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Intensity of dieback induced by Sphaeropsis sapinea in relation to site conditions

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Abstract

Following a hail storm in the southern Cape Province of South Africa, *Sphaeropsis sapinea* infected about 2000 ha of pine plantations. A series of sample plots yielded information on symptom development in relation to site factors and stand characteristics. Aerial photography and ground inspection of the area showed that, although the intensity of disease was not affected by site quality or age, it was inversely proportional to altitude.

1 Introduction

The fungus, *Sphaeropsis sapinea* (Fr.) Dyko and Sutton, is a pathogen of *Pinus* spp. throughout the world (Gibson 1979; Peterson 1978; Punithalingam and Waterston 1976). Most of its notoriety is, however, based on the devastation it has caused in South African plantations (Laughton 1937; Lückhoff 1964; Gibson 1979). The fungus-host relationship as well as site and environmental conditions favourable to pathogen development have not been fully elucidated and published work is in many cases contradictory. Trees suffering from physiological stress, especially caused by drought and nutrient deficiencies, are particularly vulnerable to attack (Stahl 1968; Wright and Marks 1970; Minko and Marks 1973; Brown et al. 1981; de Kam 1985). However, Marks and Minko

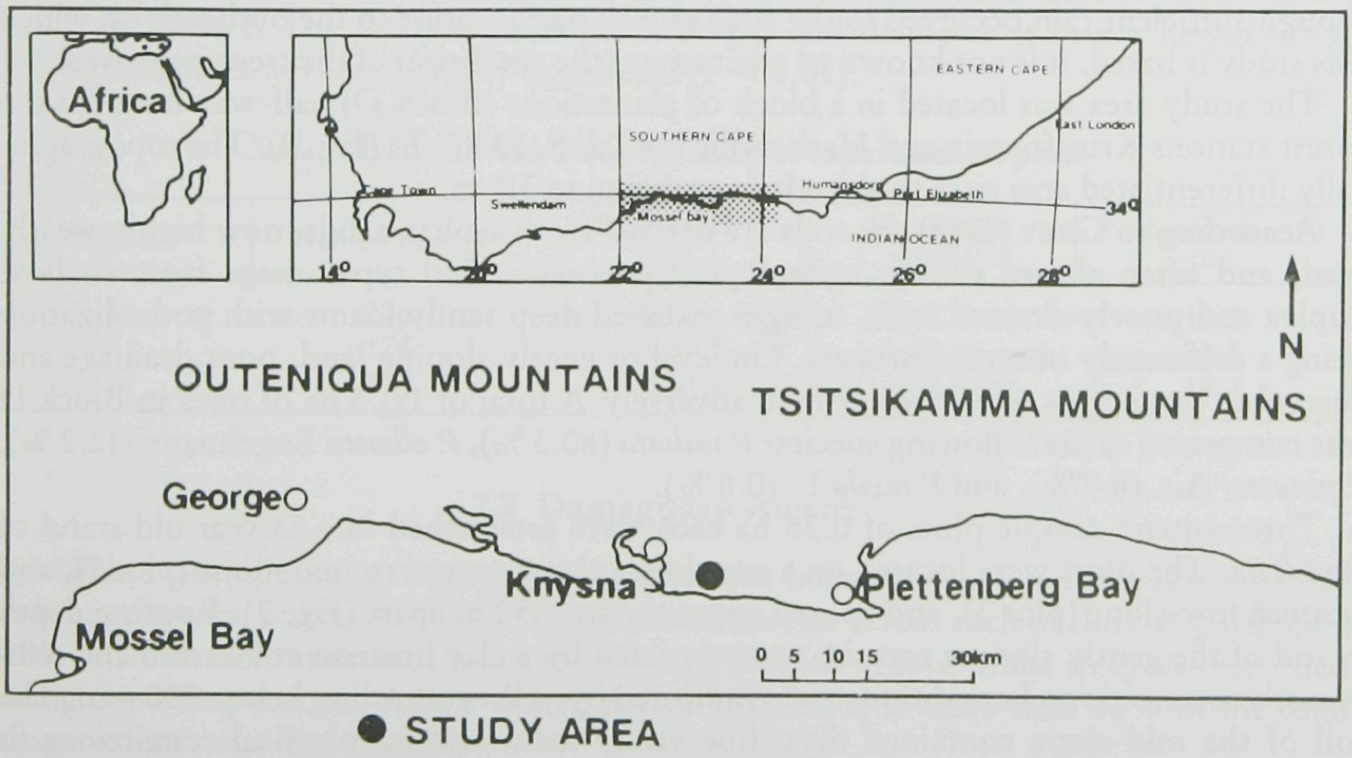

Fig. 1. General map of Southern Cape

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(1969), and CHOU (1982), reported that fast growing trees and trees growing on better sites were more severely attacked by *S. sapinea*. A similar observation was made in South African plantations by LAUGHTON (1937).

