Forestry Commission

Fruiting bodies of *Armillaria gallica*

Research Note

Potential impacts of drought and disease on forestry in Scotland

Sarah Green and Duncan Ray

September 2009

In predictions of future changes in climate, drought is expected to become a more important factor affecting the health of trees in areas of Britain, particularly in the east of the country and including areas of Scotland. Drought may cause direct physiological damage to trees as well as increase their susceptibility to a range of fungal diseases. Although a number of diseases are known to be more aggressive on trees experiencing drought stress, there are uncertainties as to which are likely to increase in frequency and severity in response to future changes in climate. This study used GIS-based modelling to develop 'drought-risk maps' to identify forest sites and tree species in Scotland most at risk by combining past and predicted climatic variables with a range of soils data. Sitka spruce, Scots pine, larch, Norway spruce, mixed broadleaves and Douglas fir were found to be major component species of drought-prone forest sites in eastern Scotland. Results from the modelling study focused a literature review of the potential risks to these species from drought-related fungal diseases. This review identified a number of diseases likely to increase in frequency and severity on drought-prone forest and woodland trees in Scotland. In addition to good silvicultural practice, it is concluded that the potential of damage to trees from pathogens must be factored into future climate change adaptation strategies.

Introduction

One of the more consistent climate change projections for the UK is for altered patterns of precipitation over the next few decades, with lower summer rainfall leading to more frequent droughts, particularly in the east of the country (Broadmeadow and Ray, 2005; Ray, 2008). Based on these projections, drought will become an important climatic factor affecting the health of trees in Britain, and a combination of drought stress and fungal diseases may limit the commercial viability of certain forest tree species in some areas. This study focuses on identifying drought-risk forest sites in Scotland, but there is the potential for a similar method to be used in the future for England and Wales.

Disease Diagnostic Advisory Service (DDAS) records held at Forest Research Northern Research Station show that 102 cases of confirmed or suspected drought damage to trees in northern England and Scotland were reported between 1972 and 2006, with many of these cases (given in parentheses below) occurring in the years following known drought episodes 1972 (8); 1977/78 (13); 1983–1985 (16); 1989/1990 (11); 1995 (11); 2004 (10). The most frequently affected tree species, with number of records in parentheses, were beech (*Fagus sylvatica*) (23); Sitka spruce (*Picea sitchensis*) (15); larch (*Larix* spp.) (10); and Norway spruce (*Picea abies*) (9).

Symptoms of drought in trees

Symptoms of direct drought damage in trees include foliage wilting and browning and crown dieback, leading – in severe cases – to tree mortality. For a number of conifer species, in particular spruce and fir, the formation of longitudinal, somewhat spiralling stem cracks (Day, 1954) is common in drought years. In 2003, drought caused severe damage to Sitka spruce in northeastern Scotland, leading to 14–20 % mortality of this species at some sites (Green *et al*., 2008). Trees which survived had varying degrees of dieback, longitudinal stem cracking, and lenticular-shaped bark lesions (Figure 1) accompanied by extensive resin bleeding. This species is generally regarded as intolerant of high moisture deficits (Pyatt *et al*., 2001), being native to the Pacific northwest coast of North America with its associated climate of high rainfall and humidity (Lines, 1987).

Splitting or cracking of the timber of Sitka spruce and Norway spruce, as a result of drought stress (Figure 2), has been reported several times previously in Scotland, sometimes only becoming apparent when trees with no external symptoms have been felled and converted into sawn timber (Gregory and Redfern, 1987). Direct drought damage may contribute to the syndrome known as 'top dying' in Norway spruce, and repeated summer drought is thought to be one of the factors causing long-term dieback of mature oak, ash and beech in Britain (Gregory and Redfern, 1998).

Figure 1 Lesion and resin bleeding on drought-stressed Sitka spruce in eastern Scotland.

Figure 2 Internal radial cracking in the wood of Sitka spruce damaged by drought.

