... in the Australian Capital Territory, however, ...well in comparison with P. radiata, and are generally ...edominant ...ght (Table 2).

...in growth at 23 years of "blue" P. muricata and P. radiata ...s in the A.C.T.

	Kowen 750 610		Blue Range 570 1020	
...ear)	P. muricata	P. radiata	P. muricata	P. radiata
...s/ha)	910	1130	990	1660
	21.6	21.6	22.9	21.0
...m)				
.../ha)	34	44	43	61
...t* (m)	17.4	22.3	21.9	27.4

...t of 124 trees of largest diameter per hectare

...ndicate that the northern blue-foliaged provenances of ...etter adapted to high altitude sites than P. radiata. Trials ...uired to confirm this suggestion.

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THE REACTION OF PINUS RADIATA TWIGS TO THE MUCUS OF SIREX NOCTILIO IN RELATION TO RESISTANCE TO SIREX ATTACK

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SUMMARY

The resistance of the foliage of Pinus radiata to the mucus of Sirex noctilio was assessed by testing twigs in solutions of mucus. The reaction of twigs was influenced by their position in the tree crown and the season of testing, symptom expression in twigs being most rapid when the tree was physiologically active. Testing of clonal material from different sites indicated that resistance to mucus was under genetic control. The relationship between resistance to mucus and tree resistance to Sirex attack was obscured by the high mortality of even the "resistant" trees under heavy Sirex attack, but mucus-resistant trees took longer to die at high attack levels.

O.D.C. 453: 174.7 Pinus radiata

INTRODUCTION

In Australia control of Sirex noctilio F. in Pinus radiata D. Don is based on the improvement of silvicultural practices and the development of biological control using insect and nematode parasites. The breeding of insect-resistant trees offers an additional means of controlling insect damage in forest stands, but little progress has been made in selecting or breeding Sirex-resistant stock although this is probably the most satisfactory long-term approach to control (Callaham, 1966).

Field observations over a ten-year period at the Tasmanian Research Station support the hypothesis that individual P. radiata trees possess different degrees of resistance to S. noctilio and that resistance is of both a genetic and a phenotypic nature. Problems associated with selecting or breeding resistant stock include the limited understanding of the basis of resistance, whether it be heritable or environmentally influenced, and the difficulty in testing the resistance of trees to such a complex host-pathogen system. If a rapid, non-destructive and reliable method for testing resistance was available it could

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encourage the incorporation of Sirex resistance into tree selection and breeding programmes.

The mucus secretion injected by *S. noctilio* during oviposition plays a major role in bringing about the death of the tree (Coutts, 1969). Bowling and Dolezal (1970) indicated a possible relationship between the reaction of twigs of *P. radiata* to mucus and the resistance of field trees to *S. noctilio*. Since that report experimentation has continued on the development of a method of twig testing and on the relationship between twig tests and *S. noctilio* attack. This paper presents the results of these studies.

MATERIALS AND METHODS

Material tested and method of treatment with mucus

Testing of twigs was standardised using first or second order twigs from the first or second whorls from the top of the tree. A comparative test of such material from 30 trees indicated only small differences in the rates of reaction to mucus of twigs from the same tree, and these differences did not effect the ultimate classification of trees into resistance classes. Twigs of the same order from the lowest whorls were found to react faster to mucus than twigs from the uppermost whorls.

The standard test procedure adopted was modified from that described by Bowling and Dolezal (1970). Mucus (0.1%) was dispersed in de-ionised water with captain (0.01%) and streptomycin (0.003%) with an ultrasonic emulsifier. Twigs 20-40 cm in length were placed in 10 x 2.5 cm vials containing 20 ml of mucus solution. The butts of the twigs were cut under water and re-cut every week. The vials were refilled with 0.01% mucus solution as necessary. Tests were carried out in a glasshouse.

An objection to this procedure is that twigs were not subjected to a uniform concentration of mucus throughout the test. A number of variations were tested, and these experiments indicated that the initial exposure of twigs to mucus was the most important and that the procedure adopted did not lead to any error in resistance assessments.

