/96.*

Question and answer session

Ian Craigie, SAC

Firstly I would like to comment on why farmers won't put up shelterbelts because of the cost. I think you said that the costs are covered even if you've got a revenue forgone. Were you taking account of the time factor, because it is possible that it will be 10 years before the farmers see any benefit?

No I didn't, and that is a good point. The transformation period to go from present state to a fully sheltered farm has a cost and I did not take that into account. Thank you for pointing that out.

Gavin Fry, Grampian Woodland Project

Do the figures that you've been putting forward represent new planting or land that has not actually supported trees before? Have you done similar sorts of studies involving unmanaged shelterbelts which already exist and calculated the costs, including the value of the products you're getting from felling and the subsequent cost of replanting?

A lot of old, neglected, draughty belts are 100 years old. The quality of the timber there is minimal. Essentially the costs of replacing are the same as starting again. When I costed the establishment costs for new shelterbelts in the lowlands I assumed a certain amount of sale of small round wood primarily. However, the market for round wood is uncertain and I think we shouldn't put too much expectation on the value of the timber from these belts but rather treat it as a bonus if it happens.

Peter Freer-Smith, Forestry Commission

Intuitively your financial analysis seems to be right, if one thinks about where one sees shelterbelts. They are seen in areas where the land is more valuable and is producing a more valuable crop such as horticultural nurseries. So one would tend to take comfort from that. Would you agree?

Yes, I think intuitively you are right. It does however raise the point which I haven't yet mentioned: why use trees for shelter? In New Zealand they use fences to provide the same effect and you don't have to take land out of production. The economics have to incorporate some kind of valuation of the other benefits which trees provide in addition to the shelter when compared with a physical structure which only provides shelter.

Peter Freer-Smith, Forestry Commission

You mentioned that you were talking mainly about Scotland and I was going to make a comment on your dismissal of soil erosion as a benefit of shelterbelts. From a south of England perspective, driving around the lanes in Hampshire on a rainy winter's day or during autumn the amount of material coming down those lanes from some agricultural systems is staggering. It seems to me that we shouldn't dismiss protection from soil erosion quite so quickly. That's a geographical perspective.

I agree that soil erosion can be a real problem in some parts of Scotland.

John Moore, New Zealand Forest Research Institute

Managing for excellent merchantable timber seems to be one of the major motivations in New Zealand for growing shelterbelts in addition to providing shelter to agriculture. A lot of what happens in New Zealand is based on apportioning the revenue at harvest time over the life-cycle of the shelterbelt, and working out a point at which the shelter becomes economic, based on what you earn at harvest time.

If we could grow timber as fast as your radiata pine and we had access to the Japanese market I would agree with you and we would be very happy.

Graham Bell, Earthward

You made the comment that we wanted to put as little land as possible into trees. I'm not sure that I agree. Given that we are likely to have a few bits of beef pasture to replace shortly we might actually be looking for more land to go into trees. Is there something I'm missing here?

Well, I think the assumption that I have worked on is that the agricultural production is something we want to enhance. There may be examples where enterprises are not going to continue and it may be more profitable or desirable for other reasons to change, but given that we wanted to enhance agricultural production then you want to minimise the area of land used for treeshelter to achieve that improvement. That was my logic, but much wider scale changes of land use due to all sorts of other factors is obviously a different area of discussion.

Section 2: Reports from the Workshops

Workshop 1: Energy conservation and pollution reduction

Workshop 2: Animal production, wildlife and landscape

Workshop 3: Sustainable management and economic implications

Workshops

Introduction

Three workshops, designed to cover all aspects of the use of trees for shelter, were held in order to ascertain the views of participants.

1. Why do we plant trees in the first place?

2. What are the research and development priorities? What do we and don't we know, and where should we be concentrating our future efforts?

3. How might collaboration between organisations be encouraged and organised in order to maximise our effectiveness?

The information presented below reflects the consensus of views expressed in concise note form.

Workshop 1: Energy Conservation and Pollution Reduction

Facilitator Graham Hunt, Forest of Mercia

Reporter Max Hislop, Forestry Commission Research Division

This workshop concentrated on the use of trees in the urban or urban fringe environment. The uses include reducing the energy consumption of buildings, reducing airborne pollutants and pollutants in the soil and reducing noise, particularly from traffic.

Why plant trees?

1. Energy conservation
2. Atmospheric pollutants
    - Trees 'lock-up' carbon by utilising carbon dioxide in the atmosphere.
        - Trees do not 'lock-up' carbon long-term; it depends on how the timber is used.
        - Sustainable coppice systems for energy are carbon neutral.
    - Trees can convert O_3 to O_2.
    - Trees intercept pollutant deposition.
        - If this leads to pollution of watercourses, then one form of pollution is converted into another.
3. Soil pollutants
    - Trees can take up heavy metals on contaminated sites.
        - What happens to the heavy metals when the wood is harvested?
        - Uptake of toxins by trees is very slow; cleaning the site with trees may take hundreds of years.

4. Noise pollution

Land managers do not generally plant trees primarily to meet energy or pollution objectives.

The Forestry Commission plants and grant-aids trees for multiple reasons, but not primarily for energy or pollution objectives.

Other parties might have a greater interest in this area, e.g. DoT, planning authorities. In the USA some polluters must plant woodlands in proportion to the pollution they generate, e.g. new roads, power stations. Perhaps environmental audits undertaken when new developments are proposed should assess the full impact of pollution and recommend tree planting to mitigate the impacts.

Research and development priorities

1. Technology transfer

    - Existing knowledge needs to be made available to planners and landscape designers.

    - Research knowledge regarding noise abatement needs to be collated and made available.

2. Management of shelterbelts

    - Management techniques for long-term consistent shelter benefits.

    - Use of modified short rotation coppice systems for long-term shelter and wood production.

    - Investigate best design(s) of shelterbelt, i.e. species, width, etc.

    - Investigate best design(s) of small-scale landscape plantings which could provide energy benefits to new developments.

3. Cost–benefit analysis of the many facets of shelter trees

    - There is currently no way of comparing cumulative benefits of shelter trees in different scenarios: a model could be developed.

    - Non-market benefit analysis needs to be developed for many of the benefits of shelter trees.

4. New measurements for pollution uptake by shelter trees

    - New species need to be studied, e.g. oak, ash.

    - New types of locations need to be studied, i.e. urban fringe or street side areas.

Collaboration

1. Who should be involved?

This research area could potentially involve many government departments and many non-government organisations. For example:

- Government departments: Forestry Commission, MAFF, SOAEFD, DANI, DoE, DTI, Scottish, Welsh and Northern Ireland Offices.

- Non-government organisations: Universities, Consultants.

The above organisations perform many roles:

- They identify current knowledge and gaps for further R&D.

- They are responsible for technology transfer.

- They provide mechanisms for implementation of technology (e.g. grants, legislation, demonstrations).

There would be merit in involving many departments to help realise the multiple benefits that trees for shelter can provide.