Association of fungal disease with drought stress in trees

It has long been recognised that interactions exist between drought stress and fungal diseases of forest trees, with drought-stressed trees being more susceptible to disease (Bier, 1959; Hepting, 1963; Schoeneweiss, 1975). A comprehensive review of studies on drought–disease interactions in forest trees has been undertaken in response to the Europe-wide drought in 2003 and predictions of an increase in such drought episodes due to climate change were given (Desprez-Loustau *et al*., 2006). In many cases, pathogens which cause damage to trees weakened by drought stress are already present on their hosts before the drought period occurs, either as saprophytes or as asymptomatic, latent endophytes. Other pathogens are opportunistic, entering the drought-weakened host through wounds caused by physiological damage or through the activities of insect vectors. It is thought that drought-stressed trees are predisposed to disease because water stressed tissues act as a better substrate for pathogen growth, and/or because drought-stressed trees have decreased defence mechanisms (Desprez-Loustau *et al*., 2006).

The approach of this study

It is currently difficult to predict which fungal diseases will become more prevalent on forest trees under conditions of increased frequency and severity of drought. This research aims to address this by first identifying forest sites where drought is most likely to occur, and then identifying the tree species associated with these sites. This process forms the basis for a theoretical assessment of the risks posed by drought and fungal disease for the predominant tree species growing on drought-prone sites.

The first section of this Research Note describes spatial modelling to indicate forest sites most at risk of drought in Scotland. The second section describes the results from a literature review undertaken to assess the risks to plantation forestry posed by drought and fungal disease in eastern Scotland. The literature review was extended to include semi-natural woodland, hedgerow and amenity trees.