According to PURNELL (1975), infection by *S. sapinea* occurred most readily during periods of rapid growth and under conditions of high temperature and humidity. These conditions were greatest at lower altitudes. WRIGHT and MARKS (1970) suggested that the incidence of Sphaeropsis dieback in Australia may be due to environmental conditions related to topography. A dramatic increase in damage on enclosed valley sites was reported in New Zealand by CHOU (1977). This author suggested that a difference in microenvironmental conditions due to variation in altitude, or related to tree age and height, is a likely explanation for differences in the amount and frequency of damage resulting from infection. In contradiction to findings from the Midwest United States where trees over 30 years of age were most severely affected PETERSON (1978), CHOU (1977) reported decreased shoot dieback after trees reached 7–8 years of age.

Following a hail storm on 3 February 1986, an extensive outbreak of dieback was recorded in the Southern Cape Forest Region of South Africa, (lat. 33°53′ South and long. 22°03′ East to lat. 34°03′ South and long. 23°14′ East) (Fig. 1). This outbreak provided a unique opportunity to obtain information on (i) the rate of symptom development, and (ii) the effect of tree age, site index and altitude on susceptibility of *P. radiata* to *S. sapinea*. Studies of the impact that *S. sapinea* infection has in exotic pine plantations in South Africa have hitherto never been conducted.

2 Materials and methods

2.1 Site description

The climate of the region is mild and moist with mean diurnal temperatures for January (summer) and July (winter) being 17.6 °C and 9.8 °C respectively. Allseason precipitation ranges with altitude from 500 to 1200 mm. On average, only 1 or 2 hail storms were recorded annually in the area during the last 27 years with the highest probability of occurrence in September. Drought stress was observed in several stands of the region in 1984 and 1985, when average maximum annual temperature was 2.2 °C higher and the annual precipitation was 13 % lower than the average for the years 1922–84 (ANON 1986). Although sufficient rain occurred in the four month period prior to the outbreak on which this study is based, it is not known to what extent the condition of the trees improved.

The study area was located in a block of plantations (Block D) half-way between the forest stations Kruisfontein and Harkerville (34°02′ S, 23°10′ E) (Fig. 2). The topographically differentiated area rises in altitude from 190 m to 310 m.

According to GREY (1985) the soils are derived from aeolian sands, now highly weathered, and often altered due to hydrological processes. Soil types range from shallow duplex and poorly-drained soils, to light textured deep sandy loams with podzolization being a commonly observed process. On level or gently sloping land, poor drainage and anaerobic conditions affect tree growth adversely. A total of 191.5 ha of trees in Block D was comprised of the following species: *P. radiata* (80.3 %), *P. elliottii* Engelmann (12.2 %), *P. pinaster* Ait. (6.7 %), and *P. taeda* L. (0.8 %).

Three square sample plots of 0.25 ha each were established in a 13 year old stand of *P. radiata*. The plots were located on a top slope (plot 1), western mid-slope (plot 2), and western low-slope (plot 3), and spaced approximately 50 m apart (Fig. 2). Rooting depth in soil of the gently sloping top site was restricted by a clay horizon at 900 mm and temporarily anaerobic soil conditions were indicated by yellow mottling below 700 mm. The soil of the mid-slope contained deep fine sandy loam and no physical restrictions to hydraulic conductivity were found. The soil of the lower slope was similar to the mid-

