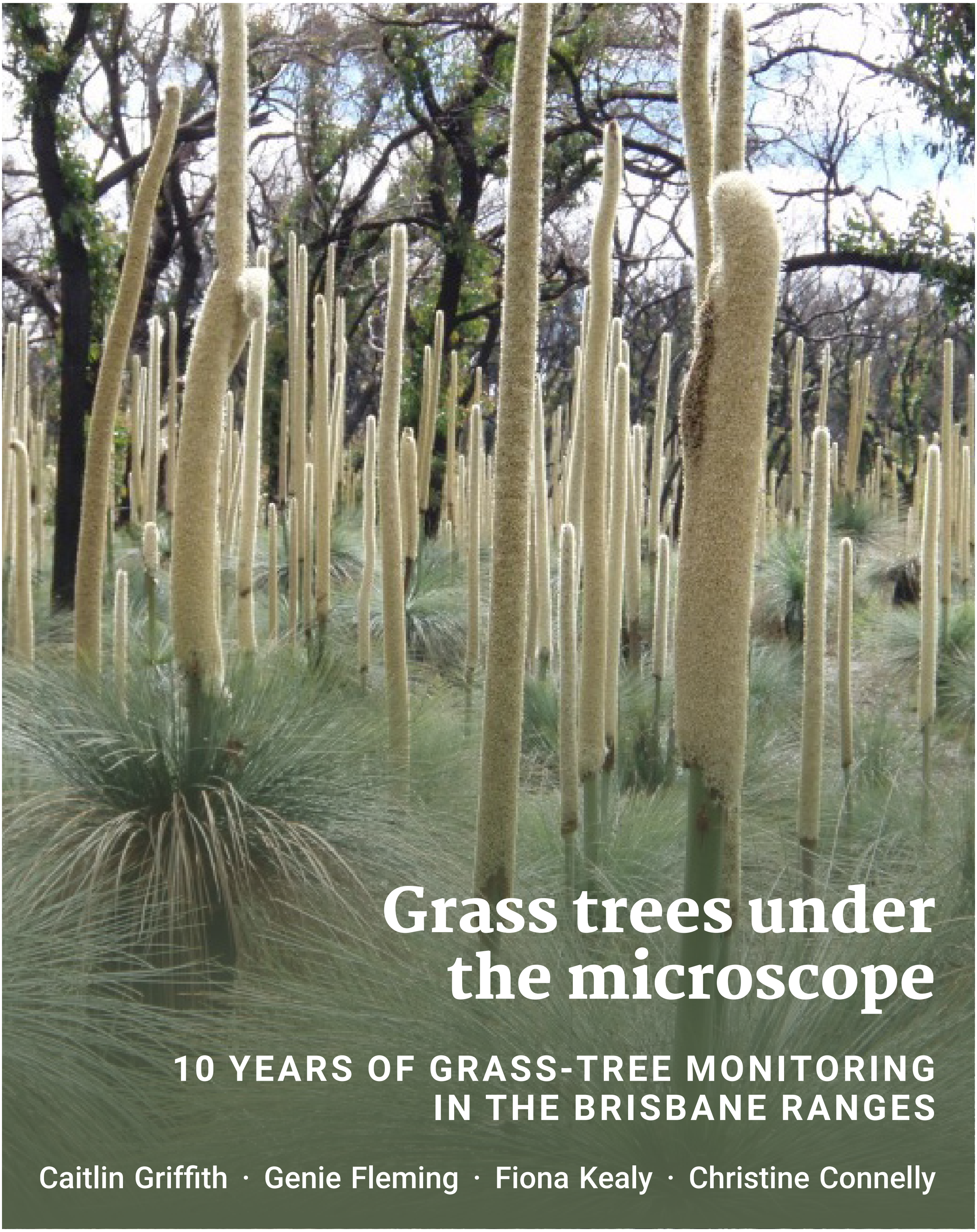

Grass trees under the microscope

10 YEARS OF GRASS-TREE MONITORING IN THE BRISBANE RANGES

Caitlin Griffith · Genie Fleming · Fiona Kealy · Christine Connelly

Victorian National Parks Association

The Victorian National Parks Association (VNPA) helps to shape the agenda for creating and managing national parks, conservation reserves and other important natural areas across land and sea. The VNPA works with all levels of government and the community to achieve long term, best practice environmental outcomes. The VNPA is also Victoria's largest bush walking club and provides a range of information, education and activity programs to encourage Victorians to get active for nature.

NatureWatch

The Victorian National Parks Association's NatureWatch program is a citizen science program which gets community involved in collecting scientific data on Victorian native plants and animals. The program builds links between community members, scientists and land managers and develops scientific, practical projects which contribute to a better understanding of species and ecosystems, and the management of natural areas.

Project partners

Friends of Brisbane Ranges National Park
The Friends of Brisbane Ranges is an active group which began in 1982. They provide opportunities for people to meet socially and learn about the environment, ecology, flora, fauna, and history of the Brisbane Ranges National Park and Steiglitz Historic Park in Victoria. They work on numerous projects within the park and are part of the statewide network of Friends Groups, initiated and organised by the Victorian National Parks Association.

Deakin University Cahill Research Group, School of Life & Environmental Sciences, Waurn Ponds Campus

Parks Victoria

Acknowledgements

VNPA: Carolyn Edwards, Sera Blair, Ada Nano, Bernie Fox, Anne Miehs, Ann Stokie, Peter Stokie and the numerous VNPA volunteers who turned up over the years to measure and record

FoBR: Colin and Wendy Cook, and the many FoBR members who turned out over the years to measure and record.

