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RESEARCH ARTICLE

Increased Long-Term Threat from Climate Change to Susceptibility of Sitka Spruce Plantations Growing in Peat Soils in Upland UK to Root and Butt Rotting Attacks by *Heterobasidion annosum*

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Abstract

The recommendations made in 2002 (Pratt 2003) for prophylactic stump treatment in UK forests against *Heterobasidion annosum* Fr. Cke. (hereafter *H. annosum*) on Sitka spruce (*Picea sitchensis* Bong. Carr.) were based on over 50 years continual research by the UK Forestry Commission into the risk posed by this destructive pathogen. They were predicated on the silvicultural and environmental conditions that were relevant during the second half of the 20th century: a period of expansion of upland forestry as techniques for establishing commercial crops on peat-dominated soils improved. The almost certain onset of climate-change and its effect on the physical, chemical and biological nature of peat, which in 2002 was assessed as of low risk from *H. annosum*, now requires to be taken into account and the need for new research into this threat examined. This paper reviews the research that underpinned the 2002 recommendations.

Keywords: *Heterobasidion Annosum*, Sitka Spruce, Climate Change, Peat, Uk.

1. Introduction

Current projections for climate change in the uplands of Britain posit hotter summers, increased winter rainfall and more extreme wind events (Yu, Berry, et al 2021). The impact these will have on the long-term risk to Britain's commercial Sitka spruce stands from root disease and heartwood decay caused by *H.annosum* has yet to be evaluated. This paper concentrates on those crops on peats which field trials between 1970 and 2000 demonstrated were at insufficient risk from *H. annosum* to justify the prophylactic stump treatment that is now advised for stands in low rainfall areas on mineral soils.However, predicted effects of climate change raise the possibility that such sites might, in fact, become highly susceptible if peat is denatured and desiccated by hotter summers. But because the factors that attenuate disease spread on shallow peat are unknown, and may take several years to evaluate, this paper makes some recommendations for research to be made into this issue without delay.This is because the area of Sitka spruce forest planted on peaty soils in the UK represents a significant proportion of our productive forest.These stands, for historical and environmental reasons, are almost clear of disease but may be very vulnerable under a hotter climate.

1.1 *H.annosum* in Britain

Rishbeth (1949) established that the pathogen spreads long distances (up to 300km) by means of airborne basidiospores released from perennial fruitbodies growing on the bases of diseased trees and stumps. It is a poorly competitive pathogen except on the "sterile" surfaces of freshy-cut conifer stumps that can be rapidly colonised by its spores. The infection of fresh stumps provides it with access into previously disease-free woods and plantations which can, once colonised, remain infected in perpetuity, since the fungus may survive in stumps for decades (Greig and Pratt 1976). From the stump surface, *H. annosum*

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grows down into the woody mass of a stump and thence out into the roots. Where infected roots are in contact with live roots of adjacent trees, the fungus can invade and kill cambial tissue in healthy tree roots, which in spruce can lead to heartwood decay stretching several metres up the stem (Pratt 1979 a,b,c.), an increased risk of windblow (Korhonen and Stenlid, 1998) and, of equal concern, raised susceptibility to bark beetles (Filip and Morrison, 1998).

An extensive survey during the 1950's of most of the FC forests discovered that the pathogen was widespread throughout Britain in older, mainly second-rotation conifer stands, the majority on mineral soils (Low and Gladman 1960). Disturbingly, it was also found to have spread by airborne spores into some young first-rotation crops where it had infected early thinning stumps. This work led to out-plantings within diseased clear-fell sites of a wide variety of conifer species to establish their resistance to the disease (Greig et al 2001).

Rishbeth (1952) recommended prophylactic control by treatment with a chemical or biological agent to prevent germination of spores on the stump surface, and this was adopted wide-scale by the Forestry Commission (hereafter FC) in the late 1960's in all crops, until further research showed if there were sites or species inimical to the fungus. Stump treatment required an investment which, in discounted terms, would not be redeemed for many years, (Pratt 1998) and was thus somewhat an act of faith. However, it remains the only cost-effective treatment available and is now used in many countries.

After 1970, British research was aimed at establishing the contributions that climate and soil exercised over the epidemiology of the fungus in first-rotation unthinned stands of Sitka spruce in the uplands. These included trials involving sampling of thousands of stumps and excavated root systems, and hundreds of felled trees, by Forest Research over some 20 years.