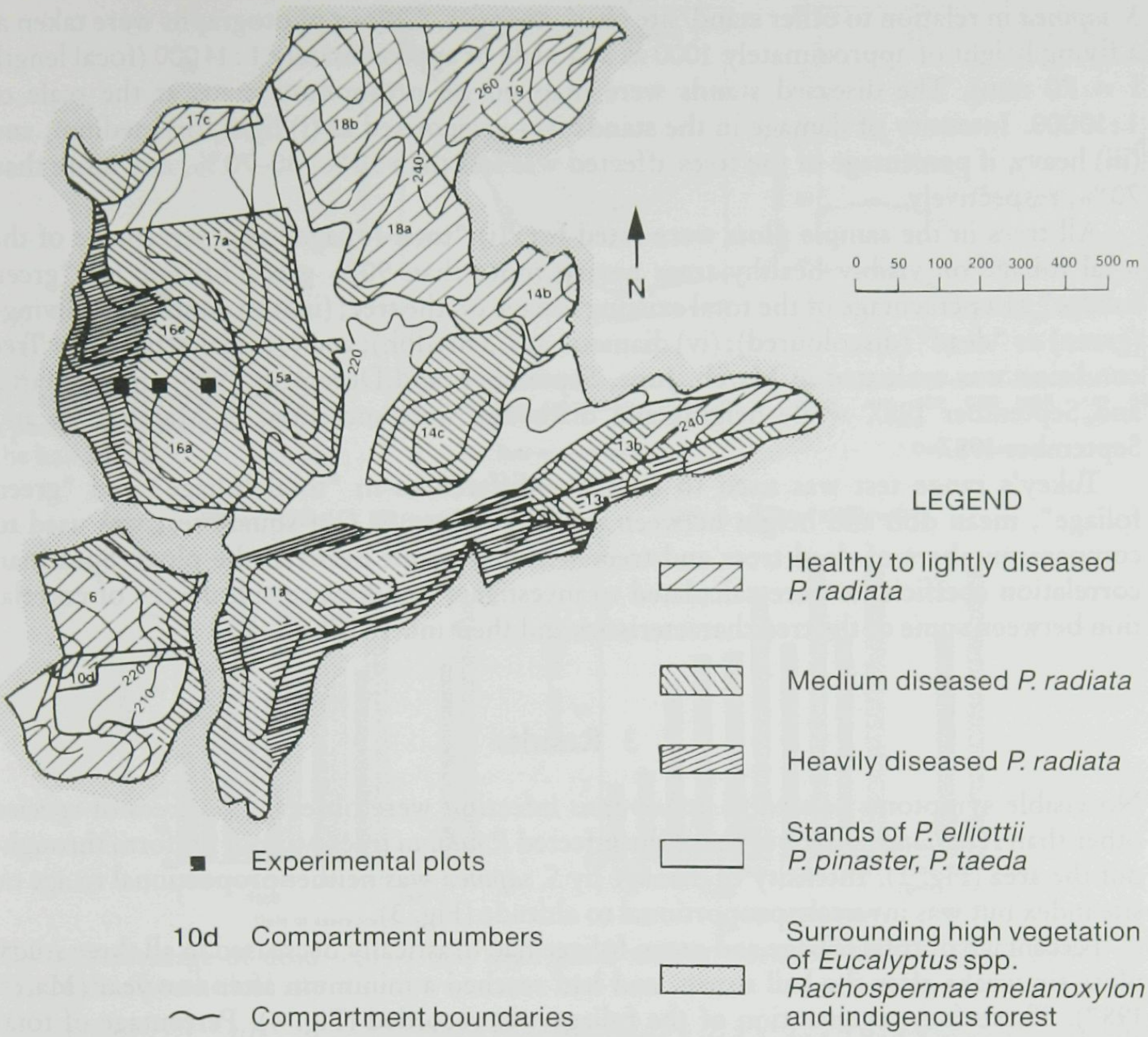

Fig. 2. Map of study area at Kruisfontein State Forest, Southern Cape Forest Region

slope soil but slightly anaerobic conditions due to temporary waterlogging were responsible for erratic tree growth. Some characteristics of the trees within each of the plots are shown in Table 1. The differences in mean height and diameter at breast height (dbh) between the plots were statistically significant ($P < 0.01$).

Table 1. **Tree and site characteristics of experimental plots**

Plot no.	Number of trees	Mean DBH (cm)	Mean height (m)	Predicted site index (m)
1	206	9.01	7.8	10.8
2	174	18.59	16.4	22.5
3	177	14.61	13.4	18.2

2.2 Damage assessment

In March 1986, approximately six weeks after the hailstorm, ground inspections were made at reference points selected randomly on transects across each of the compartments in Block D. Discolouration of foliage and recent dieback of tops of the trees was recorded during these inspections. A tree was classified as infected if more than 10 % of the total foliage volume was discoloured.