2. Involvement of end-users

End-users of the research and development of trees for shelter should be involved in the preparation of research programmes. The end-users can be classified in the following groups:

- Policymakers

- Land managers

- Industry and developers

- Advisors and consultants

- Householders

Workshop 2: Animal Production, Wildlife and Landscape

Facilitator Professor Jeff Maxwell, MLURI

Reporter Alan Sibbald, MLURI

This workshop concentrated primarily on rural issues. These include the use of trees to provide shelter for domestic animals, to improve the environment, to provide wildlife habitat and as a source of timber.

Why plant trees ?

1. Shelter
2. Landscape enhancement
3. Timber
4. Environmental and conservation benefits
5. Trees are 'nice'

Research and development priorities

1. Technology transfer
    - There is already enough information but there is a lack of dissemination.
    - Research is not related to practice (for example with respect to markets and grants).
    - The information available is too sectionalised (the farming/forestry 'gulf').
2. Policies
    - The gap between farmer and policy is too great.
    - Farmers represent a new clientele for trees; maximising income is important to them.
    - There is a social dynamic in peoples' attitudes to tree planting.
3. Grazing animals
    - Enough is known about the physiology.
    - Not enough is known about aspects of the animals' motivations.
    - Farmers are already well aware of the benefits of shelter to livestock.
4. Wildlife
    - Enough is known to make improvements but not to maximise benefits.

5. Environmental and conservation improvements

   - It is known that diversity of woodland structure leads to better wildlife value but the benefits are not predictable, especially over wide areas (e.g. covering more than one woodland or farm).

   - Local expertise/knowledge is valuable (in areas where there is a woodland tradition).

6. Shelterbelt and shelter block design

   - Physical aspects (airflow and turbulence) of shelterbelts have been extensively studied.

   - The effects of different species (especially the potentially contrasting roles of broadleaves and conifers) is an area for further work.

   - The potential roles of standards and shrubs need to be explored.

   - Temporal continuity of development is a difficult problem which has been little addressed.

Collaboration

- The Forestry Research Co-ordinating Committee could play an active role.

- There is a need for a one-stop shop to provide integrated advice.

- Efficient networking of research, with respect to customers and contractors, should be encouraged.

- There is a future role for on-farm demonstrations.

- Existing knowledge should be integrated into Decision Support Systems (DSS):

  - end-users should be involved in the design of such DSS;

  - the development of DSS and their use should identify future research priorities.

Workshop 3: Sustainable Management and Economic Implications

Facilitator James Simpson, Forestry Commission

Reporter Harriet Palmer, SAC

This workshop dealt with the management and economics of shelter trees. Participants discussed the practicalities of designing, planting, managing and financing shelter and the methods by which existing knowledge can be passed on to farmers and land owners.

Why plant trees?

1. Economic vs non-economic benefits.

2. Shelterbelts planted for economic returns.

3. 'Non-economic' benefits can have a financial value.

4. Indirect benefits important, e.g. tourism, health.

5. Sustainability is linked with economics (e.g. soil building and conservation are hard to evaluate but have an economic benefit).

While land use is subsidy driven, decisions on planting and managing shelterbelts will be based on immediate perceived economic benefits.

Research and development priorities

1. Policy

   - Objectives of policymakers (i.e. research funders) must be identified.

   - Evaluation of impact of existing policies on shelterbelt planting and management needed (e.g. Livestock Exclusion Annual Premium).

   - Policies for shelter provision either do not exist or are confused.

   - Need for joint agriculture/forestry/conservation/landscape policies to encourage planting and management.

   - Researchers have limited freedom: policymakers 'call the tune'.

2. Technology transfer

   - Use of existing data to develop models/expert (decision support) systems which have prescriptive value to practitioners.

   - Need good examples to encourage farmers.

   - Farm trials – use a range of existing sites.

3. Management of shelterbelts

    - Methods of regenerating existing shelterbelts, plus other practical management aspects.
    - Production of timber/evaluation of timber production from shelterbelts.
    - Long rotations (low timber output) versus short rotations.
    - Selection of trees/breeding to improve form for shelter.
    - Lack of (economic) small-scale harvesting systems, e.g. mobile sawmills.
    - Management problems associated with upland sites – slow growth, poor form.
    - Use of shelterbelts/nurse crops to help establish more trees.

4. Design of shelterbelts

    - Designs for self-management, low-input management.
    - Integrate shelter provision with more productive systems, e.g. short rotation forestry.
    - Landscape an important element of research.
    - Systems of design and management to meet different objectives, e.g. single lines versus wider belts.
    - Woodlands for shelter (shelter woods) may have more potential than shelterbelts.
    - Species choice – not always best used, e.g. beech.

5. Education and training

    - Need to revive skills.
    - Need to educate younger farmers.

6. Economics

    - Cumulative sum of benefits very important.
    - Evaluation of benefits and hypotheses – use existing data, develop prescriptive models.
    - Economic value of trees in shelterbelts.
    - Edge effects decrease timber value – role of pruning?

All research suffers from problems of getting the correct scale, time-span, linkages and potential high costs.

Use of existing sites recommended where possible. 'On the ground' research valuable in strengthening collaborative links.

Collaboration

- Collaboration is extremely valuable: knowledge sharing is vital.
- Broad range of interests involved in shelter: include as many as possible/relevant.
- Farmers and other end-users, particularly policymakers, should be involved.
- Farmers and others can and should be educated: lack of tree management skills can be rectified.

Section 3: Posters

1. **Choice of foraging sites by sheep given different opportunities to seek shelter**
   Alan Duncan, Bob Mayes, Sheila Young, Patricia Wilson and C. Stuart Lamb

2. **Grazing behaviour of sheep under larch saplings planted at wide spacings**
   Alan Sibbald, Jenny Dick and Glenn Iason

Poster 1

Choice of foraging sites by sheep given different opportunities to seek shelter

Alan Duncan, Bob Mayes, Sheila Young, Patricia Wilson and C. Stuart Lamb

Summary

Variation in micro-climate due to topography and vegetation may influence the foraging behaviour of upland herbivores. To test the sensitivity of hill sheep to micro-climate variation, wind speed was artificially reduced on discrete patches of an upland pasture and the proportion of grazing time spent in sheltered and exposed patches was measured over an 8 hour observation period. Data presented relate to one day during which weather conditions were such that the animals could remain above their lower critical temperature by seeking shelter. Under these conditions animals spent a greater proportion of grazing time behind shelters than in completely exposed areas.

Introduction

The topography and vegetation typical of the hills and uplands of the UK leads to considerable variation in micro-climate over a relatively short geographical scale. For example, young forestry stands represent a highly variable micro-climatic environment during inclement weather but may present relatively uniform micro-climatic conditions to herbivores under more favourable weather conditions. Although free-ranging ruminant herbivores are resilient to severe weather conditions as a result of the heat of fermentation in the rumen and the insulative properties of their coat (Webster, Chapter 3), the climatic conditions of upland environments are, on occasion, sufficiently severe to bring herbivores close to the limit of their thermoneutral zone (Mount and Brown, 1982). Under these conditions herbivores will be faced with choices about where to forage in order to maximise their intake of food while minimising the need to increase heat production (and therefore incur metabolic costs) to maintain their core temperature. The experiment presented here was designed to investigate the way in which grazing sheep respond to variation in micro-climate in relation to their lower critical temperature under different climatic conditions.