1.2 The Field Work on Sitka Spruce

Research was needed to establish:

1. The susceptibility of Sitka spruce thinning stumps to infection by airborne basidiospores of *H.annosum.*
2. The effects, within stumps, of endogenous and exogenous factors that determined the colonisation of stumps by *H.annosum* to the point where the pathogen could spread vegetatively from stump to tree.
3. The edaphic and climatic factors that affected vegetative spread of the pathogen from infected stumps into the roots and stems of adjacent standing trees.

All this work is described and summarised in detail in a series of papers by Redfern (1982, 1993, 1998). What follows is a brief summary of the results.

2. Stump Infection

A system was devised of inoculating fresh stumps with viable basidiospores of *H. annosum* at known concentrations which included over 5000 fresh stumps in trials that examined the effects of soil, climate, stump moisture content and (separately) stump treatment with urea and borates on disease initiation in Sitka spruce thinning stumps.The effects of inoculation were estimated by measuring the areas colonised by the fungus after periods of from 2 to 8 years on cross-sectional discs cut from below stump surfaces.

Inoculations (both with spores and with a sterile water control that allowed natural infection to occur) were undertaken in the main experiment on 48 sites, allocated to areas of high (>1600mm) and low (<1600mm) of rainfall, repeated on mineral and peaty soils (Fig 1).

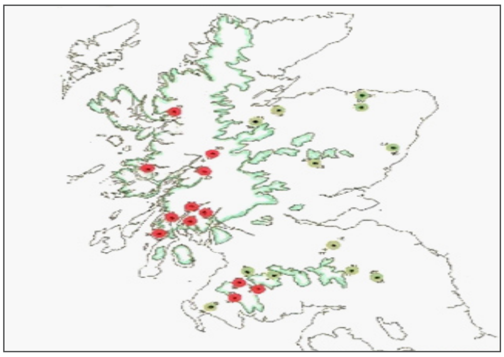

Figure 1. *Locations of inoculation sites.High rainfall (red) and low rainfall (olive) sites, at each of which one plot was established on peat, and the other on mineral soil.The 1600mm rain isohyet is marked in green.*

Table 1. *Mean frequency (%: rounded) of H. annosum in stumps inoculated with basidiospores or exposed to natural infection, averaged over 48 sites. (n=75).*

Low rainfall				**High Rainfall**			
Inoculated		Uninoculated		Inoculated		Uninoculated	
Mineral	Peat	Mineral	Peat	Mineral	Peat	Mineral	Peat
80%	69%	19%	12%	90%	74%	5%	6%

These results demonstrate the susceptibility of Sitka spruce stumps to air borne spore infection on mineral and, significantly, on peat soils in first rotation, unthinned stands in the uplands of Britain and (especially in areas of high rainfall) the relative paucity of natural inoculum available, as expressed in the lower infection of control stumps.(see Redfern, Pratt, Gregory and MacAskill, 2001, for a full discussion on these data).

3. Stump Colonisation

Unscrambling the factors that determine the ability of the pathogen to fully colonise the body of a stump that became infected by spores to the point where it can become a potent donor of disease to an adjacent, healthy tree proved the most difficult and intractable issue (see Morrison and Redfern 1994 for an in-depth discussion on the role of water in this problem). In stumps infected by spores (whether naturally or, or by inoculation) subsequent colonisation appeared to be concentrated in one of three main areas: within sapwood, within heartwood, or along the junction of the two (Redfern and Stenlid, 1998). The reason for such individual stump bias has not been studied, but what is clear is that it was not related to soil type and is not a factor to consider in relation to the hazard of the disease on peat soils.

4. Edaphic and Climatic Effects on Disease Transfer

Disease transfer depends on intimate contacts between infected roots of a stump and live tree roots in a soil environment that the pathogen can utilise.

Figure 2. *Root contact between an infected Sitka spruce thinning stump (right) and a standing infected, decayed neighbouring tree in root contact (left).The decay column, over 1m high, had developed within 6 years of stump infection. Ex-agricultural brown earth, Farigaig Forest, North Scotland, 2002.*

However, the complexities of the structure and distribution of tree roots within a soil matrix that is infinitely variable make this the most challenging aspect of the disease cycle to study and to predict.

