RESERVE MANAGEMENT CONSULTANT'S REPORT No.3

REPORT ON DIEBACK DUE TO *PHYTOPHTHORA CINNAMOMI* IN TWO PEOPLES BAY NATURE RESERVE

by

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DEPARTMENT OF FISHERIES AND WILDLIFE 1983

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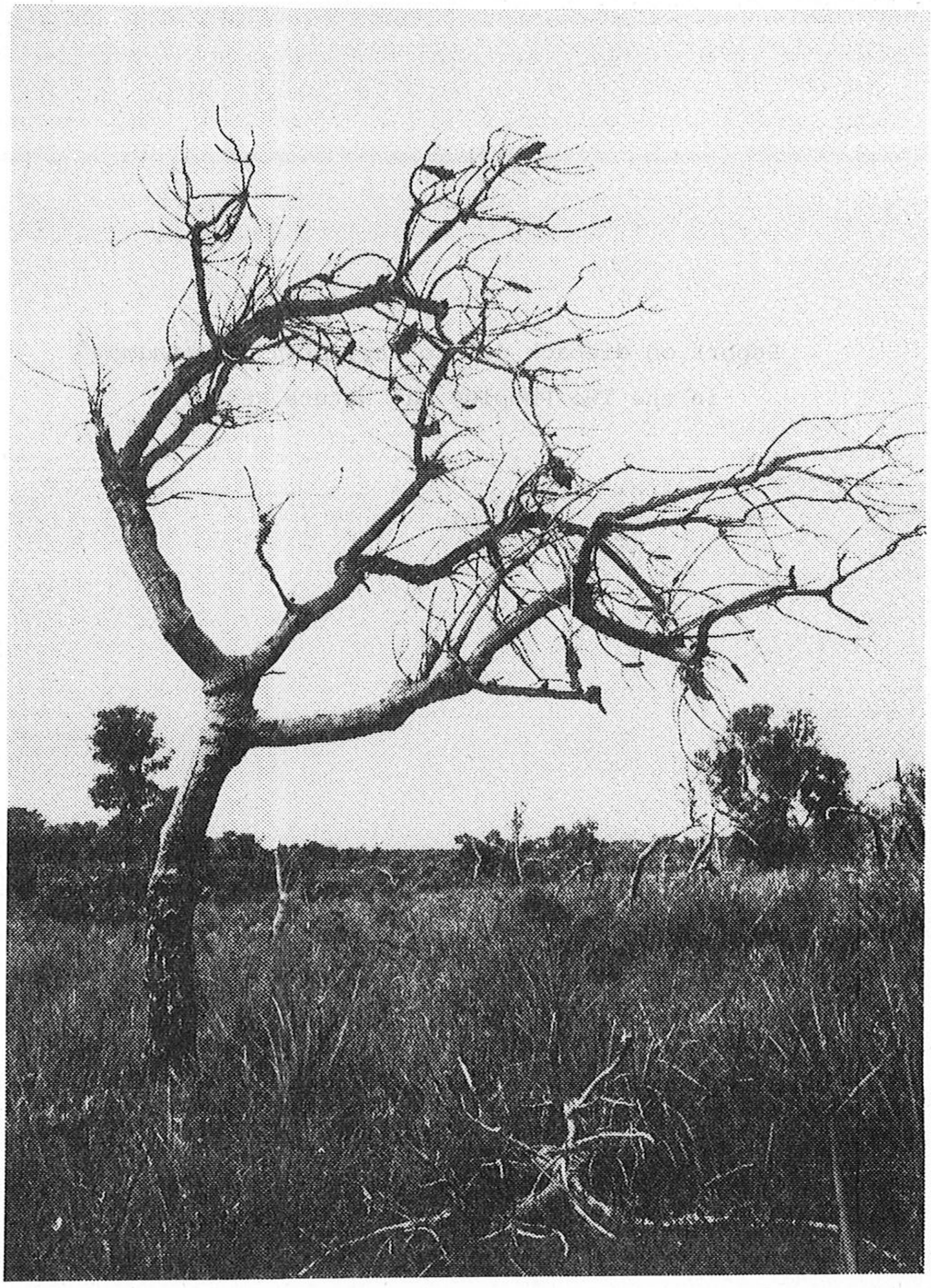

Phytophthora cinnamomi - affected landscape in the Two Peoples Bay Nature Reserve.

SUMMARY

The dieback fungus *Phytophthora cinnamomi* was studied in the Two Peoples Bay Nature Reserve.

The fungus affects primarily the *Banksia* heath, causing gross changes in species composition and structure of the vegetation. Many species are eliminated or severely reduced while others are unaffected and some increase in density with reduced competition. In total there is a large reduction in standing biomass as the rich *Banksia* heath is converted into an open woodland dominated by sedges. The avifauna is severely reduced in affected areas and it must be assumed that other elements of the fauna are similarly affected.

Although the fungus spreads naturally at about one metre per year it is widely distributed over the reserve including the Mt. Gardner area. Human activities have probably been responsible for this dispersal and this most likely occurred some decades ago. The fungus is now so widespread over the reserve that no control programme is feasible with the resources available, however quarantine measures should be continued to reduce the rate of spread of the fungus.

More than 90% of the *Banksia* heath has already been destroyed and the remainder will be lost because there are no remnants isolated from known infections. It is likely that large changes in the flora and fauna have already occurred and eventually many species may become extinct or very rare on the reserve.

The extent of *Phytophthora cinnamomi* infection in the Two Peoples Bay Nature Reserve suggests that many other reserves may be infected or are under serious threat. Only quarantine can prevent infection of more reserves and since *Phytophthora cinnamomi* is a serious threat to the conservation value of many reserves suitable quarantine is an urgent necessity.

CONTENTS

INTRODUCTION

Examination of apparent plant damage in the western part of the Two Peoples Bay Nature Reserve led to the discovery in 1981 that the "dieback" fungus *Phytophthora cinnamomi* was present in the reserve (Sivasithamparam, pers. comm., see Fig. 1). Subsequently quarantine measures were imposed to prevent spreading of the fungus.

The study reported here was undertaken to provide information on :-

- The extent of existing infections,
- The nature of the problem, and
- Possible control measures.

The field work for this study was carried out in January and February 1983.

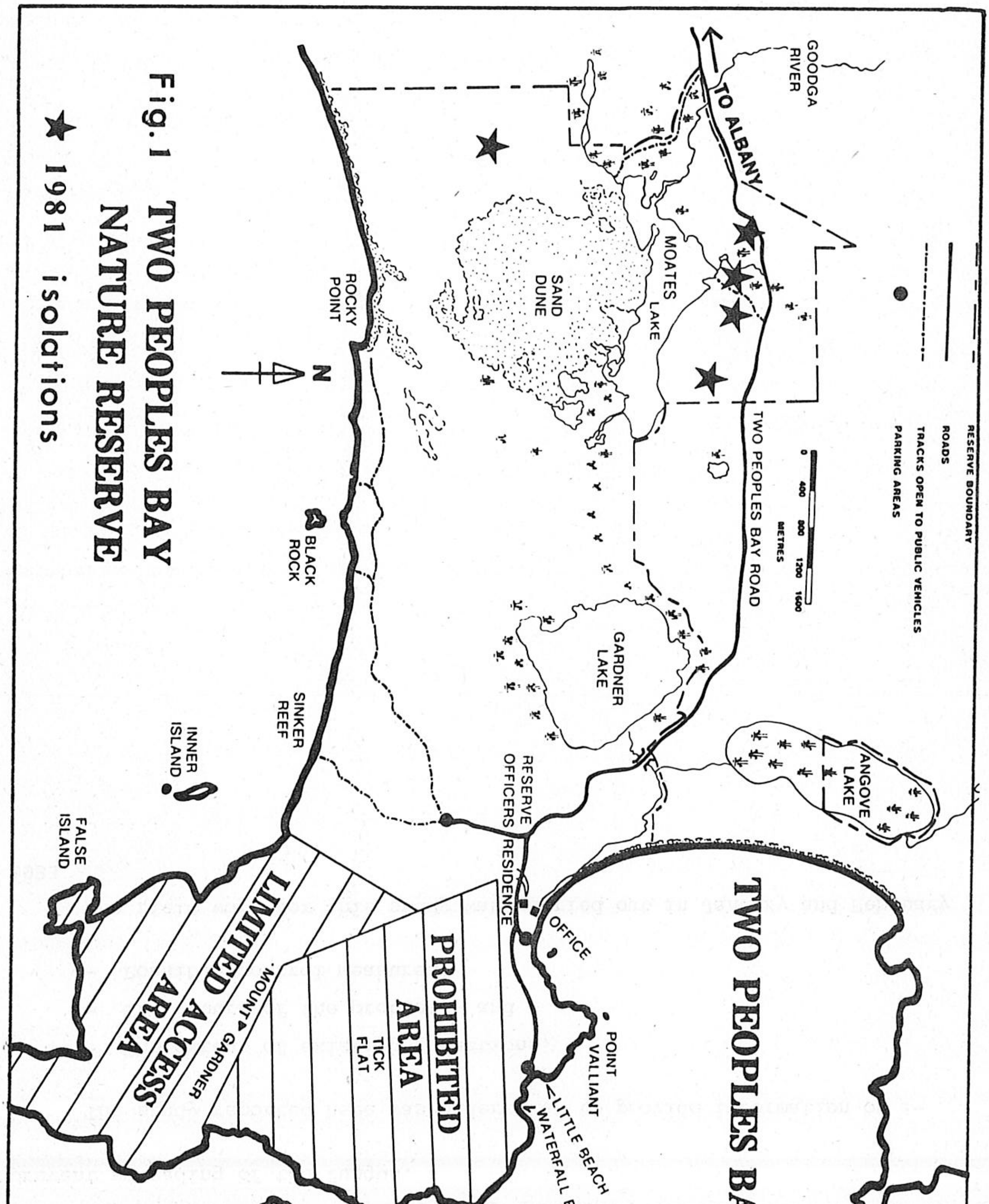

Fig. 1 TWO PEOPLES BAY NATURE RESERVE

★ 1981 isolations

METHODS

Isolation of *Phytophthora cinnamomi* from known infected areas can be difficult (Shea, 1979a). This is due primarily to the problems of actually collecting the fungus in a sample.