Parks Victoria: Des Peters, Alexandra Shellard, Peter Box, Judy Locke, Stuart Lardner

Since 2007, the project has been supported by:
Parks Victoria and Corangamite Catchment Management Authority.

Deakin University School of Life and Environmental Science: Professor David Cahill, Dr. Jim Rookes, Dr. Jane Allardyce, Campbell Learmonth

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Summary

In 2007, the Victorian National Parks Association joined with the Friends of Brisbane Ranges, Parks Victoria and Deakin University to design a monitoring project that investigated the long-term effects of *Phytophthora cinnamomi* on the iconic Austral Grass-trees of the Brisbane Ranges National Park.

The project has seen 240 volunteers monitor grass-trees on 252 quadrat assessments over a 10-year period. This volunteer effort has contributed to building our knowledge of the impact of *Phythopthora cinnamomi*. Volunteers continued the important work carried out by Dr Gretna Weste, who pioneered the study of the disease in Victoria and spent close to 40 years conducting highly valuable research and used the same methods originally established by Dr. Weste in 1968.

Phytophthora cinnamomi is a soil-borne pathogen that infects many plant species. In susceptible hosts (such as grass-trees), the pathogen causes dieback and eventual death by inhibiting water and nutrient uptake. It is a serious problem in the Brisbane Ranges National Park requiring management.

The Brisbane Ranges National Park is around 80kms west of Melbourne. Seven locations across the park were monitored regularly over the ten years. These locations are a mix of sites that were monitored previously by Dr. Gretna Weste, and new sites in both *Phytophthora cinnamomi* infected and uninfected areas, and which had varied fire histories. These include four sites that were burnt in the 2006 wildfire. Most of the sites include eight quadrats (8m x 8m monitoring plots), comprising four quadrats that displayed obvious signs of infection and four without signs of infection (i.e. that appear 'healthy'), for comparison.

That the project has continued for ten years is a tremendous collective achievement.

Key findings:

1. *Phytophthora cinnamomi* has not spread rapidly to unaffected sites where we carried out monitoring.*
2. Grass-tree density was higher among healthy versus unhealthy sites.
3. Symptoms of *Phytophthora cinnamomi* infection, such as chlorosis and plant death, appear to combine with other environmental stressors, such as drought and fire.

*Note that this only applies to sites where we carried out monitoring (which were usually discrete and flat locations). This does not apply across the Brisbane Ranges or to the ability of *Phytophthora cinnamomi* to spread more generally.

Introduction

VNPA volunteers and Friends of Brisbane Ranges have been carrying out monitoring of the health and approximate age of grass-trees in the Brisbane Ranges National Park since 2007 using methods originally established by Dr. Weste and used for ~30 years (Weste *et al.* 1999, Weste 2003).

The monitoring consists of observing and recording grass-tree health in relation to a soil-borne plant pathogen *Phytophthora cinnamomi.*

This project was established to run over the long term (i.e. >10 years).

Phytophthora dieback in the Brisbane Ranges

In the Brisbane Ranges National Park, dieback caused by the soil-borne plant pathogen *Phytophthora cinnamomi* is a serious problem, resulting in loss of vegetation and the death of many floral species, including the iconic Austral Grass-trees.

The pathogen is a serious threat not only to flora and fauna, but also to overall ecosystem function. Where *Phytophthora cinnamomi* is present, it can have disastrous effects on the natural environment. The dieback and death of these native plant species drastically alters the structure of ecosystems, including habitat, and subsequently has impacts on fauna such as small mammals.

Phytophthora cinnamomi is listed as a 'Potentially Threatening Process' in Victoria under the Flora and Fauna Guarantee Act (1988). 'Dieback caused by the root-rot fungus *Phytophthora cinnamomi*' is also listed as a key threatening processes under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999[1].

When we refer to "phytophthora" in this report, without specifying the species name, we mean *Phytophthora cinnamomi.*

1 Noting the acknowledgement by the Commonwealth that since its listing further research has determined that *Phytophthora cinnamomi* is a water mould and not a fungus.

Grass-trees

The Austral Grass-tree (*Xanthorrhoea australis*) is a unique plant in Australia and provides important and irreplaceable habitat for small mammals (Laidlaw and Wilson 2006).

Austral Grass-trees live to several hundreds of years old and can survive fire by regenerating foliage and sending up spectacular flowering spikes after fire If Austral Grass-trees do survive to an old age, they can grow a stem reaching up to 3 m high (Conn 1994).

While there are numerous grass-tree species found in Australia (including two species in the Brisbane Ranges), in this project we only monitored Austral Grass-trees.

Monitoring

Volunteers from the Friends of Brisbane Ranges and VNPA have been carrying out monitoring of the health of grass-trees and the ongoing impacts of phytophthora (30+ years after infection was initially reported) for the last ten years.

Monitoring is based on the methods established by the late plant pathologist, Dr. Gretna Weste, who carried out more than 30 years of work on phytophthora in the Brisbane Ranges and other areas.

All data collected by volunteers is available to Parks Victoria, the School of Life and Environmental Sciences at Deakin University and other interested community groups, land managers and scientists. This information has the potential to aid conservation management decisions.

Project tribute to the late Dr. Gretna Weste

This monitoring project re-established the long-term monitoring previously carried out by the late Dr. Gretna Weste from the University of Melbourne. Dr. Weste established long term monitoring sites in the Brisbane Ranges National Park in 1968. VNPA re-established her plots and used the same techniques, meaning that we have extended an existing long-term monitoring project.