Materials and methods

A series of linear experimental plots (40 x 3 m) were established on an upland pasture composed primarily of Agrostis/Festuca grasses. The orientation of the plots was perpendicular to the prevailing wind direction and a series of shelter stations were erected at intervals along half the plots (shelter stations treatment). This provided alternate sheltered and non-sheltered areas at 4 m intervals along the experimental plots. The remaining plots were devoid of shelter (completely exposed treatment). The layout of the plots is illustrated in Figure P1.1. Shelter stations consisted of Netlon shelter netting stretched across two metal frames (1m high by 4 m long) which stood perpendicular to each other, corner to the wind. On days during which behavioural trials were conducted, five adult, female Scottish Blackface sheep with a mean fleece depth of 5 cm were released onto each of two experimental plots (one of each treatment) and allowed to graze for 8 hours. During this time, time-lapse video recordings of sheep behaviour were made. Subsequent to the experiment, video tapes were analysed to record grazing activity (grazing or lying) and location of each animal at 1-minute intervals for the entire 8-hour period.

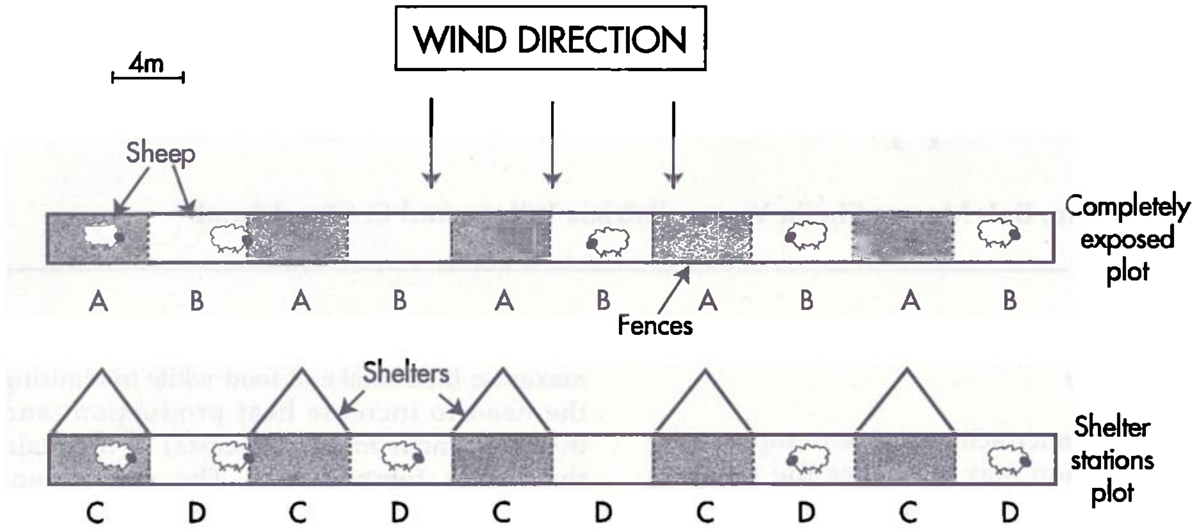

Figure P1.1 Plan view of the experimental plots showing orientation of artificial shelters

The effect of shelter stations on wind speed was determined concurrent to the behavioural measurements using cup anemometers located on an area adjacent to the experimental plot. Mean wind speed from three anemometers located on a diagonal behind shelters or in adjacent non-sheltered areas was measured at 5-minute intervals for the 8-hour behavioural observation period.

Results and discussion

Shelter stations reduced wind speed in sheltered areas by approximately 50 %. Wind speed varied over the day but wind speed reduction was relatively consistent over the measurement period. Data for one complete measurement period during which the average wind speed on the sheltered and completely exposed patches was 2.8 and 6.1 m s^{-1} respectively are presented.

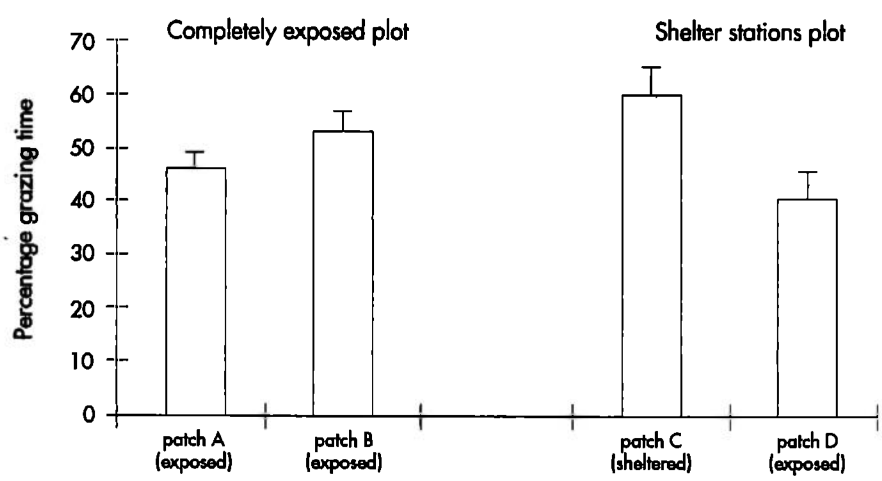

Figure P1.2 Percentage of grazing time in different patch types with or without provision of shelter (error bars = SE)

On the completely exposed plot the proportion of time spent on the two nominal patch types was close to 0.5 (Figure P1.2). Results from this plot represent the random spatial movements of sheep in the absence of variation in microclimate and the grazing movement data verify that sheep were dispersed randomly across the linear plot with no artifactual bias towards one patch type. On the shelter stations plot, sheep spent significantly more time grazing on the sheltered areas than in the non-sheltered areas (Figure P1.2). To determine the thermal constraints on the animals during the measurement day, meteorological variables (wind speed, temperature, cloud cover) and animal variables (fleece depth) were used to estimate the lower critical temperature of the animals using the equation proposed by Mount and Brown (1982). Lower critical temperatures for sheep grazing in sheltered and exposed areas were estimated to be 2.6°C and 10.6°C respectively. The actual mean temperature during the measurement period was 7.3°C. Although the estimate of lower critical temperature is approximate and would vary between animals due to, for example, different levels of food intake and insulation, the results show that the animals were close to the threshold of their thermoneutral zone. Under these conditions animals chose to spend a greater proportion of their grazing time in sheltered areas thus minimising the energetic costs of maintaining body temperature. Further work is planned to gather similar data under a range of weather conditions to establish more clearly the relationship between lower critical temperature and foraging behaviour.

Reference

Mount, L.E. and Brown, D. (1982). The use of meteorological records in estimating the effects of weather on sensible heat-loss from sheep. *Agricultural Meteorology* **27**, 241-255.

