IGNITIBILITY OF LEAVES OF AUSTRALIAN PLANTS

A CONTRACT REPORT TO THE AUSTRALIAN FLORA FOUNDATION

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GPO Box 1600, Canberra, ACT 2601.

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Cover Plate: A leaf of *Eucalyptus grossa* soon after ignition in the muffle furnace. The arms of the spark gum protrude into the furnace. The wire crib on which the specimen lies is clearly visible in the light of the flames.

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1. EXECUTIVE SUMMARY

1. Flammability is a property of plants readily appreciated in a general sense but difficult to define scientifically. In this report 'flammability' is considered to consist of three components, *viz*. 'ignitibility' or 'ignition delay time', 'sustainability' and 'combustability' (Anderson 1970). 'Ignitibility' is the focus of the research reported here on the grounds that if plants fail to ignite or ignite poorly then they pose less of a threat to assets they surround (e.g. houses) in a fire-prone environment.

2. Ignitibility - ignition delay time - is the time to first flaming from the time of first exposure to an ignition source . It is a property dependent on the type of ignition source (e.g. flame or radiant heater) and level of exposure. We used the time of exposure in a muffle furnace set at 400ºC as the main measure. Ignition was piloted using a custom-made spark gun.

3. Mature leaves, phyllodes and cladodes were chosen as the specimens of interest because they are often the first organs of a plant to ignite in a fire and their properties are likely to be those of the species rather than the environment. Properties measured as potential explanatory variables of ignitibility were specimen dimensions (including surface area to volume ratio), moisture content and mineral composition. Both fresh and oven-dry specimens were used.

4. There has been little study of the ignitibility of leaves, phyllodes and cladodes ('leaves') of Australian plant species. This study concerned the ignitibilities of mature leaves of 50 species from 19 families. The specimens were collected from plants in the grounds of the Australian National Botanical Gardens, mainly, but also from the grounds of the CSIRO Black Mt campus (5 species) and the Australian National University (1 species).

(5) Ignitibility of the materials tested varied widely. Some leaves ignited quickly and burned fiercely while others were difficult to ignite. The results could be largely explained in a statistically-significant way using only two variables - moisture content and surface area to volume ratio. Any affect of mineral content on ignitibility was masked by correlations with some of the physical dimensions of the specimens.

(6) The method used in this study could be used as a screening technique for determining the ignitibility of the leaves of many species but techniques for the measurement of the ignitibility of shoots with tiny leaves need to be evaluated.

(7) The flammability of plants is a function of their intrinsic properties, the environment and horticultural or other management practices. It is difficult to adequately describe the flammability of a species because of these factors and the effects of life stage (from seedling stage to senility). Even the description of the flammability of a single plant will have major problems for these reasons. Direct measurement is fraught with difficulty. Despite these problems there are attributes of major importance to the determination of flammability (in broad terms) that may be considered in a semi-quantitative way. These have been used in a new key as another step towards the development of a flammability rating of plants (rather than species).

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2. PREAMBLE

General

This Report is the result of a contract let by the Australian Flora Foundation following the economically disastrous fires in the Sydney, New South Wales, region in 1994. These fires destroyed more than 200 houses scattered across a wide geographic area of Sydney but concentrated in the suburbs of Como and Jannali (Ramsay *et al.* 1996, Gill and Moore in press). Such events raise questions as to the flammability of the vegetation around houses -garden, native bush or recreational parks - and whether or not this can be reduced in order to inhibit the passage of fires into suburban areas.

Defining "flammability" is difficult. Indeed there is even a scientific paper headed "Flammability -whatever that is" (Broido 1973). In the next chapter we provide an overview of the subject in order to place the main topic of this report - the ignitibility of fresh and dried leaves - into perspective. Here, we list the objectives and procedures suggested for the study as given in the Proposal to the Sponsor of the research, the Australian Flora Foundation.

Objectives

To measure the ignitibilities of leaves of up to 50 species of Australian plants in relation to their moisture contents and surface-area-to-volume ratios. Fresh leaves would be compared with dried leaves. Specifically, the hypothesis to be tested was that moisture content and surface-area-to-volume ratio control ignition delay time of leaves whether fresh or dry.

To relate mathematically the moisture contents and surface-area-to-volume ratios of leaves to their ignition delay times.

Procedures

- Experiments would consist of exposing selected leaves to high temperatures in a controlled muffle-furnace environment *
- Methods would include: carefully collecting leaves of a number of selected species growing in a known environment; preparing leaves for exposure in the muffle furnace at their usual moisture content; randomizing 10 replicates of each species; measuring leaf properties; exposing single leaves on a cradle in the muffle furnace at 400 OC in a standard fashion with a pilot present to aid ignition; and, recording time to ignition. Leaves would be collected from plants growing in the Australian National Botanical Garden, Canberra, close to the laboratory. Oven dry leaves of the same species would be similarly exposed in the furnace. If necessary - as a result of these experiments - intermediate leaf moisture contents were desirable, these would be attained by partial airdrying and by stabilizing moisture contents in glass containers.