Assessments were normally undertaken every three days over a 30-40 day period (depending on season), and a reliable classification of twigs could be made after this period. The three basic symptoms assessed were:-

(1) needle shed

(2) colour change (from green to yellow to grey or brown) and

(3) needle collapse (shrinking and desiccation of needles).

A twig was considered dead when 20% or less of the needles remained unaffected by some or all of the above symptoms. In most experiments it was convenient to rank trees into four arbitrary classes on the basis of twig symptoms. These

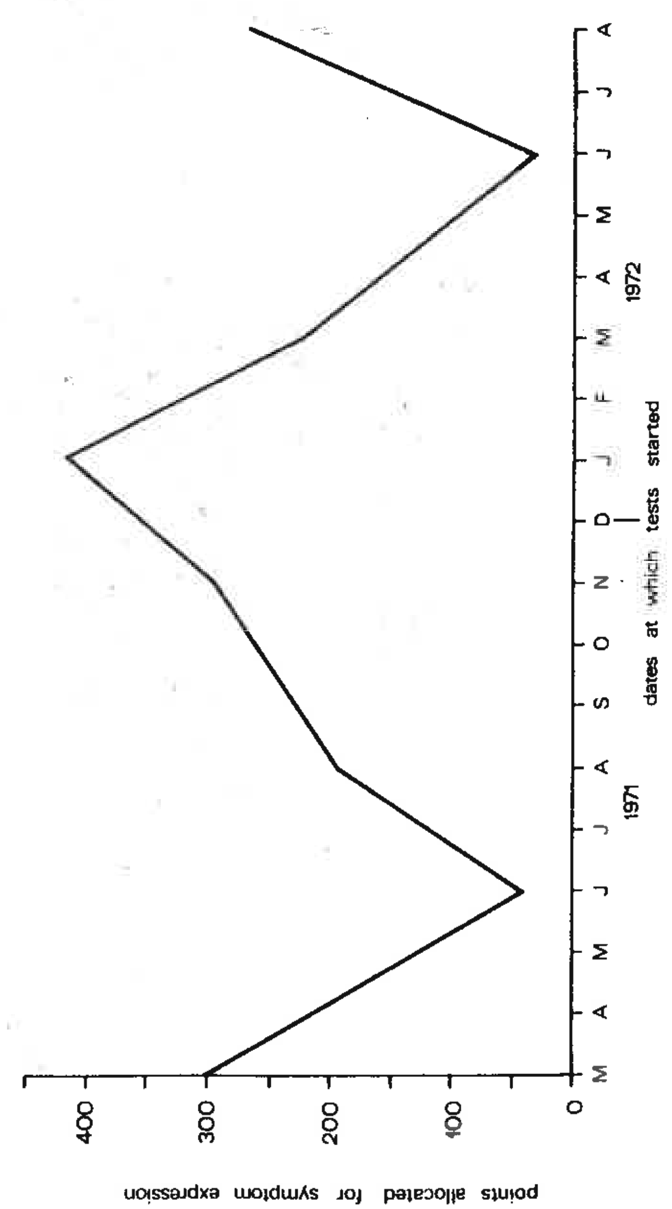

FIGURE 1 - Seasonal trend in reaction of *P. radiata* twigs to mucus of *S. noctilio*.

classes were resistant (R), intermediate resistance (IR), intermediate susceptibility (IS) and susceptible (S). For some purposes the trees were classified only into broadly opposed classes of resistant or susceptible. The criteria for classification of twigs and trees were:-

(S) Susceptible - early appearance of one or more of the basic symptoms and their rapid progress. Twigs dead within 5 days.

(IS) Intermediate susceptibility - response slower than in group 1, but twigs dead or severely affected within 5-20 days.

(IR) Intermediate resistance - some of the basic symptoms present after 20 days, possibly with death between 20 and 30 days.

(R) Resistant - twigs remain healthy for more than 30 days.