Poster 2

Grazing behaviour of sheep under larch saplings planted at wide spacings

Alan Sibbald, Jenny Dick and Glenn Iason

Introduction

Although there may be direct effects of animal activity close to trees in silvopastoral systems, such as soil compaction, nutrient enrichment and direct damage effects, there have been no UK studies to date on the behaviour of sheep in stands of widely spaced trees. These effects may be most profound at low planting densities where the high animal:tree ratio results in more animal foot pressure around the smaller number of trees. This hypothesis is supported by measurements of soil penetration resistance (Wairiu *et al.*, 1993) and may underlie the reduced shoot extension and tree survival observed at low planting densities in the UK Silvopastoral National Network Experiment (UKSNNE; Sibbald and Agnew, 1994; Sibbald *et al.*, 1994). The material in this poster has been published previously (Sibbald *et al.*, 1995).

Materials and methods

In a pilot study at the Glensaugh site of the UKSNNE (Sibbald and Sinclair, 1990), the grazing and resting behaviour of sheep in relation to planting density was monitored on two tree-spacing treatments (hybrid larch 400 stems ha^{-1} and hybrid larch 100 stems ha^{-1}) in September 1994. The trees were planted in spring 1988 and had mean top heights of 3.1 m and 2.2 m for 400 and 100 stem ha^{-1} respectively when the pilot study was carried out. The observations were carried out on one replicate of the experiment where all three treatments were simultaneously visible from a single observation point. Observations were carried out over three full daylight periods (average duration 10 hours). Each 0.8 ha plot was grazed by nine, recently weaned Greyface ewes which were uniquely identified by a number painted on both flanks. Scan-sampling (Martin and Bateson, 1986) was used to record sheep behaviour and weather variables at 10-minute intervals during 2-hour observation sessions. Each 10-minute recording noted general weather characteristics: sunny/ hazy/cloudy, rain/drizzle/dry, and subjective assessments of wind speed and direction. Each animal was then observed and a recording made of: activity (e.g. grazing, resting, ruminating, rubbing, walking); posture (e.g. standing, lying); estimated distance to nearest neighbour; estimated distance to nearest tree;

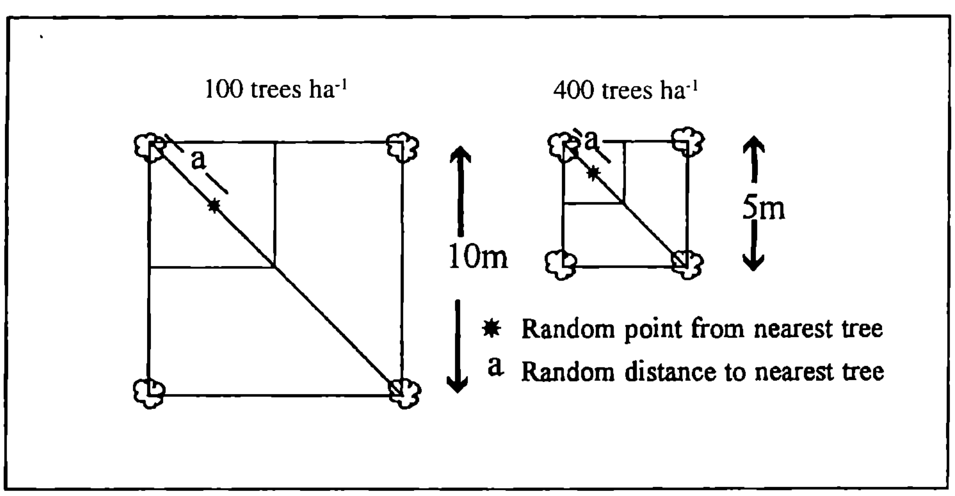

Figure P2.1 Point of random distance to nearest tree

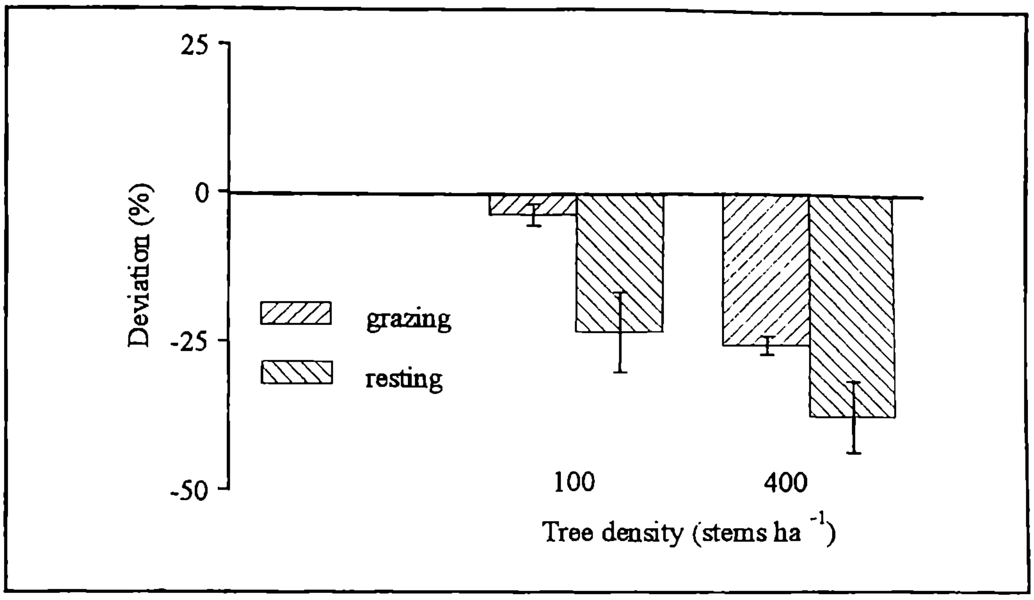

Figure P2.2 Mean deviation (± SEM) from a random distribution of sheep grazing and resting in two densities of tree planting

location with respect to tree (e.g. in shade/sun; on windward/leeward side; uphill/downhill). A total of 1602 individual animal recordings was made.

The two tree densities (100 and 400 trees ha^{-1}) have different spacings between nearest trees (10 m and 5 m). Hence if sheep were randomly distributed, the absolute distances from trees would be less in the higher tree density plot. In the low and high tree density plots, the mean distance of randomly distributed sheep is 3.54 m and 1.77 m respectively (distance a, Figure P2.1). The data presented have been re-scaled and expressed as a percentage deviation from this mean random distance: negative values indicate greater proximity to trees than expected by chance.

Results

A provisional analysis of the data indicated that the sheep were located closer to trees when resting than when grazing and both activities were carried out, on average, closer to the trees than would be the case if their behaviour was unaffected by the trees (Figure P2.2). In Figures P2.2, P2.3 and P2.4, a negative deviation indicates a greater proximity to trees than would be expected by chance.

Weather further modified this behaviour; for example, sheep rested very much closer to the trees at 100 trees ha^{-1} during windy compared to calm periods (Figure P2.3). However, wind had no significant effect on the average resting location of sheep within 400 trees ha^{-1} (Figure P2.3). Under both calm and windy conditions sheep rested closer to trees than would be expected if the trees had no effect on animal behaviour at both planting densities.