Techniques for measurement of leaves would include leaf planimetry using an electronic leaf-area meter. Thickness would be measured using calipers; moisture content would be measured by oven drying; individual leaves would be measured using an electronic balance; times to ignition would be recorded with a stop watch; ash contents would be obtained by ashing material in the muffle furnace after ovendrying and weighing.

- Data for leaves of each of up to 50 species of vascular plant of known taxonomy would consist of. collective *in* situ leaf moisture contents; individual leaf areas; individual leaf weights; individual standardized thicknesses; and times to ignition of individual leaves. Surface-area-to-volume ratio would be calculated according to individual leaf geometries. One average one ash content per species would be obtained.
- Data would be analysed using standard regression techniques. Interpretation would consider the idea that moisture diffusivity, strongly influenced by surface area-to-volume ratio (and leaf thickness for laminar leaves) and moisture content, is the significant variable in controlling ignitibility. If so, live leaf moisture is an important variable to consider in the selection of species as 'fire retardant' but the litter they produce may have no intrinsic value (from a moisture point of view) in slowing fire spread. The value of ash content would be assessed by regression also.

Modifications

We were able to obtain analyses of the mineral contents of all our materials rather than use the cruder variable "ash content". We did not need to elaborate on the variation in moisture content of specimens using partially-dried materials because the natural variation was sufficient. We measured the ignitibility of 5 species at 500ºC as well as at 400ºC. We have placed our results within the wider context of the determination of the flammability of whole plants, if not species.

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3. FLAMMABILITY OF PLANTS

What is 'flammability"

In a general sense, "flammability" is the ease of burning. In a technical sense, definitions have been elusive (Broido 1973) although Anderson (1970) in his laboratory studies divided "flammability" into three components to assist understanding: "ignitibility" - his focus - was the ignition delay time (the time from the application of an ignition source to an observed ignition); "sustainability" was the measure of "how well a fire will continue to burn" or "how stable the burning rate remains"; and, "combustability" was a "reflection of the rapidity with which a fire burns".

When these terms are examined in the light of a weight-loss curve for fuel during the combustion process some of the complications become apparent (Fig. 1). The ignition delay time in formal terms is given by t_0-t_1 where t_0 is the time at which the fuel is first exposed to the ignition source and t_1 is the time at which ignition (we'll assume flames are the evidence of ignition here) is first observed. During this time there may be substantial weight loss, $w_0 – w_i$, where w_0 is the initial weight of the fuel element and w_i is the weight of the fuel element at the time of ignition. After a period of flaming combustion, the flame dies at $t_{f.}$ Thus the period of flaming combustion is $t_f – t_i$. The weight loss during this period is given by $w_f – w_i$ where w_f is the weight of the material at the time of cessation of flaming combustion. Similarly we can define a time period and weight loss during a period of smouldering combustion following flaming as t_s - t_f and w_s - w_f respectively where t_s is the time of cessation of smouldering and w_s is the weight of the material at t_s. w_s is the weight of the residue at the end of all combustion; it may be ash only or may retain some combustible material due to inefficient combustion. "Combustability", C, may be defined then as:

$$C = (w_f – w_i)/(t_f - t_i)$$

"Sustainability", S, is more difficult to define in Anderson's terms but may be described as the period of flaming combustion:

$$S = t_f - t_i$$

It is perhaps obvious that there are many more terms that can be used to describe the combustion process or "flammability" (e.g. relating to weight loss during the ignition delay time, or the weight loss during the smouldering combustion phase for example).

An inference from the discussion of the components of flammability may be that if weight loss curves were measured then comparisons between curves may allow comparisons between fuels without resorting to the definition of its various components. In practice, comparisons of curves may be more difficult than comparisons between components drawn from curves (Armstrong and Vines 1973, Gill *et al.* 1978).