Project objectives

The original science and conservation aims of the project were:

- To monitor over the long term (>10 years), the impact of phytophthora on grass-trees in relation to fire and management practices.
- To provide high quality data and published studies to Parks Victoria and the broader scientific community on the long-term impacts of phytophthora .

Over the years, the focus of the project shifted to better suit the community group's capacity to undertake the monitoring and management resourcing and requirements available to support the project. Ultimately, the aims of the project were;

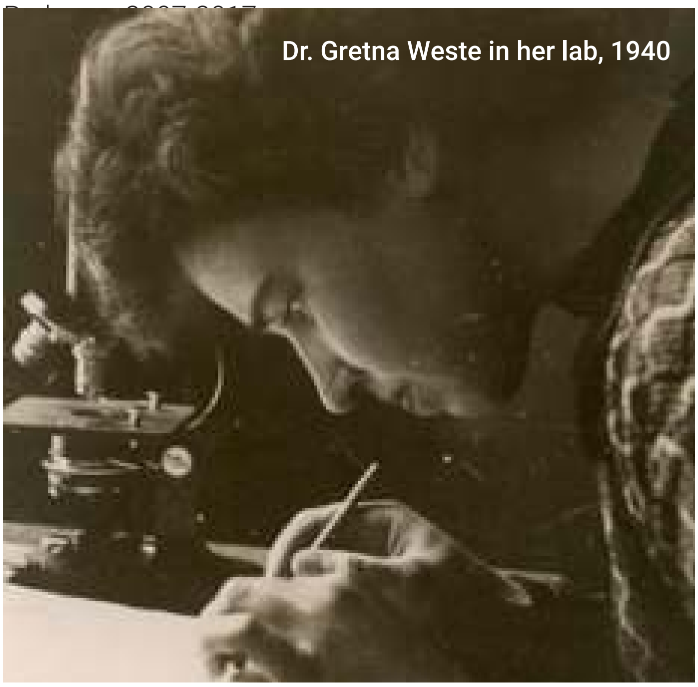
- Monitoring the impact of phytophthora on grass-trees over a 10-year period, as well as examining interactions with fire where possible.
- Providing information to park managers to help them develop strategies to mitigate the threat of phytophthora over the long term.

The project was also established with several community engagement objectives:

- To connect the local community, university students and VNPA volunteers through biodiversity monitoring.
- To collaborate with local groups and create links between community and park management.
- To empower community members through training in monitoring and leadership to have ownership over the project.

This report

This report presents the results of the Grass-tree Monitoring Project in the Brisbane Ranges National



Dr. Gretna Weste in her lab, 1940

Background

Phytophthora history and biology

Phytophthora is a soil-borne pathogen of environmental and economic significance worldwide. Although phytophthora was previously known as cinnamon fungus, it is in fact a soil-borne oomycete or 'water mould', not a fungus.

It was first discovered in 1922 in Sumatra, it is now one of the most widely distributed of all phytophthora species. Phytophthora has been recorded in all states of Australia and is most active in warm and wet conditions, however, it can remain dormant until conditions become favourable again.

The pathogen invades susceptible plant root systems and, in some species, prevents them from taking up water and nutrients, resulting in root rot. Symptoms include extensive chlorosis (yellowing caused by loss of green chlorophyll) of the leaves followed by dieback and death of the plant (Wilson *et al.* 2000; Laidlaw and Wilson 2003).

The time from infection to plant death often takes less than a year for understorey plants, and is sudden and rapid for some species such as the grass-tree and horny cone-bush (*Isopogon ceratophyllus*) (Weste 2003).

Phytophthora has resulted in major floristic and structural vegetation changes, killing many plant species and altering whole ecosystems. Studies in Victoria show that key understory species such as the grass-tree, horny cone-bush and silver banksia *(Banksia marginata)* are replaced by less susceptible plants such as the thatch saw-sedge *(Gahnia radula)* and wattle mat-rush *(Lomandra filiformis)* within 1-3 years after infection (Aberton *et al.* 2001; Laidlaw and Wilson 2003, Weste 2003).

Management of Phytophthora Dieback

Human activity is the cause of most significant rapid and large scale spread of phytophthora – for example through the movement of soil during construction or maintenance of firebreaks and roads, movement of vehicles through infected areas to other areas and timber harvesting. Recreational activities such as bushwalking and off road vehicle use also contribute to the spread (Cahill *et al.* 2008).

Current management practises rely on hygiene (keeping uninfected areas free of the pathogen by decontamination of vehicles, machinery, equipment and footwear before entering uninfected areas and after leaving infected areas), the use of chemical sprays (e.g., phosphite) to boost plant immunity to infection and quarantine (restricting access to certain areas).

However, these measures do not provide complete control over the spread of phytophthora (Cahill *et al.* 2008). Unfortunately, in Victoria, eradication of the pathogen is not considered practical in the foreseeable future due to how widespread phytophthora has become (DSE 2008).

Grass-trees

Grass-trees are unique plants in Australia. They are a group of species that are in fact not a grass, nor a tree. Grass-trees are monocots (a group that includes grasses, orchids and bamboo) and are more closely related to mat-rushes *Lomandra* spp. than any tree species. Grass-trees are slow growing, developing at a rate of approximately 1-2.5 cm per year, and some species may live for over six hundred years (Borsboom 2005).

Grass-trees are dominant understory plants that provide irreplaceable habitat for several species of small mammals, such as the marsupial brown antechinus (*Antechinus stuartii*). They also provide important nesting sites for some small mammals including agile antechinus (*Antechinus agilis*), eastern pygmy possum (*Cercartetus nanus*) and white-footed dunnart (*Sminthopsis leucopus*) (Laidlaw and Wilson 2006). Many species rely on the 'skirt' of grass-trees for shelter from predators and a decline in grass-trees has been found to affect the fossicking behaviour of the agile antechinus (Laidlaw and Wilson 2006).