Aerial photography was used to investigate the distribution of trees infected by

S. sapinea in relation to other stand/site characteristics. Colour photographs were taken at a flying height of approximately 1000 m at a scale of approximately 1 : 14 000 (focal length f = 70 mm). The diseased stands were mapped on orthophoto maps at the scale of 1 : 10 000. Intensity of damage in the stands was categorised as (i) light, (ii) medium, and (iii) heavy, if percentage of the trees affected was less than 30 %, 30–70 %, and more than 70 %, respectively.

All trees in the sample plots were rated for: (i) "total foliage" as a percentage of the total foliage on visibly healthy trees having more than 90 % green foliage; (ii) "green foliage" as a percentage of the total existing foliage on the tree; (iii) top condition: "living" (green) or "dead" (discoloured); (iv) diameter at 1.3 m (dbh); and (v) total height (ht). Tree condition was evaluated in March, June, September, and December 1986, and in March and September 1987, while heigths and diameters were measured in March 1986 and September 1987.

Tukey's range test was used to compare differences in "total foliage" and "green foliage", mean dbh and height between the three plots. A Chi-square test was used to compare numbers of dead trees and trees with dead tops between the plots. Spearman correlation coefficients were calculated to investigate significance and degree of correlation between some of the tree characteristics and their mortality.

3 Results

No visible symptoms related to *Sphaeropsis* infection were observed on trees of species other than *P. radiata*. Distribution of the infected *P. radiata* trees was not uniform throughout the area (Fig. 2). Intensity of damage by *S. sapinea* was neither proportional to age or site index but was inversely proportional to altitude (Fig. 3).

Percentage of total foliage and green foliage had drastically decreased in all three study plots six weeks after the hail storm, and had reached a minimum after one year (March 1987). Thereafter, regeneration of the foliage was recorded (Fig. 4). Percentage of total foliage and green foliage had drastically decreased in all three study plots six weeks after the hail storm, and had reached a minimum after one year (March 1987). Thereafter, regeneration of the foliage was recorded (Fig. 4). Tree mortality reached a plateau 10 months after the hail, while highest leader mortality occurred after four months (Fig. 5).

Differences between the plots in dieback of tops and tree mortality were highly significant ($X^2 = 23.8$ and 25.3, respectively, at DF = 2) due to low numbers of dead trees in plot 2 and better survival of tree leaders in plot 1. Trees were worst affected in plot 3, where average percentage of green foliage dropped to 35 % (Fig. 4), while dead trees and trees with dead leaders constituted 19 %, and 77 % of the total number of trees, respectively (Fig. 5). The least total damage, (foliar damage and tree mortality) occurred in plot 2. However, in this plot, percentage of trees with dead tops was the highest (82 %) (Fig. 5). During the first assessment, differences in "total foliage" and "green foliage" between plots 1 and 2, and 1 and 3 were statistically significant ($P < 0.05$ %). Eighteen

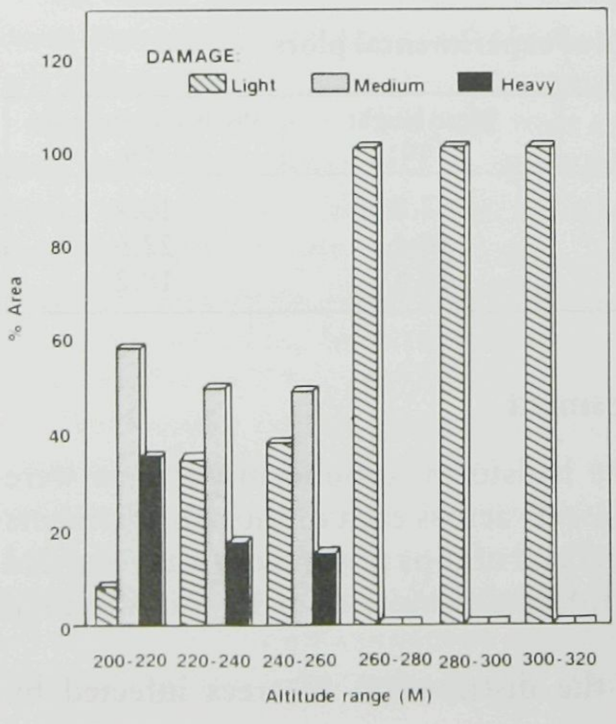

Fig. 3. Percentage area of *Pinus radiata* stands lightly, medium and heavily stressed by *Sphaeropsis sapinea* in relation to altitude