In general *Phytophthora cinnamomi* is believed to be pathogenic by killing the fine roots of its host, so that the fungus may be present as mycelium (in roots), as motile zoospores or as resting chlamydospores. However in practice it is difficult to sample the fungus because it is not necessarily present in any particular location selected as a sample.

The *Banksia* are believed to be somewhat unusual in that the fungus systematically invades the larger roots and even the stem during infection, and this is rapidly fatal to the host. *Phytophthora cinnamomi* is a saprophyte as well as a pathogen, and shortly before or during death of the host it invades the host and survives in the dead wood for at least a year. Blowes, Heather, Malajczuk and Shea (1982) have reported good rates of recovery of *Phytophthora cinnamomi* from infected *Banksia grandis* in jarrah forest, in strong contrast to the low recovery rates from soil samples.

In the study reported here, larger roots of dying or recently dead *Banksia* were used to detect the presence of *Phytophthora cinnamomi*. Soil samples were used in one study where no *Banksia* were available but the rate of recovery was considerably less than that from *Banksia* roots.

In the laboratory *Phytophthora cinnamomi* was isolated by growth on $P_{10}VP(H)$ medium which is an agar plate incorporating Potato Dextrose Agar, antibiotics, a fungicide and hydroxymethylisoxazol (modified after Tsao and Guy, 1977). The fungi were identified as *Phytophthora cinnamomi* on morphological criteria. The strain type of 12 randomly selected isolations was determined by mating them with an A^1 strain of *Phytophthora cryptogea* on 5% V8 juice agar (Elaine Davison, Murdoch University). All isolates produced oospores indicating that all isolations were of the A^2 strain of *Phytophthora cinnamomi*. (The A^2 strain of *Phytophthora cinnamomi* is associated with dieback in W.A. forests.)

The sampling procedure used was: large roots 1-3 cm in diameter were dug up with a sterile shovel, or the whole plant was dug up or pulled out. A sample, usually of 1-3 cm in diameter and 4 cm long, was cut out with sterile secateurs and stored in a plastic vial. In the laboratory the root samples were sliced up with sterile secateurs and 5-10 sections were placed on a half plate of $P_{10}VP(H)$. These were left at room temperature for 24-48 hours and searched under a microscope for the presence of *Phytophthora cinnamomi*.

Soil samples were collected by excising approximately 100 g of soil with a sterile trowel into a plastic vial. The soils were plated directly onto $P_{10}VP(H)$ medium after being subsampled with a cork borer, or after sieving into fractions.

RESULTS

The distribution of *Phytophthora cinnamomi* on the reserve

Selection of sampling areas

Plant damage thought to be due to *Phytophthora cinnamomi* was obvious in many parts of the reserve and is illustrated in Figures 2, 3, 4 and 5. One area (to the north of Moates Lake) was selected for a detailed study to determine if this plant damage correlated with the presence of *Phytophthora cinnamomi*. The area was surveyed to provide an accurate map of plant damage and samples of *Banksia* roots were collected from within affected areas and from just outside these areas. The results are given in Fig. 6. It can be seen that *Phytophthora cinnamomi* was not isolated from any of the 30 samples collected where there was no plant damage but it was isolated from 34 (85%) of the 40 samples taken from within the affected areas.

A map of the areas on the reserve showing plant damage was prepared from ground inspection and aerial photos, and this was used as the basis for sampling. The survey was extended to include areas out of the reserve if they were upstream on the Goodga River (Reserve 24991 for National Park and water) or Black Cat Creek and the Angove River (Reserve 13802 for water supply and catchment area).

Distribution of the fungus on the reserve

The results of a survey for *Phytophthora cinnamomi* on the reserve are given in Fig. 7. All samples were roots of dying or recently dead *Banksia* species (*B. attenuata*, *B. coccinea*, *B. grandis*, *B. ilicifolia*, *B. nutans* and *B. quercifolia*) except for single specimens of *Leucopogon flavescens* (positive) and *Jacksonia spinosa* (positive), and six of *Dryandra formosa* (all in the Mt. Gardner area and all negative).

In addition to the results shown in Fig. 7 samples were also collected on the Angove River in the water reserve. Six samples were collected between Clear Pool (at the end of the road along the Angove River) and the pumping station. Three of these were positive, and the area is extensively infected on the basis of plant damage.

In all, 251 specimens of roots were collected, of which 30 were controls taken from uninfected areas and of the remaining 221 specimens

Figure 2: An example of *Banksia* heath, showing *Banksia* spp. emergent from the rich understory (foreground).

Figure 3: *Phytophthora cinnamomi*-affected *Banksia* heath, with unaffected *Banksia* heath in the background.

Figure 4: Detail of *Phytophthora cinnamomi* - affected *Banksia* heath. Note the *Banksia* stump, bare ground and abundance of sedges.

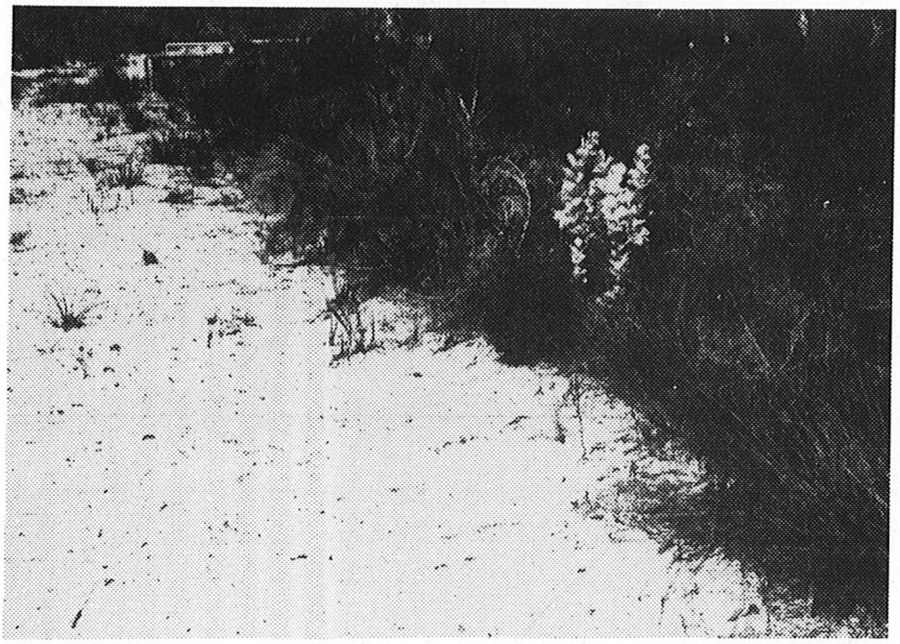

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Figure 5: Firebreak in *Phytophthora cinnamomi* - affected *Banksia* heath. Note the recently-killed *Banksia coccinea* beside the firebreak.

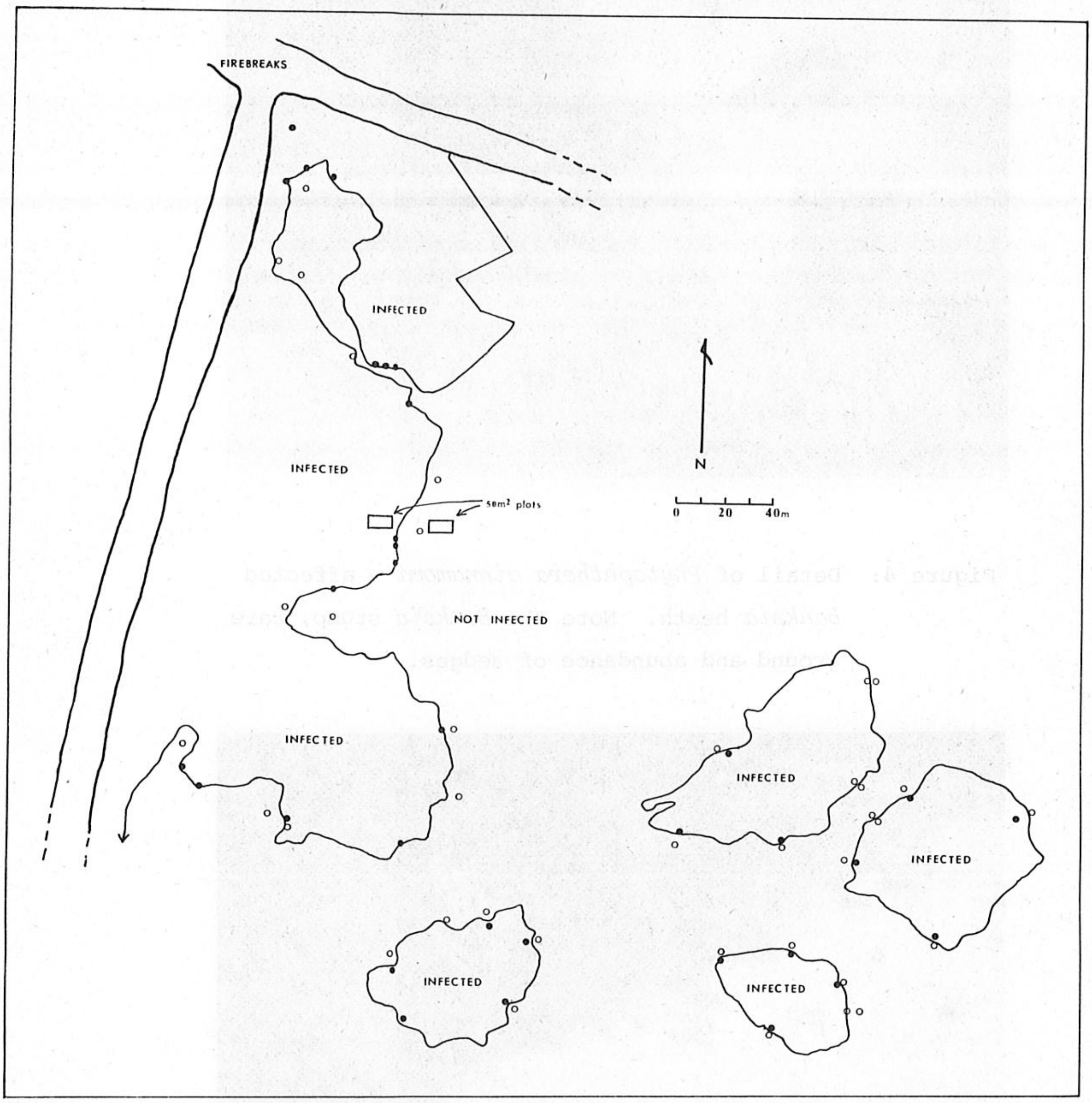

Figure 6: The distribution of samples which were positive (closed circle) or negative (open circle) for *Phytophthora cinnamomi*, in relation to areas showing plant damage. For location see Figure 9.