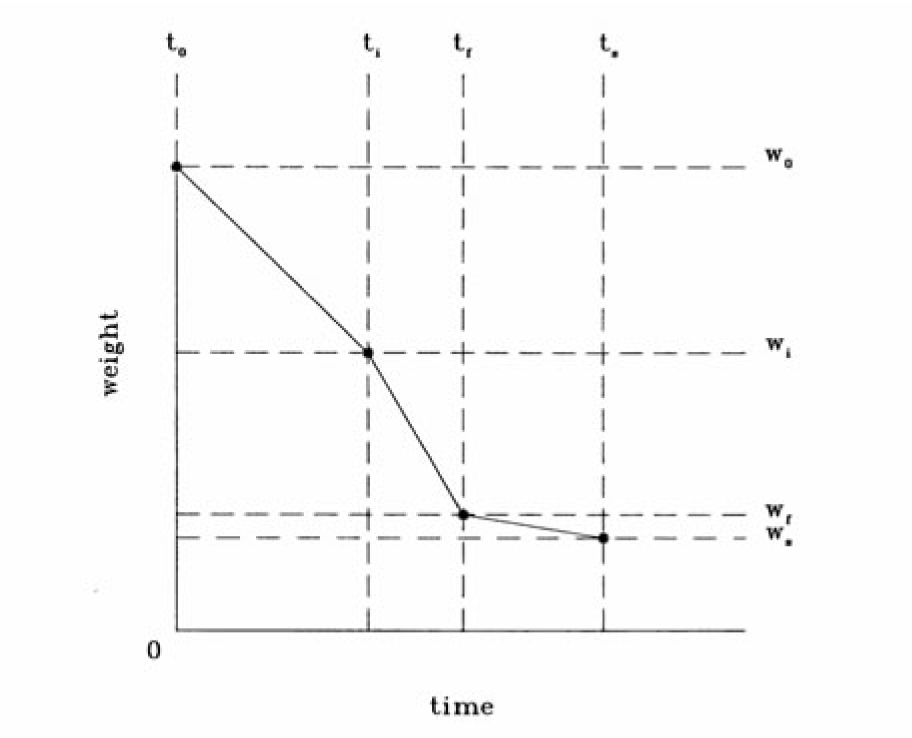

Figure 1. Hypothetical weight loss of a specimen in a furnace. Times are shown by "t”, weights by "w". Subscripts refer to: initial exposure, "o"; ignition, “i”; last appearance of flame, "f”; and end of smouldering, “s”.

There are a number of reasons why people want to know the "flammability" of certain materials. The landscape fire manager may want to know how fast a fire is moving and with what intensity (or rate of heat release, Byram 1959) it is burning in order to plan suppression operations (e.g. Luke and McArthur 1978); the planner might want to know the flammabilities of different species of plants (e.g. Ministry for Planning and Environment 1983) growing alone or in combinations with others at various times after planting; and an ecologist may want to know if there is a selective advantage attained by a species that is more flammable than a neighbour (e.g. Bond and Midgley 1995). How the user defines and measures flammability will vary according to purpose and circumstance.

There are other measures of flammability that may be used, e.g. the dimensions of flames and the propensity to produce burning brands. Gill *et al.* (1978) used the former but the latter has not been used despite its importance to the ignition of houses from burning vegetation (Ramsay *et aL* 1996).

Flammability of vegetation

Noted above was the fire manager who was concerned with the rate of spread of fire and its intensities. The intensity, I, of a fire along a portion of its perimeter has been given by Byram (1959) as:

$$I = H.w.r$$

where H is the heat yield (a modified heat of combustion), w is the weight of fuel per unit area and r is the rate of spread of the fire perimeter. Rate of spread can be measured directly (Gill and Knight 1991) or predicted as the result of empirically-determined or theoretically-based (e.g. Rothermel 1972) models. Examples of models are the equations of Noble *et al.* (1980) for the empirically derived McArthur fire meters, while the equations of Rothermel (1972) represent a theoretically based model. Whether empirical or theoretical, models assume that the vegetation is uniform over substantial areas (e.g. more than a hectare). Empirical models are derived from measurements of a series of fires directed across such areas under different weather conditions, while theoretical models are validated by, or calibrated from, such fires. There are limitations to experimental methods because the range of controllable fires is very limited (Luke and McArthur 1978) in comparison to the potential maximum intensity (Gill and Moore 1990). Experimental data are supplemented in model development by data from unplanned fires.

The first fire-spread model based on theory used the ignition delay time or 'ignitibility' as the first step in its development (Fons (1946). Fons expressed fire rate of spread as the ratio of the distance between fuel particles to the ignition delay time. Thus, he considered rate of spread to be related to 'ignitibility' rather than being "closely associated with" "sustainability" as suggested by Anderson (1970). "Sustainability" may be better related to the period of flaming combustion, or residence time (see Gill and Knight 1991) at any one point in landscape fires. "Combustibility" may be linked to intensity (Anderson 1970) but the values of "w" in calculations of fire intensity are equivalent to w_f - w_o rather than w_f - w_i as used above. The most direct heat release measurement linking laboratory and field is $(w_s - w_o)/(t_f - t_i)$ where the weight term is equal to w in the intensity equation and the time term is equal to the flame-residence time in the field. Considerable care would need to be given to the interpretation of any comparison made between the laboratory methods and field methods because the great differences in the circumstances of ignition and combustion.