The effect of rain on grazing behaviour is shown in Figure P2.4. When grazing on the 100 trees ha^{-1} plot, the sheep chose to graze, on average, further away from the trees than would be the case if their behaviour was unaffected by the trees. They continued to graze closer to the trees in dry conditions. In the 400 trees ha^{-1} treatment, there was no significant difference in proximity of sheep to trees between wet and dry conditions.

Conclusions

It may be concluded from the data presented that, under the conditions tested, sheep were attracted to the trees. Only while grazing during wet weather and within 100 trees ha^{-1} did sheep occupy positions further from trees than would be expected by chance.

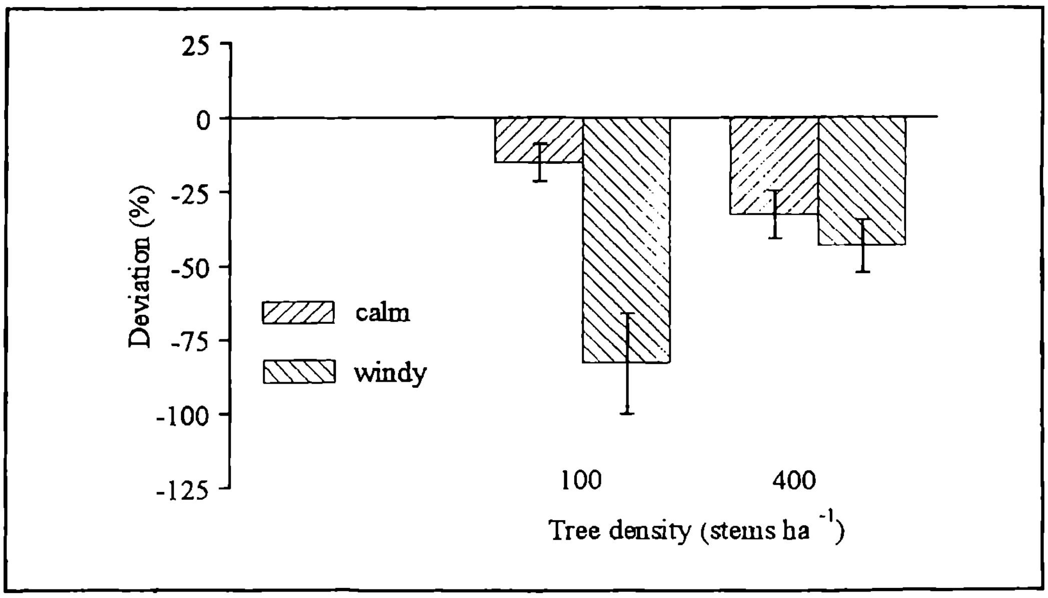

Figure P2.3 Effect of wind on mean deviation (± SEM) from a random distribution of sheep resting in two densities of tree planting

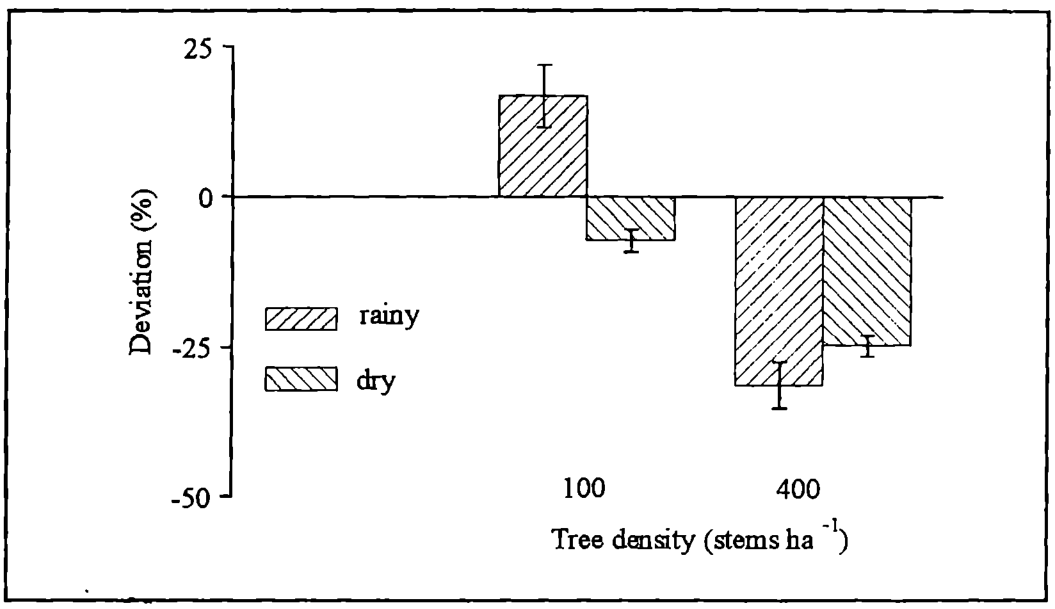

Figure P2.4 Effect of rain on mean deviation (± SEM) from a random distribution of sheep grazing in two densities of tree planting

It may be hypothesised that, under the conditions encountered at Glensaugh, the sheep benefited in some way by choosing to rest and graze close to the trees. The observations were made in September when temperatures were not high and seeking of shelter was likely to be an important factor. The additional benefit to be gained by sheep resting very close to trees within 100 trees ha^{-1} in windy weather could have arisen from the greater spatial variation in wind speed at this tree density and the sheep seeking the most sheltered location. The spatial variation in wind speed within the closer-spaced 400 trees ha^{-1} may have been less with smaller shelter benefits accruing to the sheep if they chose to move nearer the trees.

Although the precise energetic advantages of shelter are complex to determine both theoretically and practically (Pritchard, 1992; Fenn *et al.*, 1991), any thermal advantages to sheep of resting nearer to trees would not accrue unless the sheep was below its thermoneutral zone when resting at greater distances from the trees. However, regardless of the energetic arguments, our results clearly implicate wind conditions as a determinant in the selection of resting sites by sheep and wind speed is known to decrease with increasing tree density (Pritchard, 1992; Green *et al.*, 1995).

The fact that sheep chose to graze further from trees than would be expected by chance in wet weather within 100 trees ha^{-1} requires a rather more speculative interpretation. The spatial distribution of precipitation was presumably much more variable within 100 trees ha^{-1} than within 400 trees ha^{-1} because there was less canopy per unit area and less canopy interception. Since canopy drips are probably larger than raindrops and may therefore penetrate further into the fleece, sheep may have been attempting to avoid large drips from the tree canopies at 100 trees ha^{-1}. There may have been no benefit for sheep within 400 trees ha^{-1} in moving away from the canopy drips of one tree because they would be moving towards the canopy of another tree. At 100 trees ha^{-1}, canopy drips could be avoided.

These modifications to behaviour which, in most circumstances under the conditions tested, attract the animals towards the trees together with the higher animal:tree ratio of the 100 trees ha^{-1} treatment will result in a concentration of animal activity and foot pressure around the trees.

These initial observations suggest that the sheep maintain closer proximity to trees at lower planting densities. This may offer an explanation for the greater soil compaction due to sheep observed at these densities. Further work on these data and future research on the causes and effects of animal behaviour in these systems is being planned at MLURI.