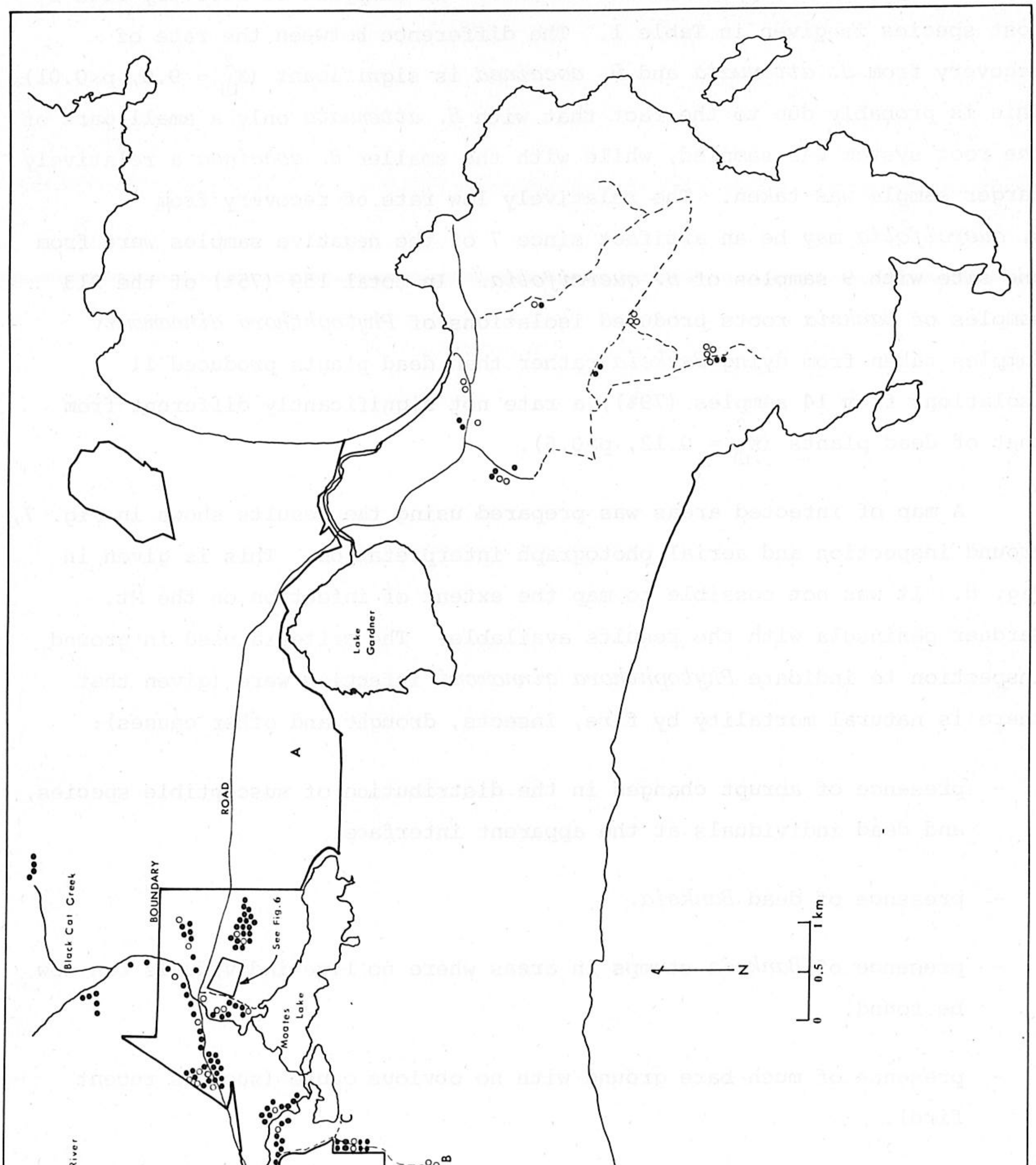

Figure 7: The distribution of samples which were positive (closed circle) or negative (open circle) for *Phytophthora cinnamomi* in and around the Two Peoples Bay Nature Reserve. A, B and C are specific locations mentioned in the text.

161 (73%) produced *Phytophthora cinnamomi*. An analysis of recovery rate by host species is given in Table 1. The difference between the rate of recovery from *B. attenuata* and *B. coccinea* is significant ($X^2_{(1)} = 9.0$, $p<0.01$). This is probably due to the fact that with *B. attenuata* only a small part of the root system was sampled, while with the smaller *B. coccinea* a relatively larger sample was taken. The relatively low rate of recovery from *B. quercifolia* may be an artifact since 7 of the negative samples were from one site with 9 samples of *B. quercifolia*. In total 159 (75%) of the 213 samples of *Banksia* roots produced isolations of *Phytophthora cinnamomi*. Samples taken from dying *Banksia* rather than dead plants produced 11 isolations from 14 samples (79%), a rate not significantly different from that of dead plants ($X^2_{(1)} = 0.12$, $p>0.5$).

A map of infected areas was prepared using the results shown in Fig. 7, ground inspection and aerial photograph interpretation. This is given in Fig. 8. It was not possible to map the extent of infection on the Mt. Gardner peninsula with the results available. The criteria used in ground inspection to indicate *Phytophthora cinnamomi* infection were (given that there is natural mortality by fire, insects, drought and other causes):

- presence of abrupt changes in the distribution of susceptible species, and dead individuals at the apparent interface.

- presence of dead *Banksia*.

- presence of *Banksia* stumps in areas where no live individuals can now be found.

- presence of much bare ground with no obvious cause (such as recent fire).

- vegetation dominated by known tolerant species (Restionaceae and Cyperaceae).

- presence of *Banksia* showing the signs of dieback. *B. attenuata, B. ilicifolia* and *B. coccinea* exhibit dieback by the progressive death of leaves from proximal to distal parts rather than distally as in the jarrah. They may be finally killed with many leaves still attached and these may be slightly green even after death. The smaller species appear to be killed very quickly and may be found dead with all their leaves attached and quite dry but still greenish.

Table 1: Recovery of *Phytophthora cinnamomi* from dying or recently dead individuals in *Phytophthora cinnamomi* infected areas.

Species	Samples positive	%	Samples negative	%	Total No. of samples
Banksia attenuata	30	64%	17	36%	47
Banksia coccinea	101	85%	18	15%	119
Banksia grandis	0	0%	3	100%	3
Banksia ilicifolia	5	71%	2	29%	7
Banksia nutans	11	79%	3	21%	14
Banksia quercifolia	12	52%	11	48%	23
Leucopogon flavescens	1	100%	0	0%	1
Jacksonia spinosa	1	100%	0	0%	1
Dryandra formosa	0	0%	6	100%	6
Totals	101	73%	60	27%	221

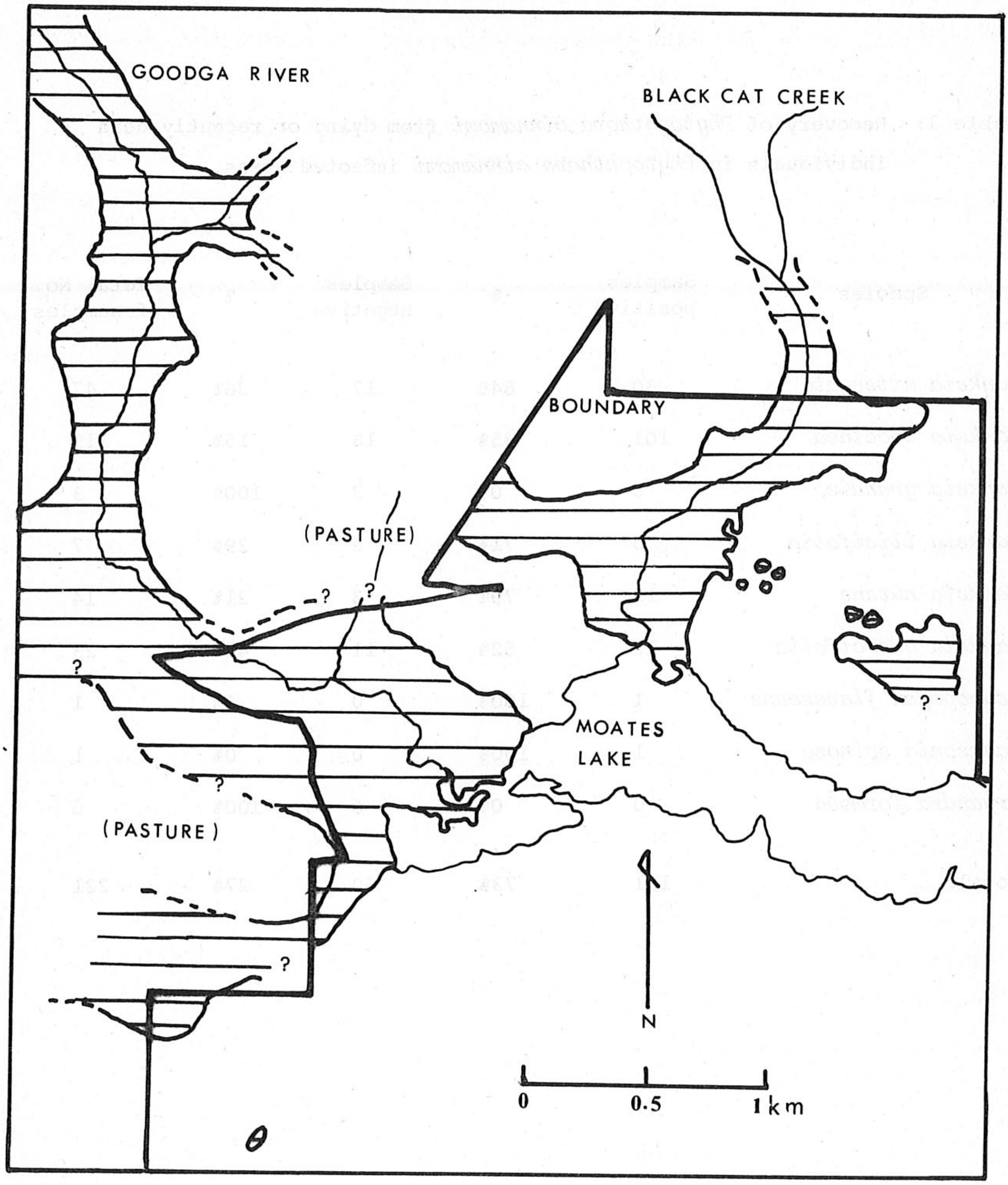

Figure 8: The distribution of areas infected by *Phytophthora cinnamomi* in and around the western part of the Two Peoples Bay Nature Reserve.