The species is highly susceptible to the phytophthora pathogen. Infected individuals produce easily observable disease symptoms including extensive leaf chlorosis (yellowing), followed by leaf browning and necrosis (tissue death), which results in the eventual collapse of the entire crown of the plant (Duncan and Keane 1996; Aberton *et al.* 2001). This is shown in Figure 1.

Some regeneration of grass-trees in previously infected areas have been observed in a few Victorian sites (Laidlaw and Wilson 2003) but this may take 20-25 years from initial invasion because regeneration from seed is usually required, or very rarely from shoots on old, diseased individuals (Weste *et al.* 1999). It has, however, been observed that grass-trees regenerated from seed in a previously diseased site often become infected due to a reoccurrence of disease (J Rookes, pers. comm. 2019). Seed production in grass-trees is rare, but may be stimulated once regeneration is established in an area through summer fire (Weste *et al.* 1999).

Once healthy plants are infected...

...the plant shows signs of stress

...before dying completely.

Figure 1. Effects of phytophthora infection on grass-trees.

Methods

Monitoring sites

Seven permanent monitoring sites were established in the Brisbane Ranges National Park (Table 1). These sites have varied fire history and include four sites that were burnt in the 2006 wildfire and three that were not (mostly at the northern end of the park).

We also considered the history of other fires. The number of years since the last fire also varied among sites, when the project was established in 2007. Time since fire ranged from 2-14 years among the sites not burned in 2006. In 2009, two sites (LOH & LOU) were affected by a planned burn, while in 2012 two quadrats within site GEU were burned.

Most of the sites include eight quadrats: four which were determined as having pre-existing phytophthora infection ('unhealthy'), and four that were not known to be affected prior to 2007 ('healthy'). The healthy quadrats were treated as a 'control' for the unhealthy ones. Some sites had only 'healthy' quadrats, with no 'unhealthy' quadrats. This was because these sites did not have areas that were 'unhealthy', but were worthwhile including because of historic value (monitored by Dr. Weste) or a good example of a 'healthy' area.

Each quadrat is an 8m x 8m square with a steel star picket that permanently marks each corner.

Table 1. Monitoring sites established in 2007.

Site name	Fire history since 2006	Monitored by Dr. Gretna Weste?	Number of 'Healthy' (H) and 'Unhealthy' quadrats (U) 2008
Lease Road and Durdiwarrah Road (LE)	2006	Yes	H-4 U-4
Geelong Ballan Road and Furze Track (GE)	2006, 2 quadrats burned in 2012 planned burn	Yes	H-4 U-4
Marshall Road (MA)	2006	Yes	H-4 U-4
Switch Road (SW)	2006	Yes - Dr Weste's control site	H-4 U-0
Kangaroo Track (KA)	No	No	H-4 U-4
Old Thompsons Track (OL)	No	No	H-4 U-0
Loggers Track and Lease Road (LO)	2009 planned burn	No	H-4 U-4

Monitoring schedule

Monitoring of grass tress was carried out by volunteers over a 10-year period from 2007 to 2017. The monitoring program included repeated surveys of these 48 quadrats.

Surveys were conducted in all but two years of the 10-year study period and were typically conducted both in Autumn and Spring. However, only a subset of quadrats was sampled in any given year and season. Table 2 (page 8) shows the schedule of surveys through time and the data included in the analyses that follow.

Field assessments

Volunteers carried out monitoring in quadrats at each of the sites listed in Table 1. At the start of each monitoring day, volunteers took part in a training session and learned how to assess each quadrat. Monitoring was then carried out over the rest of the day.

Volunteers followed the instruction booklet and filled out the data sheets shown in Appendix 1. During each survey of a quadrat, volunteers recorded the following information for all live and dead grass-trees determined to be within the boundaries of the 8 m by 8 m quadrat:

- Location of each grass-tree in the quadrat as defined by its distance along the x- and y-boundaries of the quadrat. These spatial coordinates were used to track individual grass-trees through time, by matching the locations of trees across all surveys of the quadrat.
- Health of each grass-tree (dead, alive with symptoms, or alive without symptoms).
- Crown radius of each grass-tree.
- Height of each grass-tree.
- Presence of flowering stems and evidence of flowering and seeding.

Table 2. Survey schedule of quadrats included in the current analyses. Site names ending in H were selected as “healthy” sites, while site names ending in U were infected with phytophthora. Each site contained 4 quadrats, which were usually all surveyed within the same survey period. Surveys were typically conducted in both Spring (Sp) and Autumn (Au) of a given year, only occasionally in the same sites.