In a study of seasonal effects on twig reaction to mucus it was necessary to assess differences in the rate of reaction of the twigs. Points were allotted for the occurrence of specific symptoms in individual twigs. Progressive totals for twigs from all trees for all assessments in a test were regarded as an expression of the rate of symptom development in the test.

Testing of three twigs per tree was adequate for assessing the relative resistance of a tree. Occasionally the reaction of one twig varied from that of the other two allowing the possibility of a wrong assessment. However, if uniform, disease-free twigs from comparable whorls were selected, the chances of an error in assessment by more than one resistance class were small.

INDIVIDUAL EXPERIMENTS AND RESULTS

Effect of season on the reaction of twigs to mucus

Second order second whorl twigs (2/2) from thirty, 6-year-old *P. radiata* were tested in March, June, August, and November 1971 and January, March, June and August, 1972. Tests were commenced in the first week of each month and final assessments were made after 22 days. The results are shown in Figure 1 as total points allocated at the final assessment for each test.

There was a close parallel between the trees' seasonal cycle of physiological activity and the reaction of twigs to mucus, the reaction of susceptible twigs being much faster in summer than in winter. Symptom expression also increased in resistant twigs in summer.

The January test was excluded when the trees were finally classified as to resistance because the rapid rate of reaction in that test obscured the differences between resistant and suceptible twigs. On the basis of the other tests there were 5 S trees, 9 IS trees, 9 IR trees and 7 R trees. Twenty-six trees were consistent in their classification in all seven repetitions of the test,

three varied between adjacent classes, and one tree ranged from S to IR between March 1971 and March 1972.

Comparison of mucus tests on trees and on cut twigs

Six twigs (2/2) were selected on each of five resistant and five susceptible trees. For each tree, three twigs were injected *in situ* with two 1.0 ml doses of 1% mucus solution over a 24 hour interval. The other three twigs were cut from the tree and placed into 0.1% mucus solution. After two days twigs were rinsed in sterile water and placed in 0.01% mucus. As no antibiotics were used this washing procedure was repeated every second day. All twigs were assessed for 120 days.

The symptom development showed a good correlation between the two treatments, but the rate of development of symptoms in injected twigs was about half that of the cut twigs.

The advantages of injecting twigs with mucus *in situ* included the more natural conditions, non-requirement of antibiotics and the elimination of the natural senescence of cut twigs. The disadvantages which limited its use were the labour and time factors, the restriction of tests to larger, injectable twigs and the difficulty of localising the effect of the mucus.

Mucus testing of clonal material

Six ramets from each of 10 clones growing at Pittwater, 12 miles east of Hobart, were tested for their uniformity of twig reaction to mucus and for the overall ranking of clones into resistance groups. The material tested was 6-year-old grafts planted at 1 m x 1 m spacing. The results are presented in Table 1.

TABLE 1 - Resistance classification of *P. radiata* clones growing at Pittwater.

Clone	Distribution of 6 ramets in resistance classes				Resistance class of clone
	S	IS	IR	R	
W7	2	-	-	4	?
W21	-	-	-	6	R
W22	-	2	4	-	IR
03	6	-	-	-	S
FCV CR40	6	-	-	-	S
S14	6	-	-	-	S
NZ37	-	2	4	-	IR
SAE48	-	5	1	-	IS
W10	-	5	1	-	IS
MG17	-	5	1	-	IS

There was large variation between clones in their mucus resistance, but, with the exception of clone W7, ramets reacted uniformly, and the classification of individual ramets did not vary by more than one resistance class. It was possible to assign an overall resistance ranking to each clone except W7. Both suppressed and dominant members of the same clone reacted uniformly.