Predicting drought risk

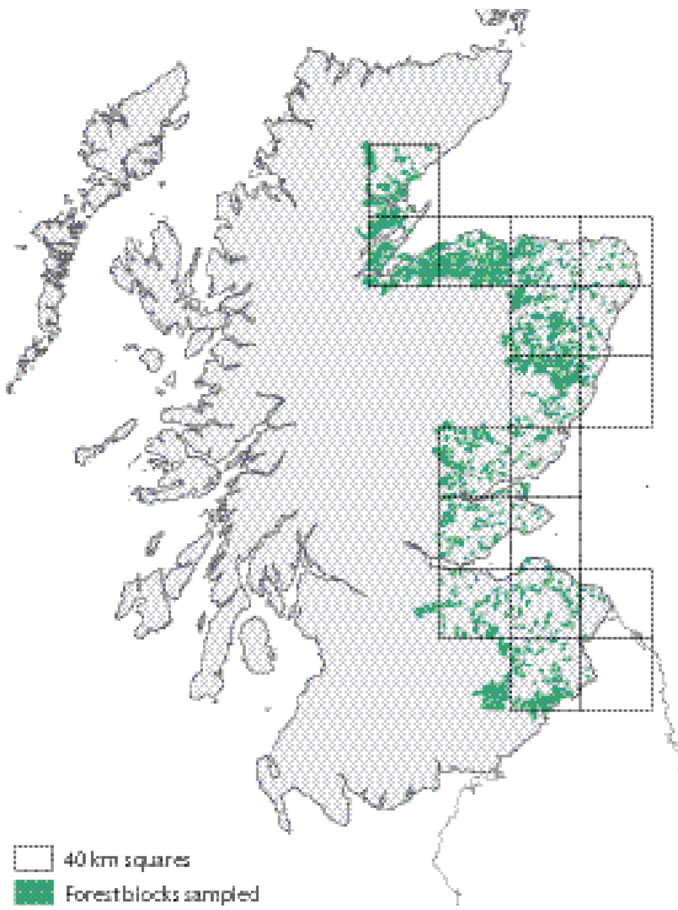
Methodology

Data from the Meteorological Office Regional Evapotranspiration Calculation System (MORECS) were obtained for Scotland for the period 2001–2005. This provided information on the distribution and severity of moisture stress in Scotland over a sequence of years which included 2003, a year of severe drought in eastern and southern Scotland. MORECS provides estimates of weekly and monthly evaporation and soil moisture deficits for the UK calculated from the Penman–Monteith method (Monteith, 1973) with synoptic weather data (rainfall, sunshine, temperature, vapour pressure, wind speed) as well as soil and surface cover information. MORECS moisture deficit output is presented as a 40 x 40 km resolution grid. Also, data used in the analysis included climate data calculated for Ecological Site Classification (Pyatt *et al*., 2001). Together, these data comprise a climatic index of moisture deficit, calculated as the maximum excess of monthly evaporation over rainfall for the 30-year climatic baseline period 1961–1990. In addition, moisture deficit predictions for Low and High carbon emissions scenarios for the 30-year climatic periods centred on 2050 and 2080 (Ray *et al*., 2008) were calculated from the United Kingdom Climate Impacts Programme (UKCIP) data (Hulme *et al*., 2002).

The Intergovernmental Panel on Climate Change (IPCC) has defined a range of scenarios to cover future uncertainties associated with the main drivers of green-house gas emissions, these include demographic, technological and economic development factors. UKCIP (Hulme *et al*., 2002) has grouped scenarios into four categories: Low, Medium-Low, Medium-High, and High, based on classes of global cumulative CO_2 emissions.

Using the high MORECS moisture deficits calculated for 2003, or from the projected moisture deficits for the High emissions scenario in 2050 and 2080, 18 of the MORECS 40 km squares in the east of Scotland (Figure 3) were considered likely to have a high frequency and severity of moisture deficit in the future climate. Drought conditions during a dry summer usually have the greatest effect on forest sites with freely-draining, shallow soils. These sites have a low inherent water holding capacity, on which moisture deficits of 180–200 mm would deplete the soil of available moisture accessible by trees. Such areas were assessed within the 18 drought-prone/risk MORECS squares by sampling the *Soil survey of Scotland soil series* published on 1:63360 paper maps (Hipkin *et al*., 1987–90) on a regular 1 km grid that intersected areas of woodland described by the *National inventory of woodlands and trees* 'Indicative forest type' data (Forestry Commission, 2003). The sampling process

Figure 3 Location of the 18 MORECS squares and sampled forest blocks considered most at risk of drought in Scotland.



provided data on the forest type (conifer, broadleaf, mixed) and the main forest soil series (converted to Forestry Commission soil type) in eastern Scotland. The tree species composition of stands was determined for all sampled Forestry Commission forest sub-compartments using a GIS-based forest management system, and for sampled privately-owned forests with the assistance of Forestry Commission Conservancy offices.

The forest soils were assessed for drought potential from the soil series summary descriptions (Hipkin *et al.*, 1987–1990). Information used to assess drought potential included available water capacity, rooting depth, texture and induration. Freely- and excessively-draining soils were classed as having a high drought potential; imperfectly- and poorly-draining soils were classed as having low drought potential; imperfectly-draining, but indurated soils likely to constrain rooting depth were classed as having moderate drought potential. Soil complexes were classed according to the primary soil component.

Classification of drought risk was obtained by linking the drought potential of sites with the eighteen 40 km squares classed with a moisture deficit of 200 mm or more from calculations based on UKCIP02 projections using the High emissions scenario, or where MORECS indicated a moisture deficit of 200 mm or more in 2003. A high drought risk class was given to high drought potential soils which were within the identified MORECS squares. A medium drought risk class was given to soils of moderate drought potential, including brown earths, and a class of low drought risk was assigned to gleys and peat of low drought potential.