Summer is probably the most suitable season for examining the *Banksia* as they are under water stress and most likely to die abruptly from *Phytophthora cinnamomi* infection, although they are presumably also more likely to die from other causes as well.

The area labelled A on Fig. 7 is private property which was cleared only recently. From aerial photographs it is likely that this area was extensively infected with *Phytophthora cinnamomi* when it was cleared.

A search was made for dead *Banksia* on tracks at their margins. Seven of these were found and five were positive for *Phytophthora cinnamomi*.

An interesting occurrence of *Phytophthora cinnamomi* is at point B on Fig. 7. This patch is a short strip of infection on either side of a bull-dozed track. There are no other infected areas near this patch and it would appear that the infection was introduced on machinery used to widen or install the track.

The effect of *Phytophthora cinnamomi* on the flora

An area to the north of Moates Lake was selected as a study site (Fig. 9), where there is a patch of *Banksia* heath which is being attacked by *Phytophthora cinnamomi*. This patch is bounded by Black Cat Creek on the west and *Casuarina fraseriana*/eucalypt forest on the other sides. This forest is based on lateritic soils on hills; it does not appear to be susceptible to *Phytophthora cinnamomi* infection. Inspection of the reserve suggested that the *Banksia* heath was the vegetation type primarily at risk.

All individual plants were counted in 50 m^2 quadrats on either side of a *Phytophthora* front (for location see Fig. 6). The control plot was approximately 10 m from the nearest apparent infection, while the infected plot was only a few metres from the front to reduce inadvertent recording of post-infection changes. The results are given in Table 2. It was found that some species (the Restionaceae and Cyperaceae) could not be counted because they were difficult to identify without flowering material and many propagate vegetatively. These species were estimated as a single group by standing biomass (see below). The data of Table 2 is not suitable for rigorous statistical snalysis but the significance of the difference between the two counts for each species has been estimated with a Chi-squared test on the assumption that the two counts are equal. The test was

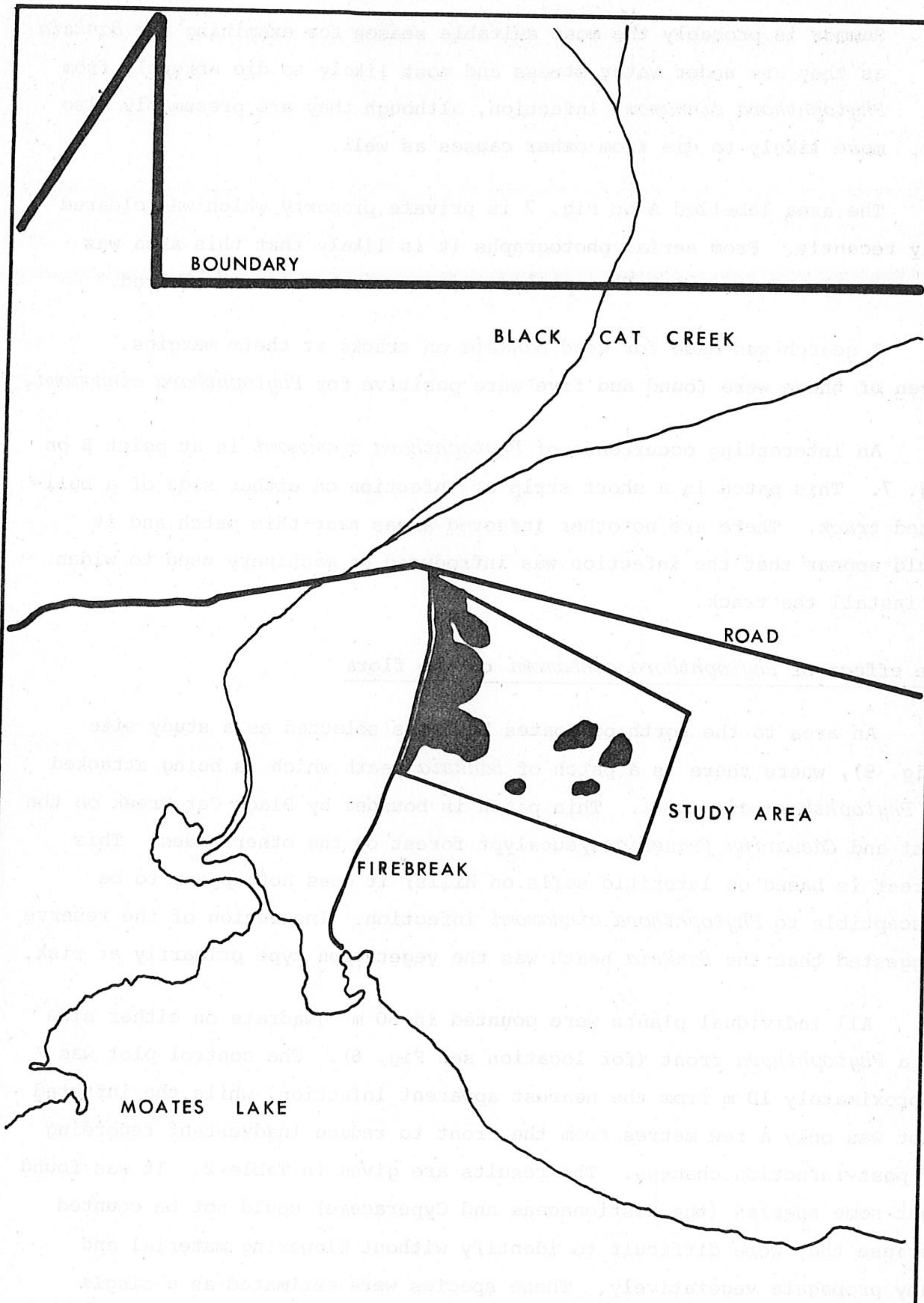

Figure 9: Sketch showing the location of the main study area. Known infected areas are given in black.

Table 2: Counts of plants in 50 m^2 quadrats in control and infected areas. See text for statistical analysis.

Species	Control	Infected	Total	$X^2_{(1)}$	Significance
Liliaceae					
Dasypogon bromeliaefolius	20	12	32	2.0	n.s.
Johnsonia lupulina	9	17	26	2.46	n.s.
Thysanotus glaucus	0	2	2	-	-
Casuarinaceae					
Casuarina fraseriana	4	5	9	-	-
Proteaceae					
Adenanthos cuneata	24	7	31	9.32	**
Adenanthos obovata	10	3	13	3.77	n.s.
Banksia attenauta	6	1	7	-	-
Banksia coccinea	8	1	9	-	-
Banksia grandis	1	0	1	-	-
Banksia nutans	31	1	32	28.1	***
Petrophile longifolia	13	0	13	13.0	***
Petrophile rigida	12	7	19	1.32	n.s.
Fabaceae					
Daviesia incrassata	6	0	6	-	-
Daviesia pectinata	2	0	2	-	-
Jacksonia spinosa	3	0	3	-	-
Latrobea hirtella	117	1	118	114	***
Latrobea genistoides	109	0	109	109	***
Dilleniaceae					
Hibbertia desmophylla	226	1	227	223	***
Myrtaceae					
Agonis hypericifolia	0	7	7	-	-
Agonis linearifolia	12	3	15	5.4	*
Beaufortia anisandra	111	31	142	45.1	***
Calytrix asperula	9	29	38	10.5	**
Darwinia vestita	5	7	12	0.33	n.s.
Melaleuca thymoides	50	35	85	2.65	n.s.

..../Cont.

Table 2 (Cont.)

Species	Control	Infected	Total	$X^2_{(1)}$	Significance
Umbelliferae					
Actinotus glomeratus	31	78	109	20.3	***
Platysace pendula	6	18	24	6.0	*
Xanthosia rotundifolia	13	22	35	2.31	n.s.
Epacridaceae					
Andersonia caerulea	302	25	327	235	***
Andersonia simplex	254	6	260	237	***
Lysinema ciliatum?	601	30	631	517	***
Leucopogon elegans	3239	16	3255	3191	***
Leucopogon flavescens	560	19	579	505	***
Leucopogon glabellus	456	30	486	373	***
Goodeniaceae					
Dampiera linearis	1	15	16	12.2	***
Stylidiaceae					
Stylidium scandens	68	219	287	79.4	***
Stylidium spathulatum	78	44	122	9.48	**
species 44 (unidentifiable)	17	0	17	17.0	***
species 67 (unidentifiable)	37	0	37	37.0	***

not carried out if there were less than ten individuals in total (i.e. where the expected value was less than five). This procedure will over-estimate the differences because the individuals of each species are not randomly distributed and a 50 m^2 block is not sufficient to encompass this variability. The given levels of significance should be taken conservatively.

The results of Table 2 can be usefully summarised by considering the species in groups (see Table 3). Of the 29 species tested statistically 17 (59%) were less common in the infected plot, 7 (24%) were unchanged and 5 (17%) were more common. The Myrtaceae show no consistent trend and cannot be regarded as a group. The 3 *Banksia* recorded in Table 2 from the infected plot were all seedlings which probably germinated after the front of infection passed through. Inspection of large areas suggested that all *Banksia* are killed by moving fronts of the pathogen. This is not true of any of the other Proteaceae species.

These results were checked by a subjective survey of the species which were common in recently infected areas. In general the results above were confirmed, and several other observations were made :-

- *Eucalyptus staeri* which is common in the *Banksia* heath appears to be unaffected by *Phytophthora cinnamomi* infection.

- *Banksia ilicifolia* which occurs in the *Banksia* woodland and heath (although not as commonly as *B. attenuata*) is eliminated by the fungus.

- *Stylidium scandens* was flowering profusely in the infected area, but only a few individuals were flowering in the control area.