	Number of quadrats																			
Site	Sp 2007	Au 2008	Sp 2008	Au 2009	Sp 2009	Au 2010	Sp 2010	Au 2011	Sp 2011	Au 2012	Sp 2012	Au 2013	Sp 2013	Au 2014	Sp 2014	Au 2015	Sp 2015	Au 2016	Sp 2016	Au 2017
GEH	3	-	4	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	4
GEU	4	-	4	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	4
KAH	-	4	4	-	-	4	4	-	-	-	-	-	-	-	-	-	-	4	-	4
KAU	-	3	4	-	-	4	4	-	-	-	-	-	-	-	-	-	-	4	-	4
LEH	-	-	4	-	-	-	4	-	-	3	-	-	-	-	-	-	-	-	4	4
LEU	4	-	4	-	-	-	4	-	-	3	-	-	-	-	-	-	-	-	4	4
LOH	4	-	4	-	-	-	4	-	-	-	-	-	-	-	4	-	-	-	4	4
LOU	4	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	4	4
MAH	-	4	4	-	-	4	-	4	-	-	-	-	-	4	-	-	-	-	-	4
MAU	-	-	4	-	-	4	-	4	-	-	-	-	-	4	-	-	-	-	-	4
OLH	-	4	4	-	-	-	4	-	-	-	-	-	-	-	4	-	-	-	-	4
SWH	-	4	4	-	-	4	-	-	-	-	4	-	-	4	-	4	-	-	-	4

Monitoring sites at LEU in 2007 and 2010

Assessing grass-tree health

When categorizing the health of each grass tree, volunteers were asked to assess if they were 'dead', 'alive with symptoms' or 'alive without symptoms'. This was not considered a confirmation of whether the individual grass-tree was infected with phytophthora.

The symptoms caused by phytophthora infection are the same as those caused by drought and other stressors and the cause can be difficult to distinguish. As such, volunteers simply assessed the health of the grass-tree, with the exact cause being unknown.

Soil tests

Deakin University carried out soil tests to confirm the presence of phytophthora in 2007, 2008 and again at all sites in 2017. Testing involved baiting soil samples with Lupin, a susceptible legume crop species. Three trowel-sized soil samples were taken around the base of the most obviously infected living grass-tree in each quadrat and each soil sample was tested in triplicate.

Analysis

One of the challenges in the analysis of these data arose from the complex nature of the data structure: monitoring through time was irregular for all sites resulting in uneven gaps in the data plus potentially strong effects of survey season since surveys were conducted in both Autumn and Spring. Our analyses included both qualitative investigation of trends in the data as well as the use of standard and advanced statistical techniques to determine whether these trends might be explained by phytophthora infection after accounting for other potentially influential factors (e.g. season or time since fire).

For our statistical analyses we used both standard univariate techniques, which are identified in the description of results below, as well as a more advanced technique - hierarchical cross-classified models (HCM; Raudenbush & Bryk 2002). This advanced technique is appropriate for the complex structure of these data, though it is best suited to data sets larger than used here. Thus, results from these analyses should be considered exploratory in nature.

We specifically used HCM to investigate trends through time in the percentage of live trees assessed as showing signs of infection. This type of model accounts for the irregular surveying of individual quadrats through time by cross-classifying individual surveys according to both the quadrat identity (e.g. GEH1) and the survey timing (e.g. Autumn 2008). HCM models were built up progressively according to three "levels": (1) individual surveys nested with (2) specific quadrats and (3) survey periods (e.g. Spring 2007).

At the survey level, we examined whether the proportion of live trees showing signs of infection varied across surveys as a function of time since the start of the study or, separately, as the number of years since the quadrat had burned. At the quadrat level, we examined whether average number of symptomatic trees or the trend through study time or time since fire varied among quadrats as a function quadrat health status (healthy, unhealthy). Finally, at the level of survey period we examined the influence of season (Autumn or Spring) on trends in observed signs infection.

Analysis considerations

We observed high variability in the number and size of grass-trees measured across surveys on individual quadrats. This was not unexpected since surveying was carried out over the years by several different volunteers with variable levels of experience. Measurement error of this sort can have substantial impact on the reliability of trends detected in the data. Consequently, our statistical analyses mostly focused on variables expected to be less sensitive to these kinds of measurement errors.

For example, we focused on the fate of individual grass trees within a quadrat across all surveys as identified by their roughly constant location across repeated surveys. For example, when examining mortality of grass-trees we focused on dead trees that could be matched spatially to formerly live individuals rather than using raw count of dead individuals within a quadrat.

Results

Patterns in grass-tree density and possible recruitment

In general, overall grass-tree density was higher among healthy versus unhealthy quadrats[2]. Across all 28 healthy quadrats, a median of 29 live grass-trees per quadrat were measured (i.e. number of individuals identified across all surveys of a quadrat that were alive when first measured; Figure 2 A).

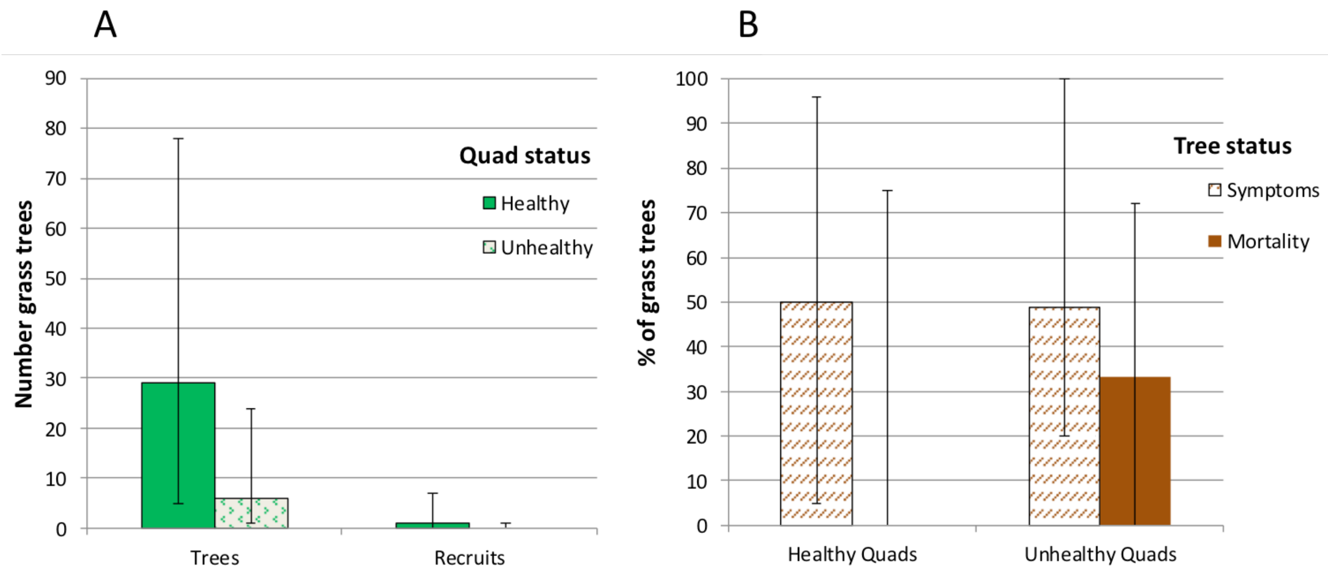
Live trees were never measured on 11 of the 20 unhealthy quadrats, but among those that did have live trees (9 quadrats) a median of 6 trees were measured per quadrat (Figure 2 A).