An examination of the effect of environmental differences on the mucus reaction of clonal material was made by testing ramets from four of the clones used in the previous experiment (W7, W21, W22 and 03) which were growing both at Pittwater near Hobart and at Upper Castra in north-western Tasmania. The major differences in environment and tree condition between the two sources were as follows:

Pittwater	Upper Castra
6-year-old grafted plants	10-year-old grafted plants
Height 2-6m	Height 13-17 m
Spacing 1 m x 1 m	Spacing 13 m x 7 m
Soil - dune sand	Soil - kraznozem
Annual rainfall 56 cm	Annual rainfall 125 cm

Despite the differences between the two sources, the reactions of the ramets from both showed close agreement (Table 2) except for clone W7, which again gave anomalous results at Pittwater. The ramets of W7 that were classified as IR or R showed fused-needle and it may be that this condition prevented or obscured their reaction to mucus. In tests on an additional 68 healthy ramets of this clone from both Pittwater and Upper Castra 80% were classed as susceptible, which supports the majority of the results for W7 in Table 2.

It will be seen that the results from the Pittwater material (Table 2) also correspond very closely with those obtained from that material in the previous experiment (first four clones in Table 1).

Relationship between twig resistance to mucus and S. noctilio attack

One hundred and seven uniform 6-year-old P. radiata were selected in February 1972. The lower branches were pruned from each tree, and the nodes were covered with plastic film to prevent the attraction of wild Sirex. A one square foot sample area of the lower stem was marked off on each tree.

In March 1972 three first order twigs were taken from the second whorl from the top of each tree and subjected to a mucus test. After 34 days the trees were classified according to the symptoms displayed by the twigs during that time, and 96 of them were used to form four resistance classes (R, IR, IS, S) of 24 trees. Each class was then divided randomly into four groups of six trees to receive Sirex attack at levels of 50, 100, 200 and 400 ovipositions over one square foot of stem.

TABLE 2. Resistance classification of P. radiata clones growing at both Pittwater and Upper Castra.

Clone	Pittwater					Upper Castra				
	Distribution of 6 ramets in resistance classes				Resistance class of clone	Distribution of 6 ramets in resistance classes				Resistance class of clone
	S	IS	IR	R		S	IS	IR	R	
W7	2	-	1	3	?	6	-	-	-	S
W21	-	-	-	6	R	-	1	2	3	IR
W22	-	1	2	3	IR	-	-	3	3	IR
03	6	-	-	-	S	6	-	-	-	S

Trees were attacked in mid-April 1972, using clipped-wing Sirex. A number of insects were placed on each tree, and, after the specified attack level was reached, they were removed. This took several days for the high attack levels. It was not possible to attain the 400 ovipositions attack level on all trees, but trees in this group received more than 300 ovipositions.

Following the Sirex attack the appearance of symptoms and the deaths of trees were recorded until December, 1972. The occurrence of symptoms such as the discolouration or shedding of needles was not closely related to the resistance classes derived from the mucus test on twigs. The numbers of trees which had died by the end of the experiment in each 6-tree group under the varying levels of attack are shown in Table 3, along with the times after attack at which these deaths occurred.

TABLE 3 - Numbers of deaths in groups of 6 trees of P. radiata 8 months after varying levels of Sirex attack, with, in brackets, the number of days after attack at which these deaths occurred. (Means and standard deviations are given for the groups in which all trees died).

Resistance class from mucus test	Level of attack (ovipositions on 1 sq ft of stem)			
	50	100	200	300+
S	0	2 (66, 191)	6 (62±35)	6 (32±3)
IS	1 (141)	1 (191)	5 (38-141)	6 (40±14)
IR	0	2 (140, 160)	6 (86±24)	6 (64±30)
R	0	1 (191)	4 (45-94)	6 (103±7)

Trees of all mucus resistance classes died if the number of ovipositions was sufficiently high. All trees which received more than 300 ovipositions died while 21 of 24 which received 200 ovipositions died. At low levels of attack only a few trees were affected and only one tree which received 50 ovipositions died. The increase in the number of ovipositions from 100 to 200 was sufficient to alter the response to attack in the majority of trees tested.

At the highest level of Sirex attack trees classified as mucus resistant died more slowly than those in the mucus susceptible group. At the 300+ attack level the differences between times of death in the S and IR and R groups were significant at the .01% level as were the differences between the IS and R groups. Within the S and IR groups the differences between the time of tree death at the 200 and 300+ attack levels were not significant, and at the 200 level the differences between the S and IR groups were not significant.