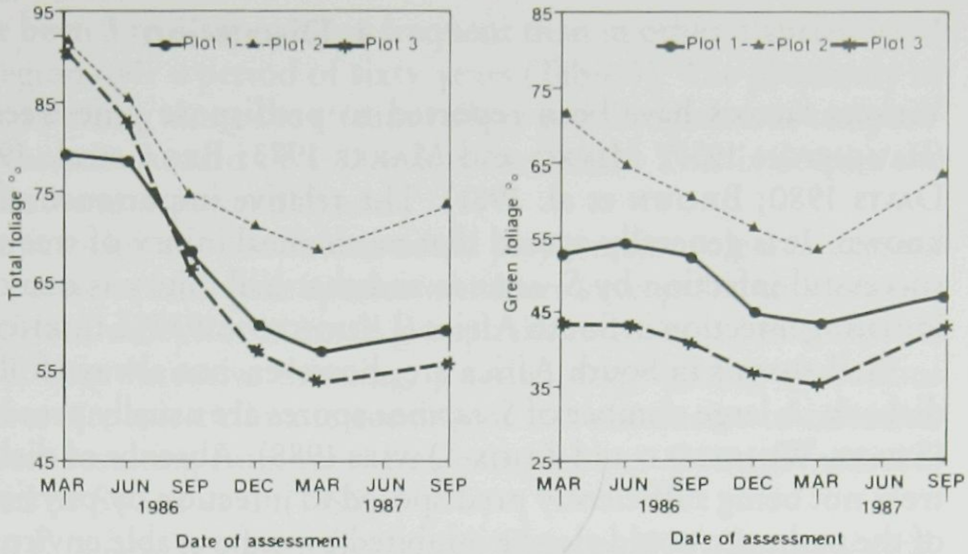

Fig. 4. Fall and discolouration of foliage of *Pinus radiata* trees infected by *Sphaeropsis sapinea* during a period of 18 months after the hail storm

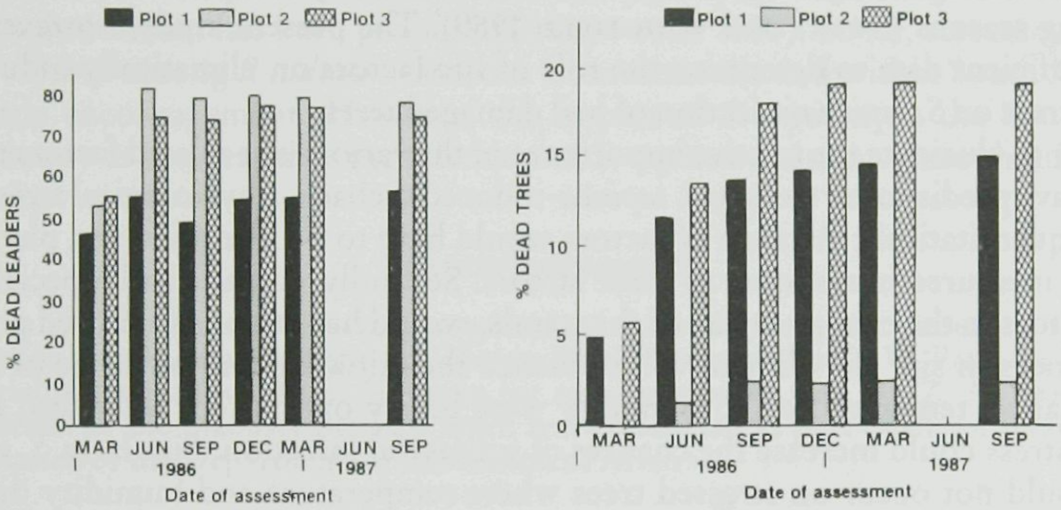

Fig. 5. Percentage of dead leaders and dead *Pinus radiata* trees recorded during a period of 18 months after the hail storm

months later, the differences recorded between plots 1 and 2, and 2 and 3 were statistically significant. However, differences between plots 1 and 3 were not statistically significant due to the rapid discolouration of foliage in plot 3.