Acknowledgements

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References

Fenn, P.D., Colgrove, P.M., Sim, D.A., Iason, G.R. and Foreman, E. (1991). The effect of shelter on the energy expenditure of two breeds of sheep in winter. *International congress on farm animals and the environment*, Bangor (Poster abstract).

Green, S.R., Grace, J. and Hutchings, N.J. (1995). Observations of turbulent airflow in three stands of widely spaced Sitka spruce. *Agricultural and Forestry Meteorology* **74**, 205-226.

Martin, P. and Bateson, P. (1986). *Measuring behaviour: an introductory guide.* Cambridge University Press, Cambridge.

Pritchard, K.M. (1992). Shelter, microclimate and heat loss from sheep. PhD Thesis, University of Nottingham.

Sibbald, A.R. and Agnew, R.D.M. (1994). UK Silvopastoral Network Experiment: Annual Report 1993. *Agroforestry Forum* **5**, 13-17.

Sibbald, A.R., Dick, J. and Iason, G.R. (1995). The effects of the presence of widely spaced trees on the behaviour of sheep. *Agroforestry Forum* **6**, 22-25.

Sibbald, A.R., Simpson, J.M., Agnew, R.D.M., Dalziel, A.J.I., Macleod, A. and Harrison, C. (1994). Multiple-benefit upland silvopastoral systems: modelling and experimentation. *Agroforestry Forum* **5**, 18-19.

Sibbald, A.R. and Sinclair, F.L. (1990). A review of agroforestry research in progress in the UK. *Agroforestry Abstracts* **3**, 149-164.

Wairiu, M., Mullins, C.E. and Campbell, C.D. (1993). Soil physical factors affecting the growth of sycamore (*Acer pseudoplatanus* L.) in a silvopastoral system on a stony upland soil in north-east Scotland. *Agroforestry Systems* **24**, 295-306.

Section 4: Seminar Summary

Summary and conclusions
Barry Gardiner

Summary and conclusions

Barry Gardiner

Summary

Objectives

In summarising this seminar it is useful to begin by restating the objectives, and then to explore how well these were met and what developed in addition. The main objectives were:

- To review current research and development on the use of trees for shelter.
- To increase the awareness of shelter-related research and development work being undertaken in the UK.
- To identify priority areas for future research and development and potential collaborative links.

The belief of the organising committee based on the experiences within their respective organisations, the Scottish Agricultural College, the Macaulay Land Use Research Institute and the Forestry Commission was that the use of trees for shelter was an underexploited resource, particularly in Scotland. It represented an area of study that fell between too many stools: it was neither a fully agricultural issue, nor a fully forestry issue nor a fully land-use issue. By hosting a joint seminar (including workshops) it was hoped that the subject could be brought to the attention of land users, planners and policymakers and provide a springboard for a renewed interest in the benefits of sheltering our homes, our livestock and ourselves with a natural and living resource.

Keynote papers

The morning session consisted of five keynote papers designed to review the current state of our knowledge.

Shelter trees for energy conservation

David Clarke of David Clarke Associates presented a review of the use of trees for reducing energy consumption in buildings based on his recently completed research commissioned by the Department of the Environment.

There is clearly a great deal of existing knowledge and information on the use of shelterbelts with buildings and the potential benefits for reducing heat loss, although most of this work appears to have been carried out in the United States. When energy savings are offset against shelterbelt maintenance costs, there appear to be potential economic benefits for older residential buildings but only marginal benefits for newer residential and commercial buildings which have been built to stricter codes. In the United States it has been found that the main benefits of shelter tree planting are by shading buildings from the sun and reducing air-conditioning costs. The same may be true in this country and the benefits may be more likely to occur in the warm south of England rather than the windy north and west of Scotland.

It was argued that case for the use of trees in the urban environment based purely on economic grounds is unlikely to be successful. Rather the benefits of trees in sheltering buildings must be taken together with other potential benefits such as reduction in damage from driving rain, visual impact, noise absorption and improvement in the urban micro-climate. An integrated approach to the use of urban trees is required.

It was obvious also from David Clarke's talk that shelter trees can have drawbacks as well as benefits and the former must not be ignored. For example, trees planted in the urban environment can cause problems by undermining building foundations and pavements and by clogging drains and guttering with leaves. The most important requirement for the future is guidance on the best design and maintenance of shelter tree planting. In this way the benefits can be maximised and the drawbacks minimised.

The uptake of pollutants by trees: benefits to air quality

Peter Freer-Smith of the Forestry Commission Research Division presented a paper on the potential of trees for reducing pollution based, again, on recent research commissioned by the Department of the Environment.

In a sense this question is looking at the problem of the effect of chemical pollutants on trees, which researchers have been concerned about for many years, the other way around. There is an enormous amount of information on pollution uptake by trees in forests during field experiments or by individual trees in laboratory studies. There is already enough information to conclude that there are benefits from pollution reduction by planting trees. However, there are many questions that need to be resolved. In particular it is important to understand what happens to pollutants once they are taken up by trees. If the pollutants are locked up that is a benefit, but if they are quickly washed out into the groundwater that might cause problems. Furthermore, most of the research carried out so far has been on a small number of tree species which are important for forestry and on pollutants which affect these trees. Much less work has been carried out on the interaction between trees likely to be planted in the urban environment and pollutants particularly injurious to human health. The complexities introduced by moving from consideration of single pollutants interacting with a single tree species to mixed woodlands of different sizes and planted on different sites were emphasised and the need for continued detailed study reaffirmed.

The benefits of trees for reducing other forms of pollutants such as particulates and noise were touched on but it was clear that much more research is required before definitive conclusions can be reached.

Shelter trees in animal production

John Webster of the University of Bristol discussed work aimed at determining energy loss from farm animals and the benefits of shelter in reducing energy loss by convection and radiation. Animals operate metabolically most efficiently when the temperature is within certain limits, the animal's 'comfort zone'. For smaller animals such as chickens the 'comfort zone' covers a very small range of temperatures whereas for the larger herbivores the range can be quite large. The range is also dependent on the animal's age so that, in general, young animals have a much tighter range and are more susceptible to extremes of weather. Usually it is best to have a situation in which a variety of micro-climates are created and the animals themselves are able to choose where to go at any particular time.

In common with the previous two talks Professor Webster pointed out that a great deal of data already exists which is relevant to animals and shelter and this data can be built readily into models for designing shelter systems and determining their benefit. However, he pointed out that there can be drawbacks as well as benefits, with shelter trees a potential harbour for insect-borne disease.

Our current research understanding is good at explaining the short-term (days) and mid-term (weeks) response of animals to shelter but is less effective at explaining the response of animals in the long-term such as over a whole winter. Trying to scale up the numbers from the short and mid-term does not make sense over longer periods and more research is required to investigate the long-term benefits of shelter.