Results

Figure 4 shows the location of all 288 sampled forest sites (Forestry Commission and privately owned), which were determined to be of medium or high drought risk. For forests managed by the Forestry Commission, a total of 870 forest sub-compartments were sampled. Of these, 217 forest sites were identified as having a medium or high drought risk, 76 of which have Sitka spruce as a major component (Table 1). For privately owned forests, a total of 231 forest sites were sampled and 71 identified as having a medium or high drought risk, 49 of which have Sitka spruce as a major component (Table 1). Scots pine (*Pinus sylvestris*) is the second most frequently occurring tree species on the medium or high drought risk forest sites identified in this study (Table 1). Other tree species which form major components of medium or high drought risk sites include:

- Larch (hybrid, *Larix* x *eurolepsis*; European, *Larix decidua*; Japanese, *Larix kaempferi*)
- Norway spruce
- Mixed broadleaves
- Douglas fir (*Pseudotsuga menziesii*).

Figure 4 Location of Forestry Commission and privately owned forest sites determined to be of moderate or high drought risk.

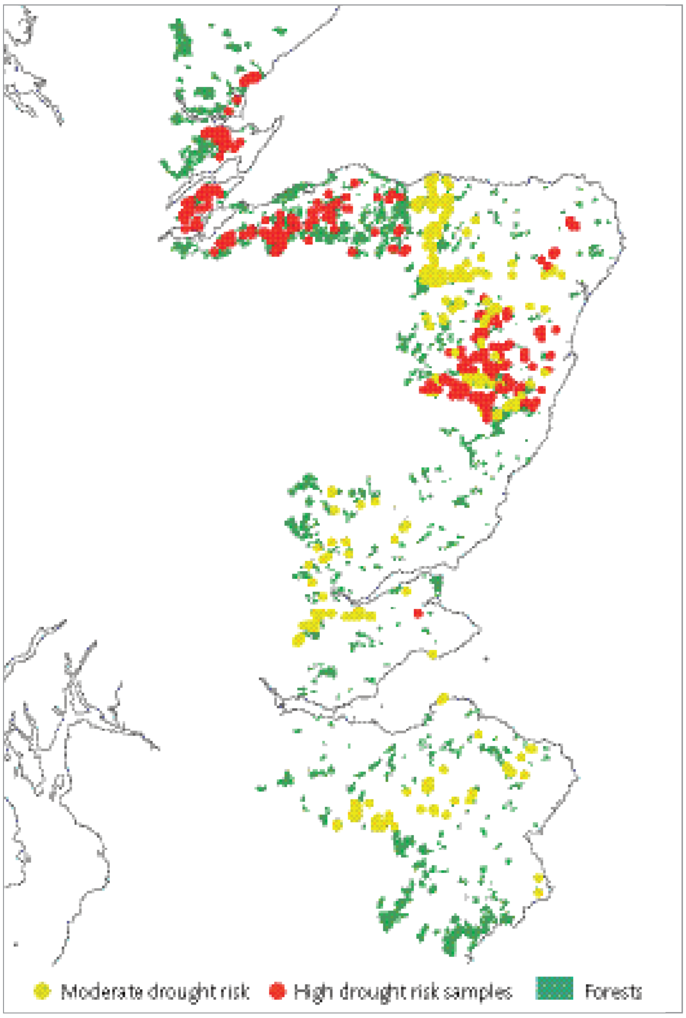


Table 1 Tree species occurring on medium or high drought risk sites in eastern Scotland. Data are the number of sampled forest blocks, either Forestry Commission or privately owned, in which each species forms a major component.

Species*	Forestry Commission forests	Privately owned forests	Total no. of drought risk forest sites per species
Sitka spruce (*Picea sitchensis*)	76	49	125
Scots pine (*Pinus sylvestris*)	60	41	101
Larch (*Larix* spp.)	24	23	47
Norway spruce (*Picea abies*)	13	10	23
Mixed broadleaves	5	14	19
Douglas fir (*Pseudotsuga menziesii*)	8	5	13

* Note that some sampled forest blocks contained more than one species.