Observations made throughout the pathogen's natural range (Korhonen and Stenlid *ibid*: p66) suggest that some soils are conducive to disease spread while others impede it. For example, in SE England open-texture, dry sandy loams above pH6 encourage rapid growth of the pathogens in pine roots of both stump and tree, while soils of similar physical structure but with lower pH (below pH4.5) impede its growth (Greig 1984) The reason for this difference appears to lie, *inter alia*, with the microflora on the root epidermis among which the roots are embedded. These soils, derived from windblown loess on chalk, are not typical of the acid soils of the uplands, where in mineral soils the pathogen thrives and yet is inhibited by wet, peaty substrates regardless of the frequency of root contacts in that often-saturated medium. This crucial aspect of the disease epidemiology was studied over a ten year period (Redfern, Pratt, Hendry and Low 2010) in which the the vegetative spread of the fungus from stump to tree in fifteen 1st rotation unthinned stands of Sitka spruce were compared, each on one of five soil types, namely: brown earth, surface water gley, peaty ironpan, peaty gley, and deep peat[1](a total of 675 trees).

On each site, 45 co-dominant trees scattered across a stand were felled, and two or three lateral roots growing towards neighbouring trees were partially exposed about 30cm from the resulting stump edge. The upper surface was drilled to accept a beech plug 25mm dia (axial) and 25mm deep, pre-colonised by one of two isolates of *H. annosum*: one from a badly-decayed Sitka spruce, and one from a Lodgepole Pine (*Pinus contorta* Dougl. Ex Loud.) that had been killed by the fungus. In other words, isolates of the pathogen with proven ability to kill roots and decay stems. After incubation periods of 5,7,9 or ten years in the forest all the stump roots down to a depth of perhaps 50cm from both the inoculated stump and each of the surrounding trees (max 8) were exposed by careful excavation, and death among roots of otherwise healthy trees was investigated (Fig 2). Those which were killed or decayed by *H. annosum* were traced back proximally to the base of the standing parent tree, which was felled and sectioned to determine presence and height of the decay column within. The work described involved the excavation of over 5000 root systems of pole-stage standing Sitka spruce, and it provided an insight into the influence that different upland soils had on the ability of the pathogen to spread underground and initiate disease in standing trees.

Table 2. *Numbers (%) of infected Sitka spruce trees on three sites in the Southern Uplands of Scotland and five soils after 5 – 10 years since inoculation of neighbouring stumps.*

	Soil type				
Time (yrs) since inoculation	**Brown Earth**	**Surface-water gley**	**Peaty iron pan**	**Peaty gley**	**Deep peat**
5	4.5	6.7	0.5	6.1	4.5
7	8.4	20.5	0.5	7.6	7.3
9	18.7	39.5	4.5	5.4	5.1
10	19.6	34.3	2.9	11.2	3.5
Mean %	18.8	36.5	4.0	8.0	4.3

Like much of this work, the results were subject to considerable variation, and it would be inappropriate to attempt to make direct comparisons between individual soil types. However, two factors of significance appear in these results. First, the gradual increase of infection over time, showing the relatively slow rate of disease spread in these upland sites. Second, the greater frequency of disease transfer on mineral soils compared to those with a peaty element is noteworthy. Major differences in rooting habits of trees on each of the soil types were observed and some work was done to attempt to characterise each, but

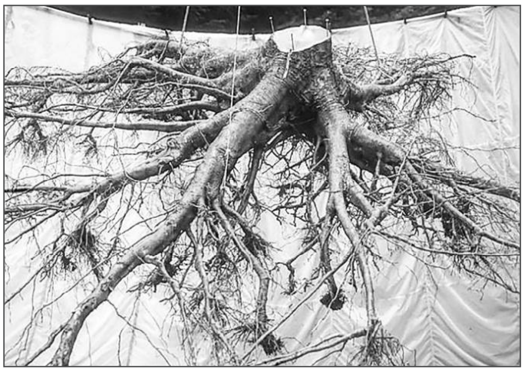

Figure 3. *The complexity of the rooting pattern, affecting inter alia root contact potential, is shown in this stump from 25 yr old Sitka spruce growing on peaty-gley. Note the proliferation of roots and bunching of fine roots at the junction of the (upper) peat layer and the mineral below.*

[1] For definitions see Pyatt D G 1970. Soil Groups of Upland Forests .Forestry Commission Forest Record np 71, Pp50.

such work fell outside the remit of the overall project and because of its complexity, inherent variability and lack of resources it was never completed.

During the extensive root excavation undertaken in this work, it proved not possible to arrive at a cause of the poor disease transmission that occurred on moist or wet peaty soils, regardless of the large numbers of intimate contacts observed between diseased stump roots and the roots of neighbouring trees growing in peat compared to mineral soil. This is a key issue and is discussed below.