DISSCUSSION

The results with the clonal material used in this study support the hypothesis that the reaction of P. radiata foliage to the mucus of S. noctilio is a character which is under a high degree of genetic control. As such, resistance to mucus is a factor which could be used in tree breeding programmes. Sampling large numbers of trees in the Pittwater Plantation indicated that in this population about 15% of trees can be ranked as mucus resistant and 15% mucus suscepti[ble] while the great bulk of the population was placed in the intermediate groups.

At present it is not possible to define Sirex resistance in absolute terms. Results confirm that all young trees can be killed if Sirex attack levels are heavy enough, although previous tests indicate that the critical level of attack will vary with factors such as seasonal conditions, tree size, age and crown class. However, the evidence also suggests that mucus resistant trees will be more tolerant of Sirex attack.

While mucus resistance may be one factor contributing to the overall resistance of a tree to Sirex, the results of this study suggest it is not necessarily the major factor. Sirex attack is a multi-factor system involving the insect, the fungus Amylostereum areolatum and a mucopolysaccaharide insect secretion (mucus). Likewise tree resistance involves multiple mechanisms. The first element in resistance is probably the relative attractiveness of the individual tree. In P. radiata this is affected by the physiological condition of the tree (Madden, 1968). Attack experiments to date have been forced attacks with no account taken of the mobility or discrimination of the insects. It remains to be determined if trees classified as mucus resistant are less attractive to S. noctilio than mucus susceptible trees. Once a tree has been attacked other mechanisms may contribute to its resistance. These include resin flow, formation of polyphenols (Coutts & Dolezal, 1966) and resistance to mucus. Resin flow and polyphenol synthesis are non-specific tree responses to mechanical or pathological stimuli. Resistance to a metabolic toxin such as mucus is probably a more specialised trait, although definitive conclusions await a greater knowledge of mucus properties and mode of action.

Little is known of the relationship between, or the relative importance of, these resistance mechanisms, although the recent discovery of ethylene production by mechanically-injured or Sirex-attacked P. radiata sapwood (Shain & Hillis, 1972) may offer a reliable means of assessing the potential resistance of a tree. It is highly desirable that trees should be selected for disease resistance as well as quality and yield characteristics, and, when dealing with genetically-controlled non-specific host responses, selection for resistance to one pathogen is likely to increase the resistance to others.

ACKNOWLEDGEMENTS

Mr.P.J.Bowling, who initiated most of the above experiments, died on 25th May, 1972. The work was concluded by Dr.G.A.Kile.

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STOCKING ASSESSMENT IN YOUNG PINE PLAN
USING 70 MM AERIAL PHOTOGRAPHS

SUMMARY

Estimates of stocking in 4-7 year old radiata pine p
from crown counts on aerial photographs taken with
compared with estimates obtained from field counts
wood weed competition was abundant, close estima
obtained from crown counts made either monocularl
on colour transparencies at a scale of 1:8000. Cro
black-and-white prints from the same negatives res
accurate estimates of stocking.

O.D.C. 587

INTRODUCTION

In planning and estimating the costs of first prunin
young plantations, information on the stocking of individ
essential to the forest manager. Stocking is usually dete
consuming ground surveys. In view of rising labour cost
area of pine plantations in Australia (1 128 943 acres, Ju
method of assessment requiring less manpower would be
was designed to investigate the feasibility of assessing
aerial photographs of young plantations of Pinus radiata I

METHODS

The study area consisted of seven compartments co
radiata pine in the Buccleuch State Forest of New South W
within the compartments was 8 feet by 8 feet. The maxim
elevation within a compartment was 200 feet, and the ave
100 feet. A summary of the characteristics of the study
in Table 1.

Photography - The photography was exposed in late wint
AEROCOLOR Negative Film 2445 (ESTAR Base) in a Vinten