Drought related diseases

Root disease

Armillaria spp. and *Heterobasidion annosum* are root diseases which have been linked with drought conditions. For example, both of these diseases increased in incidence in forests in eastern Europe following an extended drought which occurred during 1982–1984 (Przezbórski, 1987). Under future climate scenarios, these diseases are likely to increase in frequency and severity on a range of susceptible tree hosts growing on sites of medium or high drought risk in Scotland.

Armillaria spp. are ubiquitous throughout Britain and infect a range of conifers as well as many broadleaved tree species, including beech and oak. These fungi infect and decay the root systems of host trees, and also in some cases infection may spread some distance up the stems. Symptoms of infection include bleeding, usually around the stem base (resin bleeding in the case of conifers (Figure 5)) and the production of white mycelial sheets which grow in the inner bark (Figure 6). On restock sites it is common for groups of young trees to show symptoms of needle yellowing and die as a result of *Armillaria* infection.

Some species of *Armillaria*, such as *A. gallica* and *A. cepistipes*, are generally considered to be weak pathogens and only able to invade and cause mortality in trees which are stressed by other factors, whereas *A. ostoye* is more aggressive with the ability to cause mortality in otherwise healthy trees (Gregory and Redfern, 1998). There have been cases in 2004–2006 of *A. gallica* causing mortality in oak and beech in eastern Scotland (DDAS records) and this may be linked with effects of recent droughts since drought stress in trees is thought to act as a predisposing factor to infection by *Armillaria* spp. (Gregory and Redfern, 1998; Desprez-Loustau *et al*., 2006). Although studies designed to test this effect on various tree hosts have not shown a clear trend (Desprez-Loustau *et al*., 2006), Popoola and Fox (2003) demonstrated an increased susceptibility to *Armillaria* spp. of a number of plant species subjected to water stress. Since the likelihood of invasion of woodland and persistence by *Armillaria* spp. increases with successive rotations, these diseases will become more damaging in British forests, particularly on drought risk sites, due to group mortality in young restock sites as well as in older plantations and semi-natural woodland.

The fungus *Heterobasidion annosum* is a common causal agent of root and butt rot in stands of Sitka spruce, Norway spruce, Scots pine and other conifer species across Scotland. It infects cut stumps and invades the root systems and stem bases of host trees. Symptoms of disease include resin bleeding, usually around the stem base, and presence of fungal fruiting bodies which may be observed around the bases of infected trees or on adjacent cut stumps (Figure 7). However, these symptoms are not always present and infection is only revealed when the tree is felled and signs of heartwood discolouration or rot become visible (Figure 8). *H. annosum* was found to show enhanced infection and growth in young spruce trees experiencing moderate drought stress, although infection rates decreased under severe drought stress (Lindberg and Johansson, 1992). The risk of inoculum build-up and infection of Sitka spruce by *H. annosum* is considered to be greatest on freely-draining mineral soils in low rainfall areas in the east and south of Scotland (Redfern *et al.*, 2001); also pines may experience outright mortality due to the fungus on free-draining high pH soils (Gregory and Redfern, 1998). Since the fungus invades forest sites via cut stumps, stump treatment will be necessary on medium and high drought risk sites where the disease has not yet established to reduce risks of new infections arising.

Figure 5 Basal resin bleeding due to *Armillaria* infection.