Flammabilities of species' and individual plants

Planners (e.g. Ministry for Planning and Environment 1983), fire managers (e.g. Phillips *et al.* 1972) and ecologists (e.g. Bond and Midgley 1995) sometimes want to know what the flammability of a species is. However, species are manifest as seedlings, saplings, mature and senescent plants. The flammability of a species is therefore represented by the spectrum of flammabilities of individual plants at various life stages among other things (see also Troumbis and Trabaud 1989).

Determining the flammability of a plant is not only a conceptual problem but it is also a practical one. While traditional field methods of flammability determination (e.g. rates of spread and intensities) allow for the measurement of the flammability of populations of individual plants of a single species in plantations the number of species in this category is small. Furthermore, the flammability of individual plants is likely to be different when they are aggregated rather than alone. Flammability may be affected also by pruning, herbivores, fertilization, watering and raking or harvesting of litter.

Potentially flammable parts of the plant include live and dead leaves, twigs and bark. Particular species may be known for their various large proportions of dead materials retained on the plant, such as leaves (e.g. *Xanthorrhoea* spp.), twigs (many *Melaleuca* spp.) and bark (many *Eucalyptus* species, especially the stringybarks). The proportion of dead materials on the plant can be markedly affected by management history including exposure to fires. Such variation increases the difficulty of defining a 'flammability' for the plant let alone a species. Underneath the plant is litter composed of various proportions of dead plant materials modified in relation to their live state by leaching, decomposition and nutrient withdrawal prior to shedding.

Rudolph (1993a) lists 14 desirable characteristics of plants for reduced flammability. He considers 2 levels of each of these characteristics only. His idea was that each characteristic could be scored (present or absent) and the totals of 'presences' added to give a flammability rating (Rudolph 1993b). This is a useful approach in that the effects of management or history can be accounted for in the allocation of a score, e.g. whether or not a plant of *Xanthorrhoea* had or did not have an abundance of dead leaves. However there are problems to be overcome such as: the graded nature of variation in each characteristic makes a 2-part score difficult to apply; each characteristic is given equal weight yet some may be more important than others (Rudolph 1993b) and the weighting of these may vary with circumstance (e.g. canopy characteristics have more importance when canopies are near the ground but less so when high above a lawn); and, whether or not characteristics are independent. We need a systematic study of the appropriate characteristics, their inter-relationships and the quantitative contribution they make to flammability.

To measure the flammability of a plant or a species is a daunting task given the variation in attributes with life stage and management history, let alone the practical difficulties of direct measurement. Because of these problems, the measurement of the flammability of plant parts is usually undertaken rather than the measurement of the flammability of whole plants. Furthermore, certain plant parts are examined in preference to others because they are regarded as less variable in their flammabilities than others. Foremost among these are live leaves.

Flammability of leaves

The methods used for assessing the flammability of leaves (and some other tissues) may be grouped into two main categories - those that use finely-ground material and those that use intact leaves. Using finely ground material, the differences in temperature or sample weight or heat output between an inert material and the organic matter can be compared as the temperature around the sample is gradually increased (e.g. Philpot 1970, Susott 1982b). Susott (1982a), using similar materials and heating apparatus, developed "combustible gas analysis", a titration of combustible gases as they were driven from the samples at increasing temperatures.

Whole-leaf methods for measuring flammability include those using single leaves and those using groups of leaves. Among the latter are flow calorimetry (Pompe and Vines 1966) and methods involving the exposure of sprays of leaves in a muffle furnace (Montgomery and Cheo 1969) or burning leaves in weighing baskets (Armstrong and Vines 1973, Gill *et al.* 1978). Among the former are the limiting-oxygen method (Mak 1988), flame-spread methods (e.g. Dickinson and Kirkpatrick 1985, Weber 1990) and methods involving the exposure of a leaf in a muffle furnace at a constant temperature (Montgomery and Cheo 1971).

The reasons for the investigation of flammability of leaves in this study was to compare the resistance to ignition of leaves of various Australian species grown horticulturally. If the plant has leaves which do not ignite when a fire approaches it then it cannot contribute to the spread of the fire; indeed, the plant may even inhibit or stop the fire. Because methods involving finely-ground material do not provide a direct measure of resistance to ignition they were considered to be unsuitable. Single-leaf methods were preferred because methods using multiple-leaf samples involve more variables (such as degrees of packing) which complicate comparisons between species. Among the single-leaf methods flame-spread techniques do not give a direct estimate of ignitibility and the limiting oxygen method provides no time value and uses specialist equipment. In this study, single leaves were exposed in a muffle furnace. The methods used and the results arising from them are discussed in the next chapter.

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4. IGNITIBILITY OF LEAVES

Introduction

"Fire retardance" in plants has been an attribute long sought after in order to limit the spread of fires (e.g. Montgomery and Cheo 1969, Bellamy 1993). Many lists of "fire-retardant" plants have been drawn up (Bellarny 1993) and requests for such lists have been common since the Sydney fires of January 1994. However, there are few data on Australian plants and their flammabilities. King and Vines (1969) examined the ratio of the period of flaming combustion of a 5 g sample of oven-dry leaves to that of filter paper (related to the 'sustainability' of Anderson 1970). They examined the leaves of 20 species, 14 native. In this project we sought to examine the ease of ignition (rather than sustainability), *i.e.* 'ignitibility', of the leaves of 50 species of horticulturally grown Australian plants.