- Individuals of some species such as *Beaufortia anisandra, Calytrix asperula* and the few surviving *Leucopogon flavescens* are much larger in the infected area than in the control area.

- *Casuarina fraseriana* is widespread in both the infected and control areas but does not grow into an adult tree. It is an accidental intruder from the adjacent laterite hills.

The structure of the uninfected and infected plant communities was measured by the standing biomass of the plants. Five 1 m^2 quadrats were

Table 3: Counts of groups of species in 50 m^2 quadrats in control and infected areas, from Table 1.

Group	Control	Infected	Total	$X_{(1)}$	Significance
Banksia	46	3	49	37.7	***
Proteaceae (except *Banksia*)	59	17	76	23.2	***
Proteaceae	105	20	125	57.8	***
Fabaceae	237	1	238	234	***
Umbelliferae	50	118	168	27.5	***
Epacridaceae	5412	126	5538	5045	***
Total of all species	6451	692			
	(100%)	(10.7%)			

chosen at random in each area (adjacent to the 50 m^2 quadrats described above) and all live plants were harvested at ground level. The plants were divided into Restionaceae plus Cyperaceae and all other species, and weighed after oven drying (Fig. 10). The species of Restionaceae included at least *Anarthria gracilis, A. prolifera, A. scabra, Hypolaena exsulca, Lyginia barbata* and *Restio* sp., and the Cyperaceae included at least *Schoenus* sp.

Another measure of the degree of change occurring as a result of *Phytophthora cinnamomi* infection is given by the distribution of non-seedling *Banksia attenuata* and *B. ilicifolia* around an infection front (Fig. 11). *B. ilicifolia* contributed 23% of the total individuals (which could be distinguished) in Fig. 11. All of the *Banksia* have been killed by the spread of the fungus, and wind, rot and fire then progressively reduce them to stumps.

The effect of *Phytophthora cinnamomi* on the fauna

Phytophthora cinnamomi infection apparently causes gross changes in the flora of the *Banksia* heath and therefore might be expected to affect the fauna. This was estimated by recording small birds which made use of the vegetation. Individuals were recorded for one hour on each of 8 mornings just after sunrise (four in control areas and four in *Phytophthora cinnamomi* infected areas). The number of birds seen was dependent on the weather (particularly wind) but no correction was made for this and the days were selected at random. Birds were only recorded if they could be expected to be actually using the vegetation for feeding. The area used was more or less the study area shown in Fig. 9. The results are given in Table 4.

The rate of spread of *Phytophthora cinnamomi*

Three estimates were made of the unassisted rate of spread.

1. From aerial photographs of identifiable patches of infection, taken many years apart.

2. From the width of the bands of dead but unburnt plants behind advancing fronts of infection, where the date of the last fire is known.

3. From the distribution of dead *Banksia* behind an advancing front of infection.

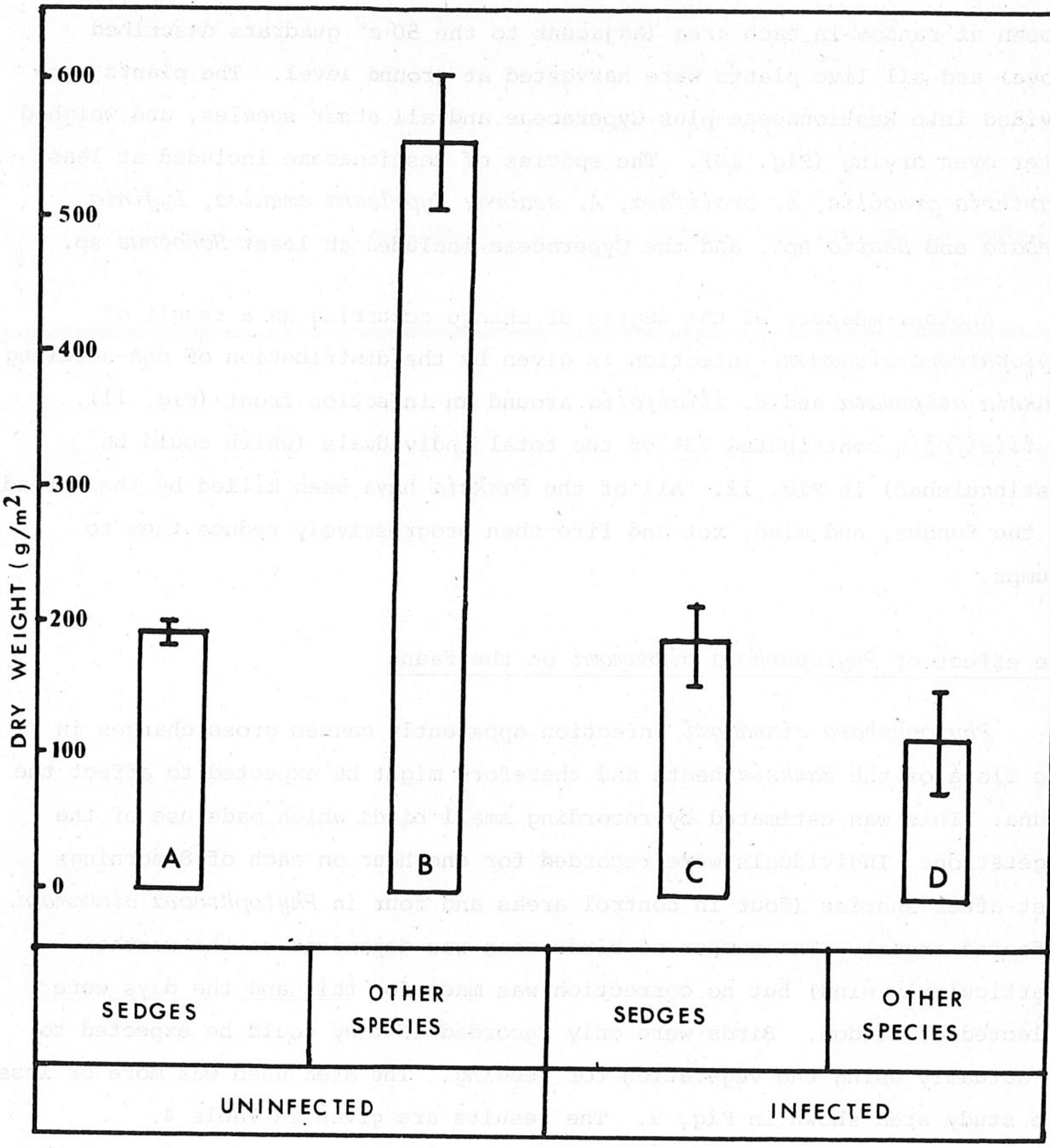

Figure 10: Dry weights of plants. The sedges are the Restionaceae and Cyperaceae species. Each value is the mean of five observations with the standard error. The difference between A and C is not significant ($t_8=0.057$, $p>0.5$) but the difference between B and D is significant ($t_8=3.67$, $p<0.01$).

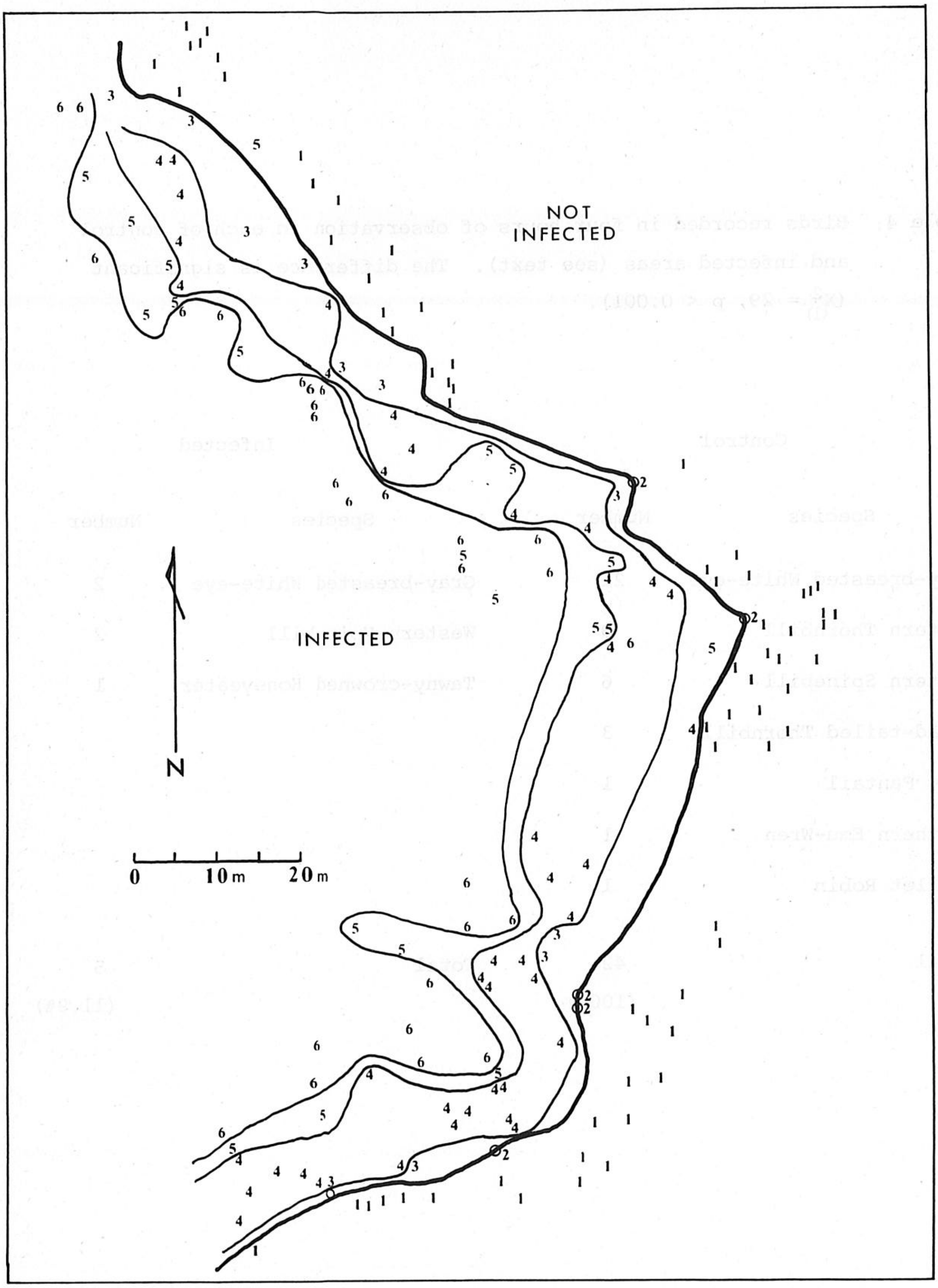

Figure 11: The distribution of *Banksia attenuata* and *B. ilicifolia* around a front of infection. The trees are classified as live (1), dying (2), dead with leaves retained (3), dead and without leaves but essentially intact (4), dead and half or more collapsed (5), or as a stump (6).