There also appeared to be slightly greater recruitment of new grass-trees, 'recruits', within healthy quadrats over the 10-year study period[3]. However, our attempt to separate recruits from those that might have been missed during the initial survey could be prone to error.

We classified as recruits those grass-trees with a stem height <0.5cm and a crown radius <20 cm that were first recorded in a survey **after** the first quadrat survey. A median of one recruit[4] per quadrat (range = 0-7 recruits) was seen among healthy sites compared to a median of 0 (range = 0-1 recruits) among unhealthy sites (Figure 2 A).

Figure 2.
(A) Differences in the average total number of grass-trees ("Trees") and the number of those potentially recruited since 2007 ("Recruits") within healthy versus unhealthy quadrats. (B) Average percentages of trees within a quadrat judged to be showing symptoms of Phytophthora infection during at least one survey ("Symptoms") or experiencing verified mortality ("Mortality") on healthy versus unhealthy quadrats. In both graphs, coloured bars represent group medians and vertical lines show observed minimum and maximum values within the group.

Figure 2



2 MannWhitney U test, P< 0.001
3 MannWhitney U test, P< 0.001
4 a 'recruit' is a juvenile plant that is likely to survive to adulthood

Trends in the appearance of phytophthora symptoms

Among both healthy and unhealthy quadrats, similar proportions of grass-trees (48-50% on average) were assessed as having symptoms of phytophthora infection during at least one survey (Figure 2 B). However, among healthy quadrats most of these “symptomatic” trees were assessed to be healthy during subsequent surveys, with very few (~10% on average) ever found dead. This suggests most symptoms that were recorded in earlier years could likely have been due to factors other than phytophthora infection.

Our HCM analysis showed that, on average, a greater proportion of grass-trees within a quadrat were assessed as showing signs of infection during Autumn surveys compared to Spring surveys regardless of the health status of the quadrat (Figure 3 A[5];).

Among unhealthy quadrats, however, the proportion of trees classified as symptomatic declined with time since fire[6], while remaining nearly constant among healthy quadrats (Figure 3 B; the slightly positive slope for healthy quadrats is not statistically significant).

The higher proportion of trees classified as symptomatic during Autumn or soon after fire suggests that other stressors to grass-trees (i.e. drought and recent fire) may have been the cause of symptoms, particularly given the low rates of mortality among “symptomatic” trees described above. (Note that it is not possible to distinguish between symptoms that are caused by phytophthora infection, drought or other stressors).

Over the entire course of the study there did appear to be a near-steady increase in the proportion of symptomatic trees noted during Spring surveys (Figure 3 A[7];) when seasonal drought stress should be less obvious. This could be an indication of continued disease progression on some sites, but may also be indicative of cumulative effects of other environmental stressors.

5 Fixed effect of season in HCM; $P = 0.017$, based on univariate *t*-test. Only effects associated with a significant reduction model deviance (likelihood ratio test, $P < 0.05$) were retained in the final model, regardless of univariate results.
6 Interactive effects of time since fire and quadrat health status in HCM; $P = 0.025$.
7 Interactive effects of study time since and quadrat health status in HCM; $P = 0.024$.