We can distinguish two schools of thought in relation to the determination of the flammability of materials. In the first, flammability is measured directly (e.g. King and Vines 1969) while in the second correlates of flammability are measured (Rudolph 1993 a,b; Hogenbirk and Sarrazin-Delay 1995) and the flammability predicted. The first has the benefit of being direct while the second may explain the direct result and be more readily used as a screening technique in some cases (according to the availability of materials and equipment). Variables used as correlates of the flammability of plant parts include moisture content (e.g. Trabaud 1976, Gill *et al*. 1978, Xanthopoulos and Wakimoto 1993), surface-area-to-volume ratio (e.g. Montgornery and Cheo 1971), contents of volatiles (King and Vines 1969, Susott 1982) and mineral composition (Broido and Nelson 1964, King and Vines 1969, Mutch and Philpot 1970, Hogeribirk and Sarrazin-Delay 1995). The roles of most of these correlates is not unequivocal possibly because of concomitant changes during fuel preheating of substances assumed to increase or decrease flammability (Trujillo 1976). The presumed inhibition of ignition by high moisture content (Ching and Stewart 1962) and the promotion of flammability by high volatile oil content (Bunting and Wright 1976) have been questioned. Broido (1973) indicated that sugar cubes can be made more ignitable by the addition of mineral matter.

In this study, we tested the hypothesis that moisture content, surface-area-to-volume ratio and mineral composition can be related to the ignition delay time of leaves whether fresh or dry.

Methods

The plant materials chosen for tests of ignitibility were the thinnest tissues on the plant *i.e.* leaves, phyllodes (Acacia spp.) and cladodes *(Casuarina sp., Allocasuarina* sp. and *Bossaeia sp.).* All plants chosen were either in cultivation in the Australian National Botanical Gardens (most species), on the CSIRO Black Mountain campus (5 species) or on the campus of the Australian National University *(Eucalyptus serraensis* only). Fifty species from 19 families were chosen for testing. Species were chosen which had material of a width and length appropriate to the size of the cradle supporting specimens in the furnace; this eliminated nanophylls typical of heathland species. Species covering a wide range of specimen thicknesses were sought for each measurement 'run'. Species were chosen to include those with high succulence *(Myoporum* sp.), volatile-oil content *(Eucalyptus dives*) and mineral content (the mistletoes, *Amyema* spp) so that detection of any influence of these properties on ignitibility might be discerned (although volatile-oils were not measured).

Care was taken to minimize changes in the moisture contents of samples in the period from collection to arrival in the laboratory, during preparation and during the ignitibility tests. Upon collection of small branches of each species the samples were placed in an insulated container. Samples were processed as soon as possible after collection. The period from the time of collection of specimens to the time of their entry into the furnace was usually about 1.5 hours.

In the laboratory, leaf material was sorted into three size classes and the median size, only, retained. Petioles were removed from most leaves and phyllodes while cladodes and strap-shaped leaves were cut to about 10 cm length, only the distal parts being retained. Then three sets of at least 10 specimens (some extra ones were included as spares) were made up at random. The specimens were placed first in appropriately labelled paper bags and then the three sets of samples for each species placed in a plastic bag. Five species were processed in each 'run', and three sets of ten Whatman No. 54 hardened 70mm diameter filter papers included as controls.

One set of specimens was used for tests of ignitibility in the muffle furnace while the material was still fresh, one set was used for ignitibility tests after oven drying and one set was used to determine moisture-content changes during the course of the ignitibility tests. The intact specimen set remaining at the end of the tests was used both for X-ray fluorescence (XRF) analysis of the mineral matter after grinding and pelleting and for analysis of Kjeldahl nitrogen following acid digestion.

On each run, specimens were removed from each of the six 'species' (i.e. including one filter paper 'species') in turn. The process was continued until ten replicates were processed. Before placing in the muffle furnace, specimens were measured for length, width, weight, area and thickness (or diameter for terete specimens). Lengths and widths were measured against a scale, weight was measured on an electronic balance and leaf area was measured using a calibrated LI-COR leaf-area meter. Leaf thickness measurements taken with callipers were standardized by taking a thickness two-thirds of the way to the midrib or central axis from the edge of the specimen near the midpoint of the specimen or where the lamina was widest. Surface area to volume ratio was taken as 2/thickness for flat leaves or phyllodes and 4/diameter for terete material. Measurement of some oven-dry specimens was impossible due to the brittle nature of the material.