5. Economic Implications

Sufficient epidemiological data were collected during the course of the 30 years of fieldwork described above for a stochastic predictive model of the disease to be created (Pratt *et al* 1989: Pratt, Shaw and Vollbrecht 1998). This was used to make a crude estimate of volumes lost through decay caused by *H. annosum* on mineral and peat soils in commercial Forestry Commission stands of spruce and larch throughout Britain over the next 150 years, assuming that the state of the peat was unaltered during that period. Each group of stands (of which there may have been 10,000) were allocated to one of 108 categories based on rainfall, current rotation, current age, yield class and a proxy for soil. In simple terms, it was estimated that in the absence of stump protection, annual losses throughout the FC would rise from around 13 000 cu m/yr^{-1} in the first 50 years to 43,000 cu m /yr^{-1} in the next 50 years (Pratt 2005).

The assumption underpinning these estimates was that the peaty soils would remain hydrated through that period and would limit the disease to the mineral soils. However, the onset of a major change in climate as predicated might lead to a drying out of peat. If this has the effect of allowing the disease to spread in crops on peat soils, the losses described above would likely be doubled during that period.

6. Discussion

At the completion of the fieldwork described above, it was necessary to answer the question “is prophylactic stump treatment needed for all first-rotation upland Sitka spruce?”, with the explicit aim to maintain disease within these crops at present levels far into the future. We wanted to avoid the levels of disease and decay that have developed throughout N European spruce forests over centuries of harvesting without recourse to stump treatment, where yearly losses were estimated in 2003 at around € 800 million (Woodward *et al* 2003). These estimates exclude losses from increased predisposition of decayed stands to windblow and insect attack, which have so far not been measured.

The stochastic spatial mathematic model described above was varied to simulate disease progression through a 1 ha stand of Sitka spruce over two succeeding rotations. The expected outcome was an estimate of the losses in volume and value incurred through the presence of butt rot, assuming no stump protection. The notional value of the decayed wood, discounted to the date of first thinning in the first rotation (i.e. when disease was initiated in an otherwise healthy crop) could be compared to the discounted cost of prophylactic treatment over the same period. This exercise suggested that on mineral soils, the cost of stump treatment would be fully justified. However, the comparatively lower losses predicted for Sitka grown in peat soils did not meet the minimum levels of loss to justify expenditure on prophylactic control. Therefore, the recommendations on stump treatment throughout the UK took account of the effects of edaphic and climatic factors on disease progression (Pratt 2003 *ibid*). The decision not to apply stump treatment to Sitka spruce stands growing on low-hazard (mainly peaty) soils was sound, with the proviso that the climatic and edaphic conditions of those stands would not change over time.

However, the increased temperatures forecast for these upland regions over the next 50 years (Yu, Berry, et al *ibid* 2021) may have a profound influence on the behaviour of this pathogen, as has been described above. Hitherto, in Britain this aspect has not been considered, either strategically or scientifically. This paper represents an attempt to do both and suggests that there is justification for research to be initiated now so that appropriate steps can be taken to protect future conifer crops if necessary. The areas involved are not small: in Scotland alone, there are some 800,000ha of forest planted on deep and shallow peat, (Housego, N., *et al*. 2024). Yet our knowledge about the mechanism by which peat appears to reduce the levels of *H. annosum* is limited to the anecdotal observations described both in this paper, and in Finland (Niemi, S. 2011; Rainio, P., 2013; Sun, H.,Terhonen,E., *et al* 2016).

The presence of peat does not inhibit the infection of stumps by aerial spores, nor the colonisation of stump masses by subsequent growth of the fungus within stump tissues. However, the spread of the disease across root contacts does seem to be inhibited by peat, which in the young first-rotation stands used in this study was invariably waterlogged.

It is this aspect of the disease cycle that needs to be explored in future research if the correct decisions on stump treatment are to be made now. This is because the dilemma facing managers is whether to spend considerable sums of money on prophylactic stump treatment on peat soils now, and thus prevent a gradual build-up of inoculum over future decades which will become active if and when the peat dries out, or delay applying stump treatment on peat soils until the nature of the threat becomes obvious as decay increases and losses are incurred. Undertaking basic research into the physical constraints of peat on disease transmission now might make that decision easier.

Note. *The comments and conclusions within this paper are those of the author alone, acting in a personal capacity. All figures are by the author.*

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