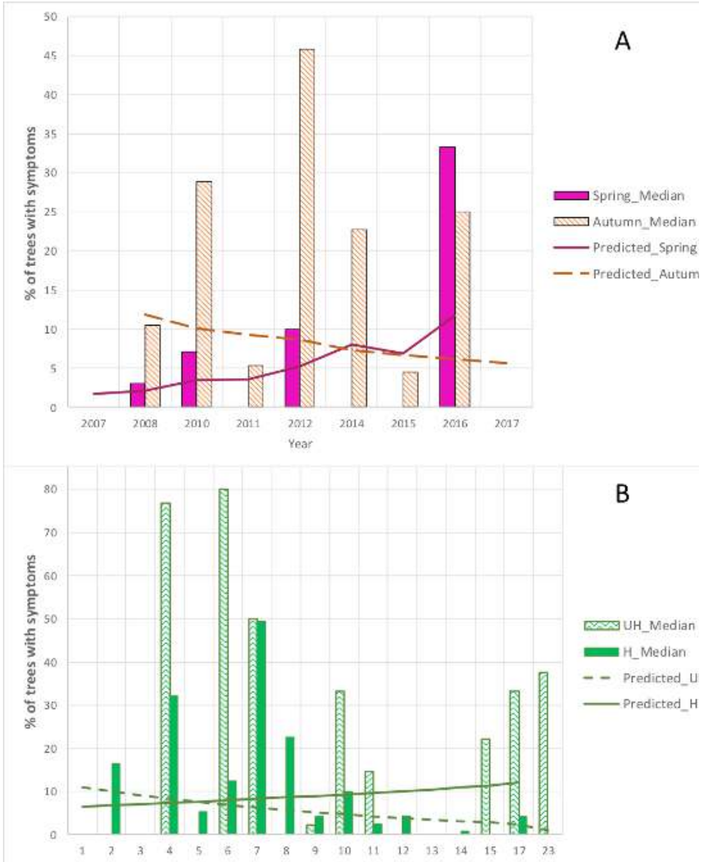


Figure 3. Differences in trends through time in the percentage of live grass-trees showing signs of phytophthora infection for (A) Spring versus Autumn surveys, or (B) healthy (“H”) versus unhealthy (“UH”) quadrats. In both graphs, coloured bars represent observed group medians and lines show predicted values for an “average” plot based on a statistical model (i.e., all other variables in the model are held constant at their means).

Trends in mortality

We distinguished between grass-trees: (*i*) that “disappeared” before, or by, the last survey of a quadrat and for which the ultimate fate was unknown (i.e. an individual measured at one survey but not matched to any live or dead individuals measured at subsequent surveys) versus (*ii*) those for which mortality was verified by the measurement of a dead individual at the same location where a live individual had previously been measured.

While disappearances might represent mortality of the individual, they might also result from unknown sources of measurement error and so provide less useful information. In fact, disappearances were roughly similar between healthy and unhealthy quadrats, which showed median disappearance rates of 15% (range = 0-33%) and 11% (range = 0-46%) respectively.

On average, the proportion of individual grass-trees within a quadrat suffering verified mortality was much higher among unhealthy quadrats (median = 33%) compared to healthy quadrats[8] (median = 0%; Figure 2 B).

Although average mortality was higher among unhealthy quadrats, as we expected, the range of mortality observed among unhealthy and healthy quadrats was surprisingly similar (0-72% and 0-75%, respectively). This was primarily due to unusually high mortality of grass-trees on healthy quadrat LOH2 (75%) between the 2010 and 2014 surveys.

In fact, the highest mortality across the entire study was concentrated in quadrats primarily located near the south-western boundary of our study area in the park within sites LE and LO (Figure 4).

8 MannWhitney U test, P< 0.048

Soil tests

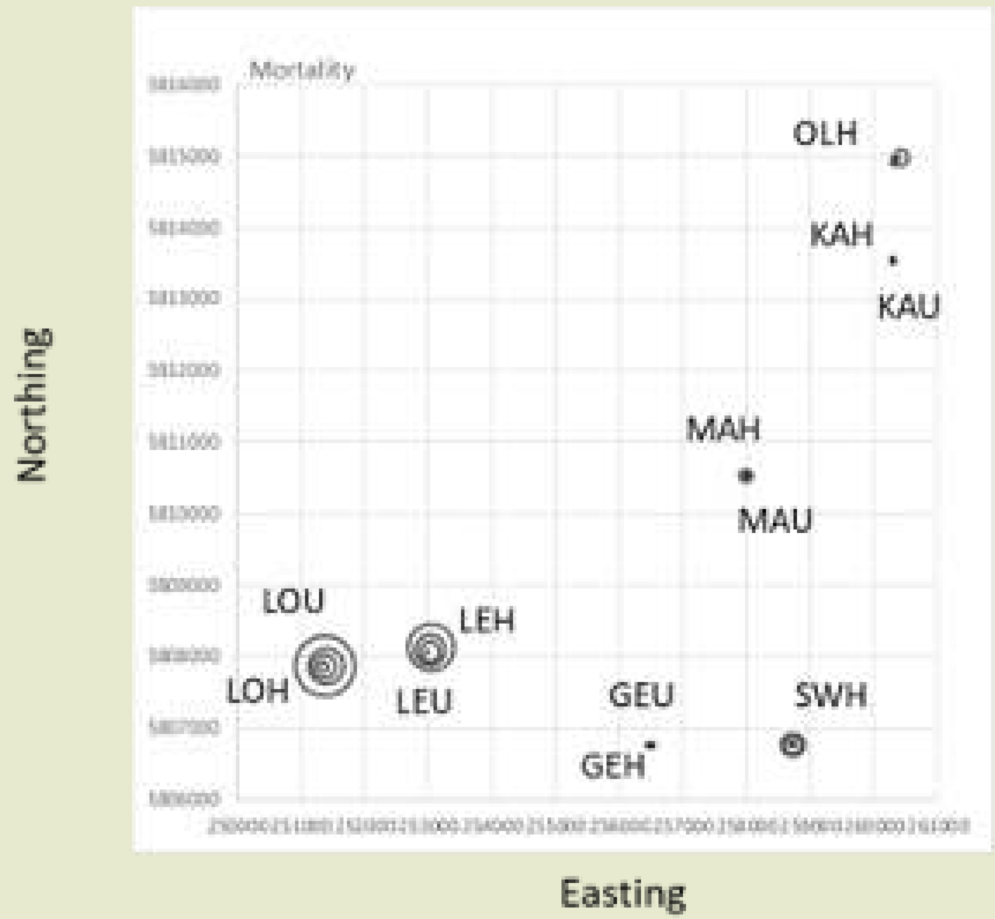
Soil testing at all sites was carried out in 2007 and 2008 and again in 2017. There was sporadic soil testing in the years in-between.