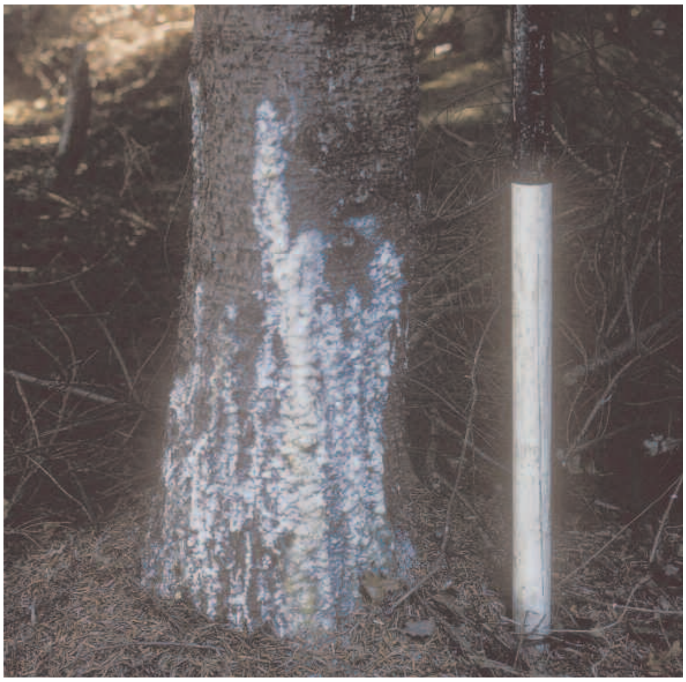


Figure 6 White mycelial sheets of *Armillaria* on bark of infected Scots pine.

Figure 7 *Heterobasidion annosum* fruit body on infected stump.

Figure 8 Discolouration and decay in logs infected with *Heterobasidion annosum*.

Insect-vectored disease

Conifers

Scots pine is a major component of 101 medium or high drought risk sites in eastern Scotland (Table 1). Although this species is more tolerant of drought than other conifers and is currently well suited to freely-draining soils in the east of Scotland, drought-stressed Scots pine are more susceptible to infection by the bark beetle *Tomicus piniperda* (Gregory and Redfern, 1998). This species generally breeds in newly-dead or felled trees and the adults infect adjacent, standing trees by boring up the centre of current season shoots which eventually break off and lie scattered on the ground (a symptom known as shoot pruning). *T. piniperda* can also infect and breed in the cambium on the main stems of live trees experiencing stress due to drought, and transmit blue stain fungi such as *Leptographium* spp. and *Ophiostoma* spp. These fungi invade the phloem and sapwood of infected trees, causing blue staining (Figure 9) which reduces timber quality, and in combination with larval feeding in the phloem may even cause tree mortality in cases of severe infection. Drought may also increase the susceptibility of Scots pine sapwood to direct infection by *Leptographium* spp. (Croisé *et al*., 2001).

Figure 9 Blue stain in timber of Scots pine.

Species of larch occur as major components of 47 of the medium or high drought risk forest sites identified in this study (Table 1), and are particularly susceptible to drought (Gregory and Redfern, 1998). Dieback and mortality of larch trees arising directly from drought damage has been recorded several times previously in Scotland (DDAS database). Larch which are subject to drought stress appear to show increased susceptibility to infection by the bark beetle *Ips cembrae* which acts as a vector for the fungus *Ceratocystis laricicola* (Redfern *et al*., 1987). The beetle infects and breeds in the cambium of the main stems of standing trees (Figure 10), particularly when trees are under stress, and adjacent to newly-felled larch logs which may harbour beetle populations.

Figure 10 Main stem of larch attacked by *Ips cembrae*.

The fungus, *C. laricicola*, which is introduced by the beetle then invades the sapwood of damaged trees, causing blue staining and associated losses in timber quality, and may also cause dieback and mortality of entire trees (Redfern *et al*., 1987). The beetle was first recorded in Scotland in 1955 and has caused periodic damage since that time, and it is likely that the number of cases will increase on drought-prone sites due to climate change. To reduce the risks of bark beetle infection of pine and larch on drought-risk sites, prompt removal of felled logs or windthrown trees will be necessary to reduce the likelihood of build-up of local beetle populations.