Table 4: Birds recorded in four hours of observation in each of control and infected areas (see text). The difference is significant ($X^2_{(1)} = 29$, $p < 0.001$).

Control		Infected	
Species	Number	Species	Number
Gray-breasted White-eye	21	Gray-breasted White-eye	2
Western Thornbill	9	Western Spinebill	2
Western Spinebill	6	Tawny-crowned Honeyeater	1
Broad-tailed Thornbill	3		
Grey Fantail	1		
Southern Emu-Wren	1		
Scarlet Robin	1		
Total	42 (100%)	Total	5 (11.9%)

Aerial photographs produced five identifiable patches which could be measured in February 1969 and January 1983 (i.e. 14 years apart). The changes are as follows:

Patch	Change in radius (m)
1, width	7.5
1, length	15
2, radius	15
3, width	5 ?
3, length	12.5
4, radius	15
5, radius	18

It should be noted that these measurements are subject to large errors because they represent changes in very small linear measurements. From these results the median value is 15 m in 14 years, or approximately 1 m per year.

For the bands of dead vegetation the results were divided into three categories of downhill, horizontal and uphill movements:

	Category	Mean (m)	Variance	Number of observations	Maximum (m)	Minimum (m)
1.	Downhill	5.14	1.0828	11	7.0	3.8
2.	Horizontal	3.71	1.7869	14	5.7	1.1
3.	Uphill	4.51	1.0652	16	6.2	3.0

None of the differences between the means are significant (for the difference of 1 and 2, $t_{23} = 1.055$, $p > 0.2$). The grand mean is 4.4 m, and in this area the last fire was seven years ago (Hopkins, pers. comm.) producing an estimate of the rate of spread of 0.63 m per year.

From the map of dead *Banksia* in Fig.11 it can be seen that no dead but intact *Banksia* is more than 15 m from the present limit of the infection. Assuming dead trees remain essentially intact for up to ten years then the rate of spread is about 1.5 m per year.

All of these calculations assume that the rate of spread is constant between years and spatially. The rate of spread is likely to be controlled by the weather (which determines the time over which the zoospores are active) and may be quite variable between years. Study of Fig. 6 suggests that there are marked irregularities in the spread of the fungus on a small scale.

The date of origin of the infection

From the estimate of the unassisted rate of spread of *Phytophthora cinnamomi* and the radius of the identifiable patches in the earliest aerial photographs, the date of origin of these patches can be calculated (i.e. to radius 0 m). These are:

Patch	Date
1, width	1949
1, length	1939
2, radius	1949
3, width	1959 ?
3, length	1959
4, radius	1954
5, radius	1956

Given that these dates are subject to large errors and that these patches are all in the same locality it is likely that these dates are all the same, and that all of these patches originated at the same time or over a short period in the early 1950's. This conclusion is supported by the absence of new outbreaks in the same area even though infections as small as a few square metres would have been detected.

Unfortunately it is not possible to distinguish plant damage due to *Phytophthora cinnamomi* in the earliest aerial photos (1947) because of their poor quality. There is no evidence to suggest that *Phytophthora cinnamomi* was not present at that time.

Persistence of *Phytophthora cinnamomi* in soils

The persistence of *Phytophthora cinnamomi* was tested in two ways - by searching for viable spores behind an advancing front of infection, and by testing the occasional killed young *Banksia* individuals which are seen in old areas of infection.

Soil samples were collected at each metre interval on a 10 x 2 m grid laid out such that the first three metres were in uninfected vegetation and the remaining seven metres were in an infected area. Five additional samples were collected on the front of infection over an adjacent five metre section. The results are given in Fig. 12. Only three samples produced *Phytophthora cinnamomi*. The rate of recovery of 3 (12%) positive samples from 25 samples on or behind the front of infection is in strong contrast to that from the root samples (73% positive). The number of positive soil samples was too small to give a useful estimate of the density of *Phytophthora cinnamomi* in old areas of infection, but the fungus was isolated from four metres behind the present front of infection.

Recently dead *Banksia* from which *Phytophthora cinnamomi* were recovered were found up to 30 metres from the nearest infection front (Fig. 13), and larger distances would be recorded if sufficient *Banksia* seedlings could be found.

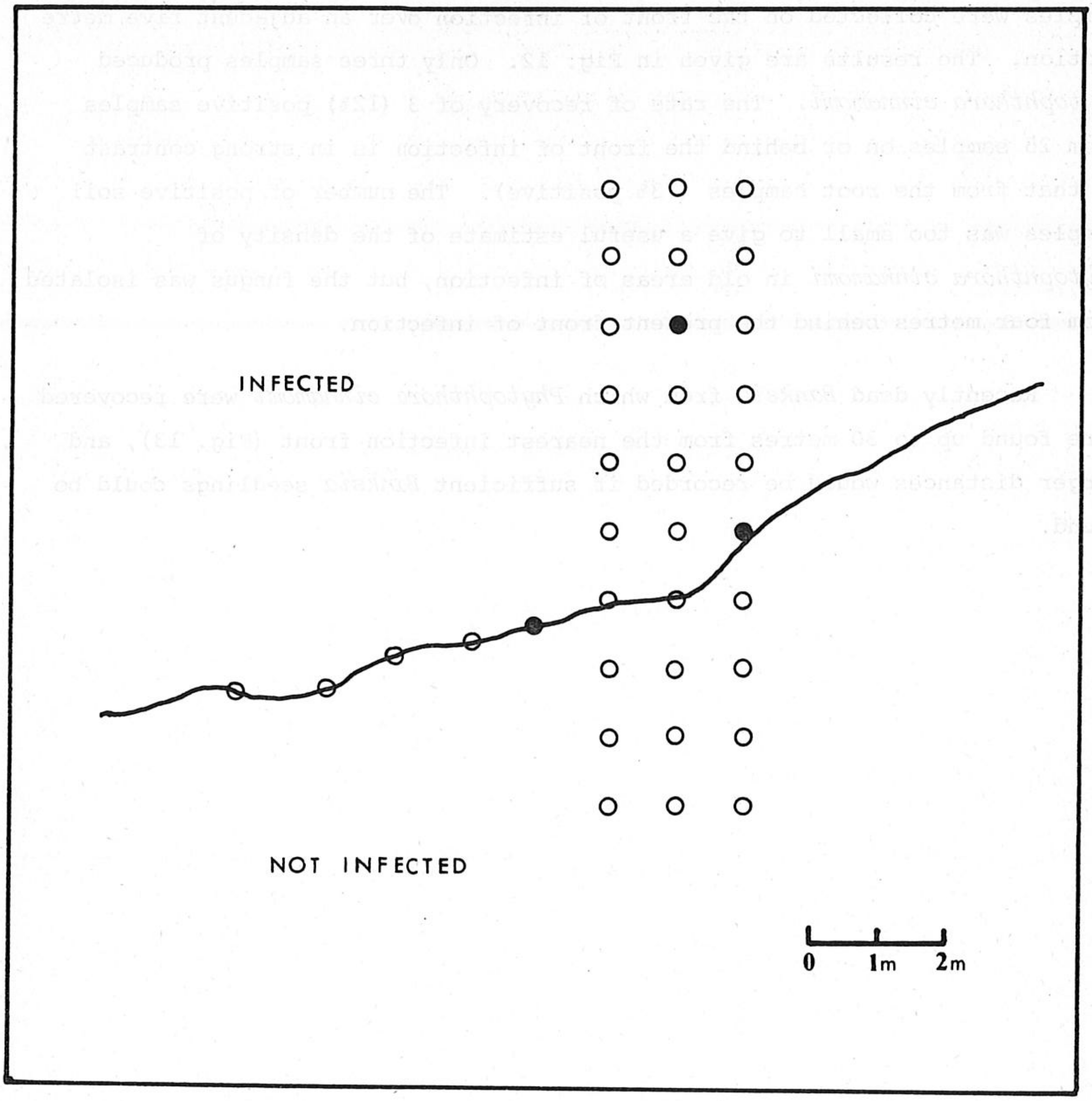

Figure 12: The distribution of soil samples which were positive (closed circle) or negative (open circle) for *Phytophthora cinnamomi*.