In 2007 and 2008 a small handful of soil samples tested positive for presence of phytophthora and none of the soil tests were positive in 2017. Table 3 lists the three sites where positive detections were indicated. Deakin University did not detect phytophthora in most of the samples we provided, and in 2017, phytophthora was not detected in any samples.

Table 3. Sites where at least one test indicated a positive detection of *Phytophthora*.

Quadrat with a positive detection of *Phytophthora*.	Date of positive test
GEU	December 2007
LOU	December 2007
LOH	December 2007

Figure 4



Discussion

Explaining the soil tests

We did not detect phytophthora at most of the sites, even though our study design included several sites known to be infected.

When considering this result, it is important to note that the soil baiting is not always an accurate reflection of infection. Positive detections are challenging, because the disease must be active at the time of sampling and detection is rare when only dead plants or no symptoms are present. Furthermore, this also relies heavily on the right soil conditions and temperature (it should be moist and warm, but not too hot), although phytophthora can stay dormant for a very long time during unsatisfactory conditions.

Even in the best conditions, positive identification of phytophthora in the soil can be challenging. Thus, the lack of positive soil tests could have also been due to seasonality of sampling and the general challenging nature of testing soil for this pathogen. Regular, repeated sampling during conducive weather conditions would be required to obtain a comprehensive analysis of presence of the pathogen at each of the sites. This was not possible within the constraints of this program (e.g. financial, need for structured scheduling of monitoring and availability of suitably trained people).

What can we say about grass tree health in the Brisbane Ranges over the long-term?

Phytophthora spread was slow

On the positive side, despite the categorization of some trees on healthy quadrats as showing signs of infection during surveys, the generally low rate of verified grass-tree mortality among most healthy quadrats suggests the pathogen is not spreading rapidly to unaffected areas. This is also supported by the fact that the highest rates of mortality over the 10-year period were concentrated in the southwest section of our study area in the park (Figure 4).

Recovery is also slow

The lower average density of grass-trees among unhealthy compared to healthy quadrats combined with a lack of any obvious signs of new tree recruitment on unhealthy quadrats indicates recovery of grass-trees on sites of known infection may only be occurring slowly, if at all.

It is, however, unclear what caused the lack of new recruitment. Naturally low rate of seedling growth in *Xanthorrhoea* species and a high likelihood that grass-tree recruitment is linked to episodic events (e.g. fire) in general (DoE 2019), could be a contributing factor to the low rate of new grass-tree recruitment among our healthy quadrats.

Young grass-trees may not have been recorded because they had not reached a detectable size during the study period. Conversely, new recruits may not have been recorded because they were lost to phytophthora before growing large enough to be seen during monitoring. We cannot be sure of the cause of low recruitment.

Given the relatively high rate of mortality observed on unhealthy quadrats, it seems the pre-existing disease cycle is still showing impacts more than 10 years after known infection.

Future studies

To improve our capacity to track grass tree health, permanent individual grass trees could be selected for monitoring. This would make the process of carrying out data analysis much more efficient and more accurate estimation of mortality, recruitment and even potential recovery of individuals.

Further work is also required to investigate the possible synergistic relationship between phytophthora infection and other environmental stressors such as drought and fire. Managers will find it useful to know whether efforts to reduce the impact of environmental stressors (e.g. through watering, fire risk management) may help improve individuals' post-infection outlook. It may also be useful to investigate the effects of trial application of Potassium phosphonate, which can improve grass-trees' natural defence against phytophthora (Daniel *et al.* 2005), in this study area.

A Community Achievement

Community volunteers from VNPA and Friends of Brisbane Ranges have completed a significant investigation into the impacts of phytophthora in grass-trees in the Brisbane Ranges National Park.

Through this project, the community has captured important empirical data about the current state of the Phytophthora Dieback infection in the Brisbane Ranges over a 10 year period.

Their work provides a valuable account of the health of grass trees across the Brisbane Ranges. The enthusiasm of the community to understand what is happening to grass-trees in their local area is inspiring.

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Appendix 1

NatureWatch

Grass Tree Community Monitoring Project
Field Data Collection Sheet

Please fill in **all** sections on this form. All details are important.

Site, time and personnel details:

Date:…………………………… Time started:…………Time finished……………

Team Leader:…………………………………...

Names of all volunteers:……………………………………………………………

………………………………………………………………………………………..

Site Name:…………………………………Quadrat Number:…………………………

Hygiene practices check:

Tick box when Phytophthora hygiene carried out prior to visiting this quadrat: ☐
Tick box when Phytophthora hygiene carried out after to visiting this quadrat: ☐

Photo points:

Camera number:

On ground point number (on stake)	Photo number (on camera, eg. 101-4253)

Grass Tree records:

In the table on the following pages, please record the details of **all** Grass Trees in the quadrat, with x and y coordinates.

In the Health column please record the health of each Grass Tree using the following parameters:

D - Dead no signs of green on foliage
WS - Alive with symptoms foliage has some browning/yellowing
A - Alive all foliage is entirely green

Project supported by Deakin University School of Life and Environmental Sciences, Geelong Campus, Parks Victoria, Friends of the Prom and The Friends of Brisbane Ranges Inc.

Table 1: Grass Tree Height and Health Details

Site Name:.................... Quadrat name.................. Date.................

X coord.	Y coord.	Above ground stem present/ absent/ hollow (P/A/H)	Multi-stemmed (Y/N)	Stem no. (if applicable)	Height (cm) (n/a if no above ground stem)	Crown radius (cm)	Health (D/SS/MS/A)	Flower stem present (Y/N)	Flowering (Y/N)	Seeded (Y/N)

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