Broadleaves

With changes in climate due to emissions of greenhouse gases, it is likely that there will be a notable increase in drought-associated long-term 'declines' of mature beech, oak and ash in Scotland. In addition to root-infecting *Armillaria* spp., both beech and oak are susceptible to *Biscogniauxia* spp. which are latent fungal pathogens with the potential to infect trees and remain asymptomatic for years until a factor such as drought stress triggers the development of disease. *Biscogniauxia nummularia* occurs on beech in southern Britain and causes elongated, blackened bark lesions known as 'strip cankers' on the stem and branches of affected trees, resulting in decay and mortality of branches. In a study in southern Britain, *B. nummularia* cankers were found to develop on beech in the years following drought periods and were more common in areas where low rainfall and high temperatures had been recorded (Hendry *et al*., 1998). This disease may become a problem in areas of eastern Scotland under extended periods of drought and high temperatures.

Conclusions

This study identified 288 medium or high drought risk forest sites in eastern Scotland, 125 of which include Sitka spruce as a major component. Sitka spruce is intolerant of drought and is known to have previously experienced drought damage such as tree mortality and stem cracking in eastern Scotland. Cases of direct drought damage, together with infections by the root diseases, *H. annosum* and *Armillaria* spp., are likely to increase on Sitka spruce and other species in eastern Scotland as a result of climate change.

Scots pine and larch are predicted to experience increased infection by bark beetles and bluestain fungi on drought-prone sites. Damage to Norway spruce due to top-dying will become more widespread and severe in the east.

Biscogniauxia nummularia, a latent fungal pathogen, has the potential to spread northwards from southern England to cause increased damage to beech, and possibly oak, in Scotland due to a combination of higher summer temperatures and drought.

Mature broadleaved species such as oak, ash and beech are also likely to show a decline in health in some areas associated with drought stress and root diseases.

In addition to good silvicultural practice, it is concluded that the potential of damage to forest trees from drought and drought-related pathogens must be factored into future climate change adaptation strategies. This means it is likely to become even more important to match tree species to site conditions. This will help to ensure that drought-susceptible species such as Sitka spruce, Norway spruce, larch and beech are planted on sites with suitable soil moisture regimes in the current climate, and the projected future climate. More drought-tolerant species such as Scots pine, Douglas fir or ash (*Fraxinus* spp.) should be considered for droughty sites.

References

BIER, J.E. (1959). The relation of bark moisture to the development of canker diseases caused by native, facultative parasites. I. Cryptodiaporthe canker on willow. *Canadian Journal of Botany* **37**, 229–238.

BROADMEADOW, M.S.J. and RAY, D. (2005). *Climate change and British woodland*. Forestry Commission Information Note (FCIN069). Forestry Commission, Edinburgh.

CROISÉ, L., LIEUTIER, F., COCHARD, H. and DREYER, E. (2001). Effects of drought stress and high density stem inoculations with Leptographium wingfieldii on hydraulic properties of young Scots pine trees. *Tree Physiology* **21**, 427–436.

DAY, W.R. (1954). *Drought crack of conifers*. Forestry Commission Forest Record 26. HMSO, London.

DESPREZ-LOUSTAU, M-L., MARCAIS, B., NAGELEISEN, L-M., PIOU, D. A and VANNINI, A. (2006). Interactive effects of drought and pathogens in forest trees. *Annals of Forest Science* **63**, 597–612.

FORESTRY COMMISSION (2003). *National Inventory of Woodland and Trees: Great Britain*. Forestry Commission Inventory Report. Forestry Commission, Edinburgh.

GREEN, S., HENDRY, S.J. and REDFERN, D.B. (2008). Drought damage to pole-stage Sitka spruce and other conifers in north-east Scotland. *Scottish Forestry* **62**, 10–18.

GREGORY, S.C. and REDFERN, D.B. (1987). The pathology of Sitka spruce in northern Britain. *Proceedings of the Royal Society of Edinburgh* **93B**, 145–156.

GREGORY, S.C. and REDFERN, D.B. (1998). *Diseases and disorders of forest trees*. Forestry Commission Field Book 16. The Stationery Office, London.

HENDRY, S.J., LONSDALE, D. and BODDY, L. (1998). Stripcankering of beech (*Fagus sylvatica*): pathology and distribution of symptomatic trees. *New Phytologist* 140, 549–565.