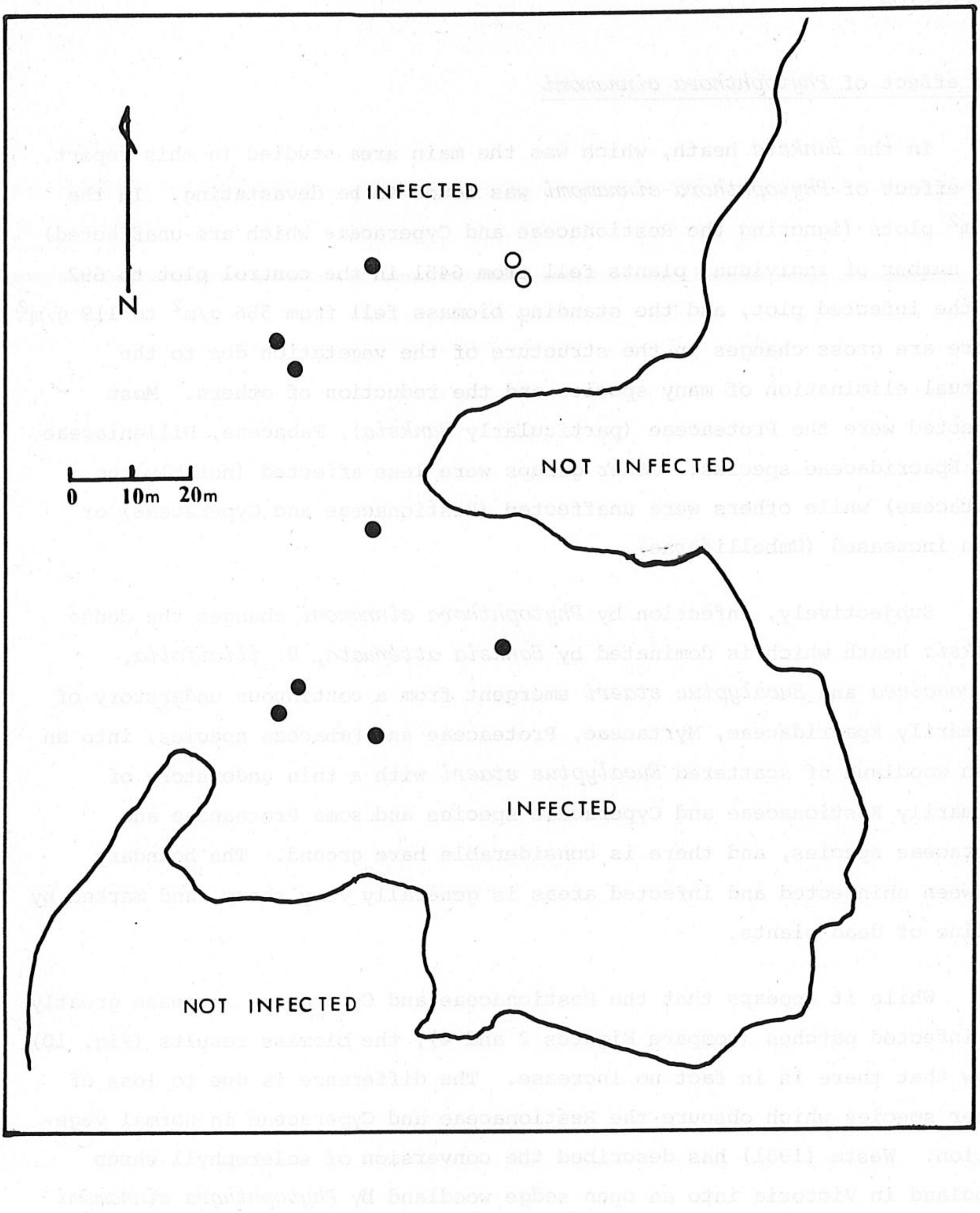

Figure 13: The locations of dead young *Banksia coccinea* which were positive (closed circle) or negative (open circle) for *Phytophthora cinnamomi*, in relation to a front of infection.

DISCUSSION

The effect of *Phytophthora cinnamomi*

In the *Banksia* heath, which was the main area studied in this report, the effect of *Phytophthora cinnamomi* was found to be devastating. In the 50 m^2 plots (ignoring the Restionaceae and Cyperaceae which are unaffected) the number of individual plants fell from 6451 in the control plot to 692 in the infected plot, and the standing biomass fell from 556 g/m^2 to 119 g/m^2. There are gross changes in the structure of the vegetation due to the virtual elimination of many species and the reduction of others. Most affected were the Proteaceae (particularly *Banksia*), Fabaceae, Dilleniaceae and Epacridaceae species. Other groups were less affected (notably the Myrtaceae) while others were unaffected (Restionaceae and Cyperaceae) or even increased (Umbelliferae).

Subjectively, infection by *Phytophthora cinnamomi* changes the dense *Banksia* heath which is dominated by *Banksia attenuata, B. ilicifolia, B. coccinea* and *Eucalyptus staeri* emergent from a continuous understory of primarily Epacridaceae, Myrtaceae, Proteaceae and Fabaceae species, into an open woodland of scattered *Eucalyptus staeri* with a thin understory of primarily Restionaceae and Cyperaceae species and some Proteaceae and Myrtaceae species, and there is considerable bare ground. The boundary between uninfected and infected areas is generally very sharp, and marked by a line of dead plants.

While it appears that the Restionaceae and Cyperaceae increase greatly in infected patches (compare Figures 2 and 4), the biomass results (Fig. 10) show that there is in fact no increase. The difference is due to loss of other species which obscure the Restionaceae and Cyperaceae in normal vegetation. Weste (1981) has described the conversion of sclerophyll shrub woodland in Victoria into an open sedge woodland by *Phytophthora cinnamomi* infection, although in this case there was an increase in the number of sedges as well as a decline in the numbers of many other species.

There is no evidence that new species invade infected areas, although surviving individuals may grow larger, flower more profusely or increase in number, presumably with the reduction of competition. Exotic species such as grasses could invade infected areas but in the Two Peoples Bay Nature Reserve there are probably only limited opportunities for invasion by such species. In the long term damage caused by *Phytophthora cinnamomi* is likely to encourage the invasion of exotic species. Weste (1974) has described how in Victoria infection by *Phytophthora cinnamomi* has resulted in an influx of weeds and grasses in the Brisbane Ranges but not in the Wilson's Promontory National Park.

In the western part of the Two Peoples Bay Nature Reserve the *Banksia* heath occupies an intermediate belt of deep sand between the watercourses and the hills (which are based on laterite). From Fig. 8 it can be seen that the *Banksia* heath is now almost completely infected. The vegetation of the reserve has not been mapped but a ground survey suggested that greater than 90% of the area of this vegetation type has already been lost. Only isolated remnants now remain and none of these are isolated from fronts of infection. It is likely that this vegetation type will be virtually lost from the reserve in a matter of decades. As this process continues many species of plants will become very rare or extinct on the reserve. These include many of the *Banksia*, Fabaceae and Epacridaceae species.

In the watercourses the vegetation is largely Restionaceae and Cyperaceae. No attempt was made to detect *Phytophthora cinnamomi* in the margins of the watercourses because there are no known susceptible species occurring there. It is not clear whether susceptible species once grew there but all of the watercourses must now be infected by downstream movement of spores. Comparable uninfected areas are needed to resolve this question.

The forest on the laterite hills does not appear to be susceptible to *Phytophthora cinnamomi* infection, although at least one highly susceptible species (*Banksia grandis*) occurs there. This may be due to some peculiarity of the soil, to the relative absence of susceptible species, or to the presence of species such as *Casuarina fraseriana* which may be hostile to the fungus through root exudates, bacteria or mycorrhizal fungi (Malajczuk, pers. comm.).

The other major areas of infection are the low vegetation on the isthmus leading to Mt. Gardner and mixed heath on the peninsula itself. These were less well studied. In both cases there are no obvious fronts of infection, which may be due to a lack of suitable hosts or to the possibility that hosts have already been largely eliminated. It is not possible to resolve this without a botanical study of comparable uninfected areas. Certainly there are now few *Banksia* or other obvious susceptible species and the vegetation is dominated by Restionaceae, Cyperaceae and Myrtaceae species. If the area is now generally infected (which must be considered likely) changes in the vegetation within recent historical time may have been profound.

The net effect of *Phytophthora cinnamomi* infection on the reserve has been a considerable loss of species and biomass, and at least some areas are now impoverished. There seems little doubt that many species of animals would be disadvantaged by these losses. Table 4 shows the apparent effect on the avifauna in one situation. The three most important affected families (Proteaceae, Fabaceae and Epacridaceae) are almost certainly essential to the survival of many invertebrates and possibly some vertebrates. The almost complete loss of the *Banksia* and reduction of the other Proteaceae for example might well be sufficient to drive out nectar feeding birds and mammals which depend on a seasonal progression of food sources. As *Phytophthora cinnamomi* infection proceeds at least some animal species could become extinct or very rare on the reserve.

<u>The distribution and transport of *Phytophthora cinnamomi*</u>

From Fig. 7 it can be seen that *Phytophthora cinnamomi* is now generally distributed over the Two Peoples Bay Nature Reserve, including areas around Mt. Gardner which have been regarded as relatively remote and undisturbed.

The unassisted rate of spread of the fungus has been found to be approximately one metre per year in the deep sands of the *Banksia* heath. A similar figure has been reported by Shea and Dillon (1980) in jarrah forest. In some circumstances (associated with downslope surface movement of water) rates of hundreds of metres per year have been recorded (see for example Weste and Law, 1973). In most areas of the reserve surface soils are sandy and free draining, however granite rocks, laterite and other features could all produce lateral movement of water and therefore potentially more rapid spread of the fungus. Certainly the rate of spread would be extremely rapid along watercourses.

Phytophthora cinnamomi spreads naturally by infective zoospores which are motile and swim or are carried along in soil water until they attach to a host. This is undoubtedly the mechanism used in the slow spread of the fungus through the *Banksia* heath where there is no lateral movement of water.

The fungus also produces non-motile resting spores (chlamydospores) which remain in the soil or dead plants for long periods. It is now generally agreed that the major vector of *Phytophthora cinnamomi* in W.A. is human activity resulting in the movement of infected soil. While it is possible that the fungus was introduced into the reserve only once, it must have been spread through the reserve by human activities. Natural spread may allow the fungus to infect the entire length of a watercourse but human activities must introduce it to each watershed. Spread of *Phytophthora cinnamomi* by wildlife is feasible and has been proposed (see for example Keast and Walsh, 1979); however no evidence in support of this was found in the present study. In Fig. 6 no new small patches of infection were found, and these would be expected if wildlife is acting as a vector.

The results of this study suggest that *Phytophthora cinnamomi* was present in the area now occupied by the reserve at least 30 years ago, and there is nothing in the results to indicate that the fungus was not already widely distributed at that time. A review of the history of *Phytophthora cinnamomi* (Newhook and Podger, 1972) gives an insight into the difficulty of defining the progress of the fungus in an area like Two Peoples Bay. The first recognisable description of Jarrah dieback in Western Australia was made in 1921. The fungus itself was first described in 1922 (on cinnamon trees in Sumatra). The first isolation of *Phytophthora cinnamomi* in Australia was made in 1930 (from pineapples in Queensland) and the first isolation from W.A. was made in 1964. *Phytophthora cinnamomi* was identified as the cause of jarrah dieback in 1965. From this history it is likely that the fungus was well established in the jarrah forest by the 1920's. Almost nothing is known of the spread of the fungus in non-forest areas except that it was distributed over the entire coastal south-west by the 1970's (Anon, 1978).

Persistence of *Phytophthora cinnamomi*

Damage due to *Phytophthora cinnamomi* has been present in the Two Peoples Bay Nature Reserve for at least 30 years but there is no evidence from inspection of large areas that infected vegetation has ever regenerated. The infected areas are uniformly occupied by an impoverished form of the original vegetation.