At the first assessment, there was a significant correlation between the heights of trees and the percentage of green foliage in plots 1 and 2 (Table 2). Eighteen months after the first assessment, trees in plots 1 and 2 showed significantly better survival of their foliage but not of their tops. No significant correlation between height and foliage survival was recorded in plot 3, where significantly more dead tops were recorded on taller trees at the last assessment.

Table 2. **Relationship between heigths of trees, percentage green foliage, and condition of tree tops at first and last assessments**

Assessment	Plot no.	Spearman correlation coefficients	
		% Green foliage	Condition of tops[1]
First	1	0.27 ***	0.11 NS
	2	0.33 ***	0.19 ***
	3	0.04 NS	−0.06 NS
Last	1	0.32 ***	0.05 NS
	2	0.36 ***	−0.01 NS
	3	−0.02 NS	−0.23 ***

[1] (1 – alive; 0 – dead)
*** $P < 0.001$

4 Discussion

Various factors have been reported to predispose pine trees to infection by *S. sapinea* (LAUGHTON 1937; MINKO and MARKS 1973; BEGA et al. 1978; WINGFIELD and KNOX-DAVIS 1980; BROWN et al. 1981). The relative importance of these factors is largely unknown. It is generally agreed that mechanical injury of tree tissue is usually essential for successful infection by *S. sapinea* and that hail injury is one of the most common factors initiating infection in South Africa (LAUGHTON 1937; LÜCKHOFF 1964; SWART et al. 1985).

Hail storms in South Africa are, however, not always followed by *S. sapinea*-induced dieback. A large number of *S. sapinea* spores are usually present in a pine stand at any time (SWART, WINGFIELD and KNOX-DAVIES 1988). Absence of dieback after hail may be due to trees not being sufficiently predisposed to infection by physiological stress. Development of the pathogen could also be inhibited by unfavorable environmental or host related conditions. The susceptibility of pine tissue to colonisation by *S. sapinea* has been shown to vary among seasons (SWART and WINGFIELD 1989). The present study, however, did not provide sufficient data to determine the role of site factors or, climatically induced physiological stress on *S. sapinea* infection of hail damaged trees.

In order to elucidate the relative importance of the various site related factors that could possibly have predisposed trees to *S. sapinea*-induced dieback, physiological stress must be measured quantitatively. A range of factors would have to be identified and physiological stress then measured in response to these factors. Secondly, climatic and especially microclimate factors in the canopy layers of the stands, would have to be monitored precisely.

Differences in site and climate will influence the initiation and outcome of infection. If, for instance, temperature and humidity were barely optimal for infection, then physiological stress could increase the chances of successful infection. Similarly, *S. sapinea* infection would not occur on stressed trees where temperature and humidity did not fall within the required range for infection (GREY 1987). If it is assumed that poor growth is the effect of long-term physiological stress, then such stresses cannot be associated with the post-hail dieback observed at Kruisfontein. There was, however, an indication in experimental plots 1 and 2 that taller trees resisted *S. sapinea* infection better than smaller trees. This was despite the fact that taller trees were more exposed to hail damage. This was not applicable in plot 3 where microclimatic conditions were probably highly favourable to pathogen development.

Microclimatic conditions seemed to be most important factor affecting *S. sapinea* infection. In enclosed valley sites and sheltered stands, these conditions were most probably characterised by higher air humidity and smaller temperature variation. Conversely, heavily thinned stands were exposed to winds which probably prevented large scale *S. sapinea* infection. This interpretation would support earlier reports (WRIGHT and MARKS 1970; CHOU 1977).