HEPTING, G.H. (1963). Climate and forest diseases. *Annual Review of Phytopathology* 1, 31–50.

HIPKIN, J.A., DRY, F.T., LILLY, A., WALKER, A.D., NOLAN, A.J., HUDSON, G., CAMPBELL, C.G.B., GAULD, J.H., HENDERSON, D.J., HESLOP, R.E.F., TOWERS, W. and BELL, J.S. (1987–90). *Soil series description sheets*. Macaulay Land Use Research Institute, Aberdeen.

HULME, M., JENKINS, G.J., LU, X., TURNPENNY, J.R., MITCHELL, T.D., JONES, R.G., LOWE, J., MURPHY, J.M., HASSELL ,D., BOORMAN, P., MCDONALD, R. and HILL, S. (2002). *Climate change scenarios for the United Kingdom*. The UKCIP02 Scientific Report. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich.

LINDBERG, M. and JOHANSSON, M. (1992). Resistance of *Picea abies* seedlings to infection by *Heterobasidion annosum* in relation to drought stress. *European Journal of Forest Pathology* 22, 115–124.

LINES, R. (1987). *Choice of seed origins for the main forest species in Britain*. Forestry Commission Bulletin 66. HMSO, London.

MONTEITH, J. L. (1973). *Principles of environmental physics*. Edward Arnold, London.

POPOOLA, T.O.S. and FOX, R.T.V. (2003). Effect of water stress on infection by species of honey fungus (*Armillaria mellea* and *A. gallica*). *Aboricultural Journal* 27, 139–154.

PRZEZBÓRSKI, A. (1987). Effect of a long drought on the occurrence of root rots caused by *Fomes annosus* [*Heterobasidion annosum*] and *Armillaria mellea*. *Sylwan* 131, 43–52.

PYATT, G., RAY, D. and FLETCHER, J. (2001). *An ecological site classification for forestry in Great Britain*. Forestry Commission Bulletin 124. Forestry Commission, Edinburgh.

RAY, D., PYATT, G. and BROADMEADOW, M.S.J. (2002). Modelling the future climatic suitability of plantation forest tree species. In: *Climate change: impacts on UK forests*. Forestry Commission Bulletin 125. Forestry Commission, Edinburgh. 151–167.

RAY, D. (2008). *Impacts of climate change on forestry in Scotland – a synopsis of spatial modelling research*. Forestry Commission Research Note (FCRN101). Forestry Commission Scotland, Edinburgh.

REDFERN, D.B., PRATT, J.E., GREGORY, S.C. and MACASKILL, G.A. (2001). Natural infection of Sitka spruce thinning stumps in Britain by spores of *Heterobasidion annosum* and long-term survival of the fungus. *Forestry* 74, 53–71.

REDFERN, D.B., STOAKLEY, J.T., STEELE, H., and MINTER, D.W. (1987). Dieback and death of larch caused by *Ceratocystis laricicola* sp. nov. following attack by *Ips cembrae*. *Plant Pathology* 36, 467–480.

SCHOENEWEISS, D.F. (1975). Predisposition, stress, and plant disease. *Annual Review of Phytopathology* 13, 193–211.

Enquiries relating to this publication should be addressed to:

Sarah Green
Forest Research
Northern Research Station
Roslin
Midlothian EH25 9SY
Telephone: +44 (0)131 445 2176

sarah.green@forestry.gsi.gov.uk
www.forestresearch.gov.uk

For more information about the work of Forest Research, visit: www.forestresearch.gov.uk

For more information about Forestry Commission publications, visit: www.forestry.gov.uk/publications

If you need this publication in an alternative format, for example in large print or another language, please telephone us on **0131 314 6575** or send an email request to: **diversity@forestry.gsi.gov.uk**

FCRN004/FC-GB(ECD)/ALDR-1.5K/SEP09

ISBN: 973-0-85538-784-6