For the oven-dry specimens drying took place at 95ºC for at least 22 hours. On removal from the oven, the material was placed in a desiccator and allowed to cool. Then the specimens were allocated to replicates and placed in plastic bags in readiness for treatment as for fresh specimens.

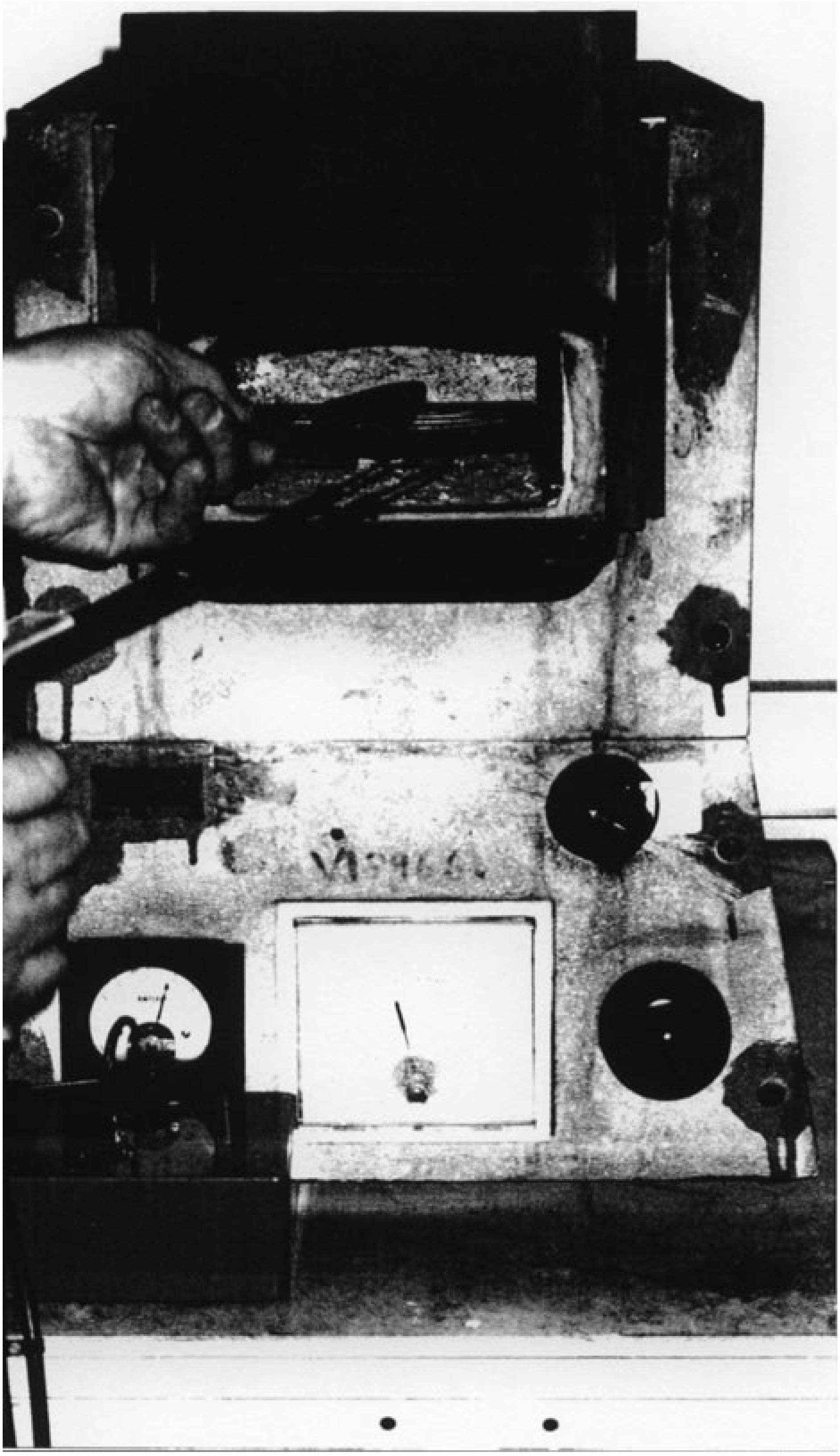

Plate 1. Photograph of the test apparatus. A specimen is being placed on the wire cradle in the muffle furnace and the spark gun has its arms located near that used in tests. The orange box holds the circuitry (Figure 2) used for the generation of the spark.

Each specimen was placed apex first onto a wire cradle about 3.5 cm above the floor of a muffle furnace (manufactured by Charles Moloney, Sydney, with a chamber size of 15x10x23 cm) at a furnace-designated temperature of 400 ºC. A strong exhaust fan in the ceiling of the small room in which tests took place was operating whenever the furnace was on. The door of the furnace remained open at all times. Thus, actual temperatures at the specimen would vary from 400ºC due to the furnace door being open and a temperature gradient existing in the furnace. A high frequency electrical spark, from a custom-made spark generator (Plate 1, Fig. 2), was held approximately 1 cm above the centre of each specimen from the time of entry of the specimen into the furnace until ignition. The period of time from entry into the furnace to the ignition of the specimen (with flames) - the ignition delay time - was measured using a stopwatch. Plate 1 is a photo of the apparatus.