Shelter and wildlife

Michael Usher of Scottish Natural Heritage discussed the benefits shelter can have for wildlife. A key issue is to identify the scale of interest (tree, woodland or landscape) as this will determine the manner in which the benefits to wildlife are assessed. Some wildlife only needs a limited area in order to benefit (e.g. soil mites) whereas other wildlife needs suitable habitat over a much larger area (e.g. raptors). The shape and size of woodlands can have a major impact on wildlife variety; the type and age of the woodland is probably less important. In other words a variety of physical habitat and distance from open ground can be extremely important when attempting to maximise diversity. Some wildlife is completely restricted to the area of woodland shelter, other wildlife uses the shelter as a refuge but obtains its food in the open.

In common with the other topics discussed there is a huge amount of data on the benefits of shelter trees for wildlife. Such information can provide the basis for modelling the interaction between wildlife and shelter. Unfortunately, most past research has concentrated on particular groups of plants and animals and more effort needs to be placed on understanding the interaction of the whole ecosystem.

Professor Usher warned that designing shelterbelts for wildlife goals may conflict with other goals of the shelterbelt such as improving the landscape. No particular benefit of shelter trees can be taken in isolation from other benefits and it needs to be recognised that there are always advantages and disadvantages to any system of shelter employed.

The economics of shelter provision on farms

John Blyth of the Institute of Ecology and Resource Management at Edinburgh University presented a paper exploring the economic benefits of shelterbelts. The economic benefits of shelterbelts for agriculture are well proven in some countries but the case in the UK is still not conclusively settled. In Britain most trees planted by farmers tend to be planted for amenity, conservation and sporting considerations rather than for shelter.

The question still remains as to why there are so few well-designed and integrated shelterbelt systems in this country. Is the problem due to land ownership, tradition or lack of usable information? In many cases shelterbelts appear to be designed to meet too many goals but only succeed in failing to meet any of them adequately. In common with other speakers, Dr Blyth reminded the audience that shelter can have both benefits and drawbacks and cannot be seen simply as a panacea to all problems.

The financial benefits are more certain and calculable for productive lowland farms rather than marginal hill farms. This is the opposite of one's instinctive reaction and also the opposite of where shelterbelts are generally used. Dr Blyth emphasised that there were still many questions left to be answered concerning the benefits of shelter. In particular the problems of differing time scale needs to be addressed. The benefits of a shelterbelt can be relatively easily measured at a particular instance but it is much more difficult to assess the benefit over an entire year.

Workshops

Three workshops were held in order to encourage participants at the seminar to identify what we already know about the use of trees for shelter, where our knowledge is weak and how we move forward. The first workshop concentrated on issues particularly relevant to the urban environment, the second on issues relevant to the rural environment and the third workshop dealt with management and economics.

Energy conservation, noise and other pollution

The use of trees for energy conservation and pollution reduction tend to be secondary aims of tree planting. In justifying tree planting there is a need to consider the cumulative benefits of trees which might include visual and aesthetic benefits in addition to their practical value in reducing energy needs or pollution. There is a great deal of information available on the use of trees for energy conservation and pollution control. Much of the information on the benefits of trees for reducing air-borne pollution has been recently summarised in a publication by Broadmeadow and Freer-Smith (1996) for the Department of the Environment. Many organisations are working in the subject area but there is an obvious need for more centralised co-ordination of future research and information dissemination.

Animal production, wildlife and landscape

There are many reasons for planting trees in addition to their benefits for animals, wildlife and the landscape. Tree planting for a specific objective is rare and we need to consider it as a complex issue which may have multiple effects, both positive and negative.

A large amount of information is already available but it tends to be dispersed and not readily accessible to practitioners. There is also perceived to be a gap between policymakers and practitioners. There is a definite need for better dissemination of knowledge and suggestions were:

- One-stop advice shop for those seeking practical advice. Currently knowledge and experience is scattered amongst various organisations.
- Demonstrations of shelter systems on farms.

- Development of a decision support system to aid those designing shelter systems. A decision support system would also point to weaknesses in our current knowledge and indicate areas where further research is required.

Areas which require further research are the effect of shelterbelt/shelterblock structure (size, shape, etc.) and animal behaviour in response to shelter.

Economics and sustainability

Reasons for planting trees may vary widely. The benefits may be direct, quantifiable and rational but equally they may be indirect, unquantifiable and irrational. The ability to correctly assess the benefits is essential.

At present land use is subsidy driven. It is, therefore, important to identify the objectives of policymakers and to evaluate the success of incentives in determining land use. For this reason it is vital to have farmers and other land users involved in attempts to revitalise the use of trees for shelter in the UK.

Collaboration between organisations (both government and non-government) involved in shelter research is valuable so that we share our current knowledge. The alternative is that work is repeated needlessly and information is not made available to practitioners.

Posters

A number of poster presentations were made dealing with issues from the behaviour of animals in relation to the availability of shelter to the benefits of shelter for improving the landscape and wildlife habitats. Two papers resulting from these posters, presented in Section 3, deal specifically with the foraging behaviour of sheep.

Conclusions

1. There are always both benefits and drawbacks to the planting of trees for shelter. These require clear identification before any assessment of the overall benefit of tree planting can be made.

2. It is best to regard trees as having multiple benefits rather than seeing benefits individually. This assists in the designing and justification of systems involving shelter trees.

3. There is a huge body of knowledge and information already in existence which can be used to benefit practitioners.

4. A lot of work is going on in parallel in different organisations on aspects of the use of trees for shelter. There is a need for future efforts to be multidisciplinary so that the points made in 1 and 2 above can be properly addressed.

5. The large number of organisations from a wide spectrum involved in this area points to the need for more central co-ordination. Such a central co-ordinating body would:

   (a) Oversee the development of a Decision Support System to aid in the design of shelter systems. There may be a requirement for different systems for different circumstances, i.e. rural versus urban.

   (b) Identify further research needs.

   (c) Liaise between researchers, policy-makers, funding bodies and end-users. This would help to ensure that there was a clear idea of what was of most benefit to the nation and how this could best be achieved.

Reference

Broadmeadow, M.S.J. and Freer-Smith, P.H. (1996). *Urban woodland and the benefits for local air quality.* Department of the Environment, Research for Amenity Trees No. 5. The Stationery Office, London.