The importance of climatic factors on the pathogenicity of *S. sapinea* can also be observed on a regional scale. In proportion to the area planted, recorded outbreaks of

Table 3. **Outbreaks of Sphaeropsis sapinea-induced dieback between 1923 and 1983 and area planted at Kruisfontein State Forest compared to other plantations in the Southern Cape Forest Region**

Species	Kruisfontein		Other plantations		Total	
	Outbreaks (%)	Area (%)	Outbreaks (%)	Area (%)	Outbreaks	Area (ha)
P. pinaster	36.4	6.0	63.6	94.0	11	14984
P. radiata	44.0	14.2	56.0	85.8	25	11310

dieback at Kruisfontein have been 3 to 6 times more frequent than in other plantations of the Southern Cape Forest Region over a period of sixty years (Table 3). The proximity of the Indian Ocean with moist air rising along the stream valleys and mitigation of temperature extremes seems to increase the hazard of a *S. sapinea* outbreak. This is despite the decreasing probability of hail storms at lower altitudes.

This study suggests that microclimatic conditions could play a major role in *S. sapinea* dieback. Therefore, in areas prone to hail, pine species which are susceptible to *S. sapinea* should not be planted in enclosed valleys or in small groups sheltered by other stands. If such planting is unavoidable, then intensive thinning, pruning and weeding operations should be applied. This will create microclimatic conditions less conducive to infection and reduce physiological stress resulting from inter-tree competition. Control measures against *S. sapinea* are discussed by SWART et al. (1985).

Resistance to *S. sapinea* in *P. radiata* is genetically based (GIBSON 1979; BURDON et al. 1980). Thus, the selection of *P. radiata* and other pine species resistant to *S. sapinea*, is a long term solution that has been proposed (SWART et al. 1985). So far, screening for resistance to *S. sapinea* among *P. radiata* selections from Australia and within South Africa have offered little encouragement. However, the impact of *S. sapinea* on the South African timber industry is so great that the selection of *S. sapinea* resistant pines should be given high priority.

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Summary

A series of sample plots were established in hail-damaged *Pinus radiata* plantations in the southern Cape Province of South Africa in order to collect information on infection of trees by *Sphaeropsis sapinea* in relation to site factors and stand characteristics. The study provided evidence that microclimatic conditions play a major role in *Sphaeropsis*-induced dieback of pine trees. Aerial photography and ground inspection of the study area showed that, although the intensity of the disease was not affected by site quality or age, infection by *S. sapinea* was most severe in enclosed valley sites and sheltered stands characterised by higher air humidity and smaller temperature variation.

Résumé

Importance du dépérissement à Sphaeropsis sapinea en relation avec les conditions d'environnement

Un ensemble de placettes a été établi dans des plantations de *Pinus radiata* endommagées par la grêle dans le Sud de la province du Cap en Afrique du Sud, afin de recueillir une information sur l'infection par *S. sapinea*. Cette étude a montré que les conditions microclimatiques jouent un rôle majeur sur le dépérissement des pins induit par *Sphaeropsis*. La photographie aérienne et l'examen au sol ont montré que l'intensité de la maladie n'est pas influencée par la qualité de la station ni l'âge, mais que l'infection est plus sévère dans les vallons confinés et dans les peuplements abrités où l'humidité de l'air est plus élevée et où les variations de températures sont moindres.

Zusammenfassung

Die Intensität eines von Sphaeropsis sapinea verursachten Triebsterbens in Abhängigkeit von Standortsbedingungen

In der südlichen Kapprovinz Südafrikas wurde in vom Hagel geschädigten *Pinus radiata*-Plantagen ein Reihe von Probeflächen mit dem Ziel, Informationen über die Infektion der Bäume durch *Spaeropsis sapinea* in Abhängigkeit von Standortsbedingungen und Bestandeseigenschaften zu erhalten, eingerichtet. Die Untersuchung ergab, daß kleinklimatische Bedingungen eine wichtige

Rolle bei dem von *Sphaeropsis* verursachten Triebsterben spielen. Luftbilder und Untersuchungen vom Boden aus ergaben, daß die Infektion durch *S. sapinea* auf Talstandorten und in geschützten Beständen, die durch höhere Luftfeuchtigkeit und geringere Temperaturschwankungen gekennzeichnet sind, am schwersten war. Die Krankheitsintensität war nicht von der Standortsqualität oder dem Alter der Kiefern abhängig.

Literature

Anonymus, 1986: Climate of South Africa. Report of the Weather Bureau, Department of Environment Affairs, Pretoria, Republic of South Africa. 474 pp.

Bega, R. V.; Smith, R. S.; Martinez, A. P.; Davis, C. J., 1978: Severe damage to *Pinus radiata* and *P. pinaster* by *Lophodermium* spp. on Molokai and Lanai in Hawaii. Plant Dis. Rep. **62**, 329–331.