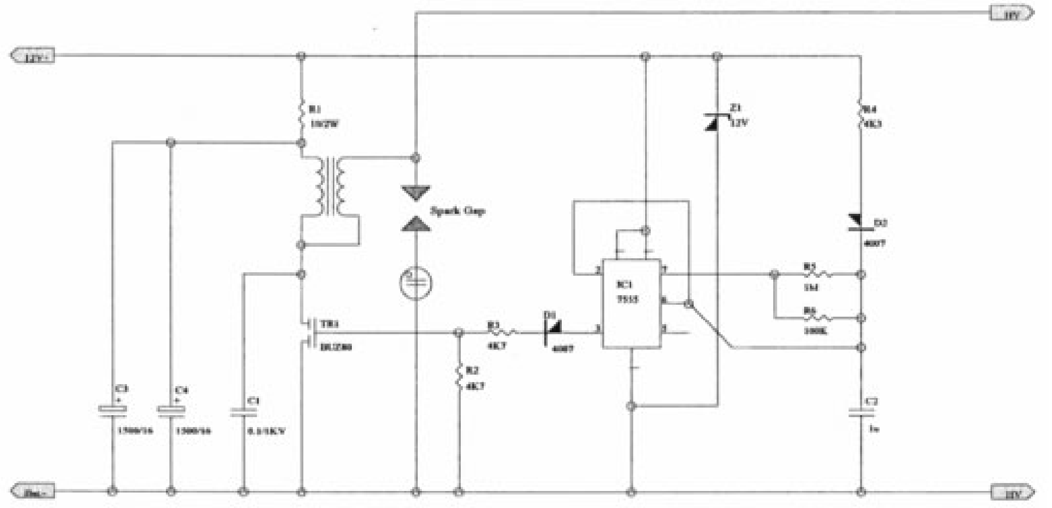

Figure 2. Spark Gun Circuit

Because some specimens rarely or never ignited at 400ºC, five species were collected again and specimens retested for ignitibility at a furnace temperature of 500ºC.

Results

Materials

Samples were collected in March and April 1996. The species selected are listed in Tables 1 and 2. The samples included: phyllodes of *Acacia* (3 species); the cladodes (leafless green twigs) of *Casuarina (1* species), *Allocasuarina (1* species) and *Bossaiea scolopendria* (Fabaceae); the strap-shaped leaves of *Anigozanthos flavidus* (Kangaroo Paw, Haemodoraceae) and *Lomandra longifolia* (Xanthorrhoeaceae); and, the terete leaves of *Hakea macreana, Amyema cambagei* (a mistletoe, Loranthaceae),

Table 1. Characteristics of freshly collected specimens of the species used together with their average ignition delay times at 400ºC.