List of delegates

Robert Agnew
Macaulay Land Use Research Institute
Craigiebuckler
Aberdeen
AB15 8QH

W. Beattie
The Forestry Authority
Highland Conservancy Woodlands
Fodderty Way
Dingwall, Ross-shire
IV15 9XB

Graham Bell
Earthward
Tweed Horizons
Newton St Boswells
Roxburghshire
TD6 0SG

Jacques-Eric Bergez
Macaulay Land Use Research Institute
Craigiebuckler
Aberdeen
AB15 8QH

Dr John Blyth
Institute of Ecology and Resource Management
University of Edinburgh
Edinburgh

John Brodie
Edinburgh

Prof. Ian Cunningham CBE
Bruaich
Hazlieburn
West Linton
Peebleshire
EH46 7AS

Douglas Clark
The Forestry Authority
Grampian Conservancy
Ordiquhill, Portsoy Road
Huntly
Aberdeenshire
AB54 4SJ

David Clarke
David Clarke Associates
Toll House Studio
Cambridge Cottages
Kew Green
Richmond
TW9 3AY

Ian Craigie
The Green
Portree
Isle of Skye
IV51 9BT

Andrew Dalziel
Macaulay Land Use Research Institute
Craigiebuckler
Aberdeen
AB9 2QJ

Alan Duncan
Macaulay Land Use Research Institute
Craigiebuckler
Aberdeen
AB9 2QJ

David Farrow
Student Delegate

Peter Fothergill
Wood Howe
Keldwyth Drive
Troutbeck Bridge
Windermere, Cumbria
LA23 1NJ

Dr Peter Freer-Smith
Forestry Commission Research Division
Alice Holt Lodge
Farnham
Surrey
GU10 4LH

Gavin Fry
c/o Economic Planning & Development Division
Grampian Regional Council
Woodhill House
Westburn Road
Aberdeen
AB9 2LU

Barry Gardiner
Forestry Commission Research Division
Northern Research Station
Roslin
Midlothian
EH25 9SY

Claire Glaister
Tilhill Economic Forestry
Little Mill Nursery
Glamis Road
Forfar, Angus
DD8 1TR

Douglas Hendry
Scottish Agricultural College
Rural Centre West Mains
Ingliston
Newbridge
Midlothian
EH28 8NZ

Roger Herbert
Forestry Commission
231 Corstorphine Road
Edinburgh
EH12 7AT

Max Hislop
Forestry Commission Research Division
Northern Research Station
Roslin
Midlothian
EH25 9SY

Graham Hunt
Forest of Mercia
Rumer Hill Road
Cannock
Staffordshire
WS11 3EX

Simon Jacyna
Scottish Agricultural College
Clifton Road
Turriff
Aberdeenshire
AB53 7DY

Sally Johnson
Student Delegate

Ben A. Jump
Scottish Agricultural College
57 High Street
Lanark
ML11 7LF

J. W. B. King
Cottage Farm
West Linton
Peebleshire
DH46 7AS

Derek Mackenzie-Hook
Earthward
Tweed Horizons
Newton St Boswells
Roxburghshire
TD6 0SG

Bill Mason
Forestry Commission Research Division
Northern Research Station
Roslin
Midlothian
EH25 9SY

Prof. T. J. Maxwell
Macaulay Land Use Research Institute
Craigiebuckler
Aberdeen
AB15 8QH

Robert Mayes
Macaulay Land Use Research Institute
Craigiebuckler
Aberdeen
AB9 2QJ

G. I. McCulloch
Scottish Woodlands Ltd
Research Park
Riccarton
Edinburgh
EH14 4AP

Dr Susan McFadzean
Susan McFadzean Associates
45 Earlspark Drive
Bieldside
Aberdeen
AB1 9AH

Archie McNab
Crofters Commission
4/6 Castle Wynd
Inverness
IV2 3EQ

Dr J. A. Milne
Macaulay Land Use Research Institute
Craigiebuckler
Aberdeen
AB15 8QH

John Moore
New Zealand Forest Research Institute
c/o Forestry Commission Research Division
Northern Research Station
Roslin
Midlothian
EH25 9SY

Harriet Palmer
Scottish Agricultural College
Edinburgh
EH9 3SG

Chris Quine
Forestry Commission Research Division
Northern Research Station
Roslin
Midlothian
EH25 9SY

Veronica Ross
V. Ross – Landscape Design
Burnroot Farmhouse
Dinnet
Aboyne
Aberdeenshire
AB34 5PN

Ken Rundle
BBC Scotland
Beechgrove Terrace
Aberdeen

Lesley Samuel
Susan McFadzean Associates
45 Earlspark Drive
Bieldside
Aberdeen
AB1 9AH

Tony Sharpe
Forestry Commission
The Forestry Authority
Silviculture (North) Research Office
Newton Nursery
Elgin
Morayshire
IV30 3XR

Nicholas Shepherd
Forestry Authority (Scotland)
National Office
231 Corstorphine Road
Edinburgh
EH12 7AR

Alan Sibbald
Macaulay Land Use Research Institute
Craigiebuckler
Aberdeen
AB15 8QH

James Simpson
Forestry Authority
231 Corstorphine Road
Edinburgh
EH12 7AT

Eric Todd
Scottish Agricultural College
Edinburgh

Prof. Michael Usher
Scottish Natural Heritage
Edinburgh

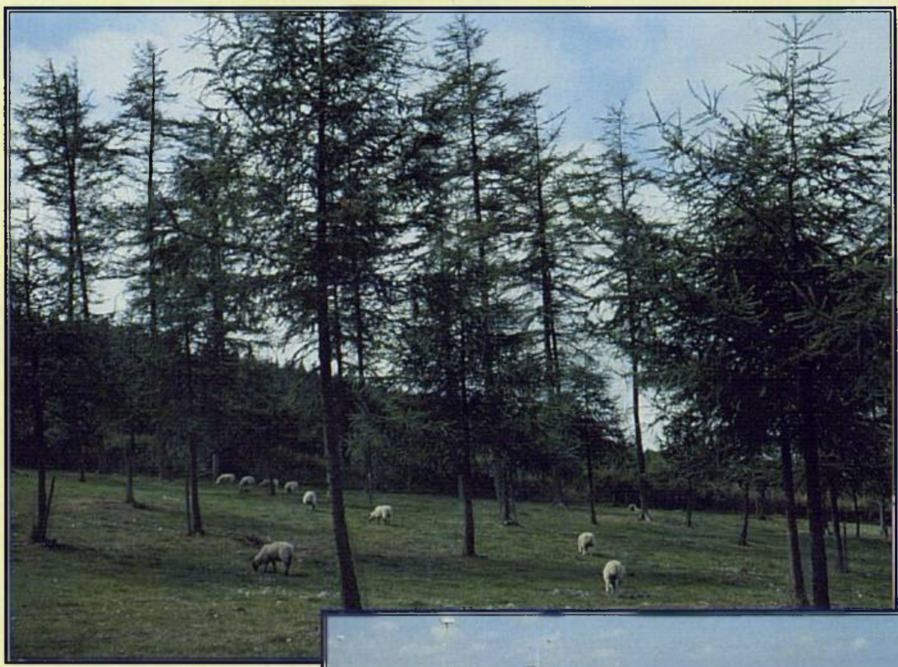
Eamonn Wall
Eamonn Wall & Co.
15 West Burnside
Dollar
Clackmannanshire
FK14 7DE

Prof. John Webster
University of Bristol Veterinary School
Bristol

Adrienne Wilson
CSCT
Hillhouseridge
Shottskirk Road
Shotts
Lanarkshire
ML7 4JS

Joanne Winston
Student Delegate

This Technical Paper provides comprehensive coverage of the *Trees for Shelter* seminar jointly organised by the Forestry Commission Research Division, the Macaulay Land Use Research Institute, and the Scottish Agricultural College in Aberdeen, Scotland on 27 March 1996. The objectives of the seminar were:



- To review current research and development on the use of trees for shelter.
- To increase the awareness of shelter-related work being undertaken in the UK.
- To identify priority areas for future scientific effort and potential collaborative links.

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