Susceptible species do still occur in old areas. In Fig. 13 individuals of *Banksia coccinea* which had died recently in old areas were found to be infected. These plants were approximately 0.5 m high and up to 30 m from existing fronts of infection. Since there is no evidence that *B. coccinea* plants can survive infection it is likely that these individuals germinated long after the front passed by and have been killed after growing normally for some years. There are several possible mechanisms for this: long term survival of spores which ultimately infect growing plants, infection by contact with an infected but tolerant host, and infection from a continuous supply of spores from newly-germinated susceptible hosts.

From inspection of large areas it was apparent that while susceptible species can regenerate, very few individuals survive. In the case of the *Banksia* no individuals of *B. attenuata*, *B. ilicifolia* or *B. coccinea* which had reached flowering age were ever observed in old areas of infection.

Recovery of spores from areas behind the infection front (Fig. 12) showed that spores were detectable 4 m behind the front, although there is no indication whether these spores have persisted or been replenished.

These results are most easily interpreted if it is assumed that spores can persist for years but that they are occasionally replenished by germination of susceptible species. Inspection of large areas shows that there are always sufficient spores present to prevent any effective regeneration of the original vegetation, and recently infected areas appear to be identical to areas which have been infected for decades.

It is not clear whether this process will go on indefinitely or if the fungus will ultimately be eliminated by lack of hosts, although the former seems more likely. In either case the affected vegetation type will be lost.

Management of *Phytophthora cinnamomi*

The problem

In Australia *Phytophthora cinnamomi* is best known as a disease of eucalypt forests, and is well known to the public on this basis. Most research on the fungus has been aimed at control in the forest situation, and in Western Australia at control in the northern jarrah forest (Shea, 1979b).

The potential of the disease to damage other vegetation types has been recognised for some time (Newhook and Podger, 1972) but very little work has been done. Weste (1974) has reviewed the situation in Victoria and Malajczuk and Glenn (1981) have discussed the threat to the heathlands in Australia. The primary causes for concern are the extraordinary wide host range of the fungus (at least 404 species from 131 genera and 48 families in Australia were known to Newhook and Podger (op. cit.) including a lycopod, cycads and a podocarp as well as angiosperms); the extreme pathogenicity of the fungus; the importance of some of the susceptible groups in the Australian flora (Proteaceae, Fabaceae, Epacridaceae and Myrtaceae); and the importance of the susceptible species to the fauna. The work of Weste (1974, 1981) in Victoria shows clearly that in southern Victoria *Phytophthora cinnamomi* is a serious pathogen of the native vegetation of swamps, heathland and woodland.

The results of the study reported here are entirely consistent with the status of *Phytophthora cinnamomi* as a serious pathogen capable of virtually destroying at least some vegetation types and the associated fauna. The dominant feature of the problem has been the lack of information. It has only been in the last ten years that there has been general agreement on whether the fungus is native or not, and isolation procedures which are effective, inexpensive and simple have only recently become available. There is little information on the distribution of the fungus in non-forest areas (although see Anon, 1978 for a broad scale map), and there are no facilities available for the routine testing of samples for *Phytophthora cinnamomi* by private or government bodies. Virtually no information is available to land managers on the control of the fungus even if it has been proven to be present.

Possible control measures

The extent of infection at Two Peoples Bay was unexpected in that the reserve (particularly the Mt. Gardner area) has generally been regarded as relatively remote and undisturbed. There are two possible explanations:

- The fungus is much more widespread than generally believed.
- The Two Peoples Bay area has been more visited than generally believed.

Phytophthora cinnamomi is certainly widespread on the south coast. It is definitely proven from National Parks at Torndirrup, Porongurups, Stirling Ranges, William Bay, Fitzgerald River, Leeuwin-Naturaliste and Cape Le Grand (Watson, pers. comm.) and in the Stirling Range National Park it is known from relatively remote areas including hill tops where there has been little or no vehicle activity (Muir, pers. comm.). In most cases infections are associated with known use of machinery.

The wide distribution of *Phytophthora cinnamomi* is not so remarkable if the fungus has been present for many decades and its presence was completely unsuspected. Likely sources of infection are private vehicles, track and road making machinery, pipe and cable laying operations, survey crews, fire-fighting equipment, tractors and timber-cutting. In Victoria Weste and Law (1973) have described how *Phytophthora cinnamomi* was probably introduced to the Wilson's Promontory National Park by tracked vehicles brought in to fight a fire.

It is also likely that the Mt. Gardner area has had more vehicle access than might be expected. The area is a natural feature which would attract visitors in private vehicles. If the initial infection took place some decades ago then subsequent vehicle usage would be sufficient to distribute the fungus widely.

An important consideration is the difficulty of detecting *Phytophthora cinnamomi* or the damage it causes and the complete lack of information until recently. At Two Peoples Bay damage was probably very extensive when the reserve was set up in 1966. The course of events with a moving front also hides the infection. Dead plants are removed by the recurrent fires so that the landscape is unchanged except for the slow movement of the front.

There are two management options for the control of *Phytophthora cinnamomi* in the Two Peoples Bay Nature Reserve:

- quarantine, to reduce the rate of spread, and to prevent new infections;
- chemical control to eradicate the fungus, or to prevent further spread.

Quarantine has been used extensively in the jarrah forest of W.A. on the basis that the primary vector is human activity resulting in the transport of infected soil (Anon, 1979). The quarantine has involved restrictions on entry to very large areas (particularly by vehicles) and the systematic cleaning of vehicles. Although there is little evidence that the quarantine has been successful there is general agreement that it must represent the first defence. While quarantine will not eradicate the fungus it is thought to be capable of reducing the rate of spread of the fungus and of completely protecting uninfected areas. Quarantine also has the advantage that it is relatively fast, simple and inexpensive to introduce.

It has been shown in this study that *Phytophthora cinnamomi* is now generally distributed over the reserve. The *Banksia* heath is the most severely affected and there are no isolated uninfected areas remaining. The Mt. Gardner peninsula was less well surveyed but it does not seem likely that large uninfected sections remain. The only parts of the reserve which appear to be uninfected and which also contain obvious susceptible species are the patches of *Banksia littoralis* in the west of the reserve and around Lake Gardner. *Phytophthora cinnamomi* has not been isolated from *B. littoralis* but it is likely to be highly susceptible.

Quarantine may be useful in slowing down the rate of spread in all affected areas and is worthwhile to reduce pressure on the fauna. There is also the possibility that a practical large-scale control method will become available in the future before all susceptible plant species have been eliminated.

The areas of *Banksia littoralis* can and should be protected by quarantine, along with any other area which can be identified as susceptible but uninfected. An example is the grove of *B. littoralis* at the end of the vehicle track which gives access to the sand dunes south of Moates Lake (marked C on Fig. 7).

The results of this study have shown that all old areas of infection and including any tracks or firebreaks running through them must be regarded as permanently and continuously infected.

The direct control of *Phytophthora cinnamomi* has been considered mainly in eucalypt forests. Possible methods include (Anon, 1978):

1. Treatment of the soil to render it inhospitable to the fungus by using lime to generate high calcium levels.

2. Use of antagonistic micro-organisms or attenuated strains of *Phytophthora cinnamomi*.

3. Planting *Casuarina* spp. which are antagonistic to the fungus.

4. Encouraging naturally occurring legumes which are antagonistic to the fungus, and discouraging highly susceptible species by the manipulation of fire.

5. Use of fungicides.

Only the last of these methods is applicable at Two Peoples Bay. The first three are unproven and the fourth could not be used at Two Peoples Bay because there are no suitable species present (see Table 2).

Although fungicides have been used successfully in orchard and nursery situations, their use in natural bushland is unproven. The most suitable fungicide is metalaxyl (Urech, Schwinn and Staub, 1977) which is claimed to be somewhat specific for *Phytophthora cinnamomi* and related fungi. Metalaxyl is sold as 'Ridomil' by Ciba-Geigy.

There are several problems with this fungicide: the dose and means of application in bushland have not been studied properly, it is phytotoxic (Nesbitt, Gardner and Malajczuk (1980) found it mildly phytotoxic to *Banksia grandis* at fairly low doses of 1.25 and 2.5 g/m^2), side-effects of its use are unknown in relation to water pollution and other problems, and it would be expensive for large-scale use.

Aside from these problems, the fungus is now generally distributed over the reserve and the resources necessary to control it are not likely to be available in the foreseeable future. However the fungicide might be useful if small patches of infection were found on other reserves and the threat to larger areas could be eliminated by prompt treatment. Small scale trials to prove that Ridomil can eliminate *Phytophthora cinnamomi* from bushland with high doses would be necessary for this purpose.

Weste, Cook and Taylor (1978) and Weste and Law (1973) have described field trials with fungicides in Victoria. They emphasised the difficulty of eradicating the fungus without killing all plants on the site and recommended removal of all vegetation, fumigation and sowing with non-susceptible species for three years to achieve eradication of the fungus. Ridomil may be more selective than fumigation with more toxic compounds, but again the method is not appropriate for large scale use.

Phytophthora cinnamomi as a threat to other reserves

The extent of infection by *Phytophthora cinnamomi* in the Two Peoples Bay Nature Reserve suggests that many other reserves are already infected or are likely to become infected and suffer similar damage. There is little doubt that *Phytophthora cinnamomi* is a serious threat to the conservation value of many reserves.

Newhook and Podger (1972) in a comprehensive review of *Phytophthora cinnamomi* in Australia and New Zealand stated, "The epidemic (of *Phytophthora cinnamomi*) poses a serious problem for conservation in dry sclerophyll heath, woodland, and forest communities, not only for the flora including the wild-flowers for which these communities are famous, but also for the many dependent species in the fauna. Many of Australia's national parks and reserves are in jeopardy; it is a matter of the utmost urgency that they be protected from *P. cinnamomi* infestation for as long as possible. Without protection all of the highly susceptible elements of vulnerable communities will be eliminated."

It would appear that this elimination is now well advanced, and may well have been severe at Two Peoples Bay long before 1972.

The only practical protection which can be given to reserves is to prevent introduction of the fungus. This requires firstly a survey of existing infections, secondly a survey of likely threats to and the vulnerability of each reserve, and thirdly adoption and maintenance of effective quarantine measures.

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