Brown, B. N.; Bevege, D. I.; Stevens, R. E., 1981: Site stress and *Diplodia*-induced dieback and death of hail damaged slash pine. XVII IUFRO Congress, Japan. Joint meeting P2.01/P2.03.

Burdon, R. D.; Currie, D.; Chou, C. K. S., 1980: Responses to inoculation with *Diplodia pinea* in progenies of apparantly resistant trees of *Pinus radiata*. For. Res. Inst., New Zealand. Research Notes.

Chou, C. K. S., 1977: Effect of tree age on *Diplodia pinea* infection of *Pinus radiata*. Plant Dis. Rep. **61**, 101–103.

– 1982: Susceptibility of *Pinus radiata* seedlings to infection by *Diplodia pinea* as affected by pre-inoculation conditions. New Zealand J. For. Sci. **12**, 438–441.

de Kam, M., 1985: *Sphaeropsis* (= *Diplodia*) shoot-dying: an incident or a permanent problem? Nederlands Bosbouwtijdschrift **57**, 118–122.

Gibson, I. A. S., 1979: Diseases of Forest Trees Widely Planted as Exotics in the Tropics and Southern Hemisphere. Part II. The genus *Pinus*. Commonwealth Mycological Institute, Kew and Commonwealth Forestry Institute, University of Oxford, 135 pp.

Grey, D. C., 1985: Classification of forest sites: Kruisfontein State Forest, Blocks E and G. Report No. S. 85/4 South African For. Inst., Pretoria. 69 pp.

– 1987: A study of the relationship between environmental factors and mensurational parameters in *Pinus radiata* (D. Don). Ph. D. Thesis, University of Stellenbosch. 130 pp.

Laughton, E. M., 1937: The incidence of fungal disease on timber trees in South Africa. South Africa J. Sci. **33**, 377–382.

Lückhoff, H. A., 1964: Diseases of exotic plantation trees in the Republic of South Africa. FAO/IUFRO Symposium Meeting No. VI. 4 pp.

Marks, G. C.; Minko, G., 1969: The pathogenicity of *Diplodia pinea* to *Pinus radiata* D. Don. Australian J. Bot. **17**, 1–12.

Minko, G.; Marks, G. C., 1973: Drought index and the sensitivity of *Pinus radiata* to *Diplodia pinea* infection. Research Activity 72. Victoria, Australia, For. Comm. 47 pp.

Peterson, G. W., 1978: Effective and economical methods for controlling *Diplodia* Tip Blight. American Nurseryman **147**, 13–72.

Punithalingam, E.; Waterston, J. M., 1970: *Diplodia pinea*. C. M. I. Descriptions of Pathogenic Fungi and Bacteria. No. 273.

Purnell, H. M., 1957: Shoot blight of *Pinus radiata* D. Don caused by *Diplodia pinea* (Desm.) Kickx. For. Comm. Victoria, Australia, Bull. **5**, 11 pp.

SAS Institute Inc., 1985: User's Guide: Statistics, Version **5**, 956 pp.

Stahl, W., 1968: *Diplodia pinea*: A preliminary report on some aspects of fungus host relationship. Australian For. Res. **3**, 27–32.

Swart, W. J.; Knox-Davies, P. S.; Wingfield, M. J., 1985: *Sphaeropsis sapinea*, with special reference to its occurrence in *Pinus* spp. in South Africa. South African For. J. **35**, 1–8.

Swart, W. J.; Wingfield, M. J.; Knox-Davies, P. S., 1987: Conidial dispersal of *Sphaeropsis sapinea* in three climatic regions of South Africa. Plant Dis. **71**, 1038–1040.

Swart, W. J.; Wingfield, M. J., 1990: Seasonal susceptibility of *Pinus radiata* to infection by *Sphaeropsis sapinea*. Plant Disease (in press).

Wingfield, M. J.; Knox-Davies, P. S., 1980: Observations of diseases in pine and *Eucalyptus* plantations in South Africa. Phytophylactica **12**, 57–63.

Wright, J. P.; Marks, G. C., 1970: Loss of merchantable wood in radiata pine associated with infection by *Diplodia pinea*. Australian For. **34**, 107–119.

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