Family	Genus	Species	Ave. Weight (g)	Ave Thick-. Ness (mm)	Ave. Length (CM)	Ave. Width (CM)	Ave. Area (CM^2)	Ave. Ignition Delay Time (sec)	Ave. Surface area to vol.ratio (mm^{-1})	Ave. Moisture (% odw)
Fresh specimens										
Asteraceae	Olearia	argophylla	0.750	0.288	11.14	4.63	28.95	14.73	6.94	116
Casuarinaceae	Allocasuarina	distyla	0.156	1.212	11.22	1.21	0.84	33.85	3.30	122
Casuarinaceae	Casuarina	glauca	0.174	1.093	15.21	1.09	0.90	43.02	3.66	147
Euphorbiaceae	Beyeria	viscosa	0.165	0.249	6.78	1.29	5.80	21.88	8.03	136
Fabaceae	Bossiaea	scolopendria	0.257	0.363	9.26	0.63	4.58	39.22	5.51	164
Fabaceae	Daviesia	arborea	0.152	0.197	11.11	0.89	6.21	12.65	10.15	100
Haemodoraceae	Anigozanthos	flavidus	0.370	0.397	11.08	1.07	9.40	40.05	5.04	412
Loranthaceae	Amyema	cambagei	0.122	1.323	9.93	1.32	0.72	38.94	3.02	160
Loranthaceae	Amyema	miquelii	2.470	0.987	12.23	2.70	22.50	57.07	2.03	155
Mimosaceae	Acacia	implexa	0.457	0.298	13.88	1.27	13.07	18.98	6.71	161
Mimosaceae	Acacia	melanoxylon	0.296	0.270	8.99	1.47	8.71	22.50	7.41	116
Mimosaceae	Acacia	podalyrifolia	0.211	0.252	5.17	2.58	8.57	16.49	7.94	147
Myoporaceae	Myoporum	acuminata 1	0.781	0.335	12.65	2.68	18.37	32.32	5.97	337
Myoporaceae	Myoporum	acuminata 11	0.448	0.485	8.90	1.61	7.81	39.48	4.12	411
Myrtaceae	Acmena	smithh	0.532	0.251	8.38	4.29	21.14	18.48	7.97	132
Myrtaceae	Angophora	costata	0.674	0.293	14.27	2.37	20.22	17.04	6.83	78
Myrtaceae	Callistemon	citrinus	0.166	0.343	5.85	1.03	3.65	22.61	5.83	80
Myrtaceae	Callistemon	sp.	0.204	0.400	6.76	1.18	4.66	34.20	5.01	122
Myrtaceae	Eucalyptus	cinerea	0.505	0.273	7.24	3.35	15.96	14.79	7.34	92
Myrtaceae	Eucalyptus	dives	0.540	0.282	10.40	2.50	15.72	13.33	7.09	92
Myrtaceae	Eucalyptus	elata	0.281	0.227	11.56	1.34	10.68	11.57	8.81	123
Myrtaceae	Eucalyptus	grasbyi	0.826	0.384	12.21	3.03	20.98	19.21	5.21	111
Myrtaceae	Eucalyptus	grossa	2.181	0.649	9.87	5.34	30.27	29.74	3.08	83
Myrtaceae	Eucalyptus	mannifera	0.373	0.263	12.97	1.34	11.44	13.67	7.61	107
Myrtaceae	Eucalyptus	neglecta	1.434	0.338	8.42	6.11	38.46	17.10	5.92	103
Myrtaceae	Eucalyptus	parramattensis	0.458	0.290	11.20	1.86	12.88	15.42	6.90	83
Myrtaceae	Eucalyptus	serraensis	1.794	0.668	9.25	4.06	25.08	33.22	2.99	105
Myrtaccae	Eucalyptus	sideroxylon	0.643	0.356	9.77	2.84	16.22	18.10	5.62	97
Pittosporaceae	Pittosporum	undulatum	0.489	0.211	9.17	3.44	20.12	16.99	9.48	131
Podocarpaceae	Podocarpus	elatus	0.277	0.376	8.11	1.08	6.12	27.64	5.32	102
Proteaceae	Banksia	paludosa	0.524	0.460	9.50	1.85	10.44	25.40	4.35	116
Proteaceae	Grevillea	shirlessii	0.334	0.247	11.06	1.85	12.85	14.52	8.10	106
Proteaceae	Hakea	cristata	0.578	0.489	6.80	3.64	12.37	27.58	4.09	95
Proteaceae	Hakea	macreana	0.116	1.285	9.37	1.29	0.65	35.41	3.11	90
Proteaceae	Hakea	multilineata	0.549	0.560	14.62	0.87	8.68	31.85	3.58	74
Proteaceae	Hakea	petiolaris	1.190	0.504	10.95	4.24	24.32	23.08	3.97	78
Proteaceae	Hakea	salicifolia	0.336	0.312	11.24	1.59	10.74	15.39	6.41	128
Proteaceae	Lomatia	arborescens	0.612	0.308	8.28	3.42	18.26	18.88	6.49	126
Proteaceae	Persoonia	levis	0.877	0.543	7.11	3.91	16.86	32.11	3.68	157
Proteaceae	Telopea	sp.(hybrid)	0.960	0.427	16.49	2.36	19.44	22.03	4.68	135
Rhamnaceae	Pomaderds	apetala	0.579	0.431	9.52	3.85	23.99	13.25	4.64	120
Rutaceae	Asterolasia	hexapetala	0.147	0.235	5.89	1.63	6.32	22.80	8.51	140
Rutaceae	Correa	lawrenciana	0.255	0.284	5.90	2.52	9.20	21.74	7.04	154
Rutaceae	Eriostemon	myoporoides	0.242	0.419	7.37	1.00	4.99	36.55	4.77	179
Rutaceae	Geijera	parviflora	0.174	0.265	11.61	0.63	5.34		7.55	151
Sapindaceae	Dodonaea	viscosa	0.090	0.193	8.04	0.71	3.58	16.28	10.36	112
Sterculiaceae	Brachychiton	populneus	0.303	0.184	8.33	3.67	15.81	13.78	10.87	135
Sterculiaceae	Lasiopetalum	macrophyllum	0.669	0.341	10.39	3.79	26.74	12.95	5.87	92
Winteraceae	Tasmannia	insipida	0.348	0.231	9.19	2.39	12.90	16.10	8.66	152
Xanthorrhoeacae	Lomandra	longifolia	0.367	0.374	10.92	0.91	8.69	38.53	5.35	149

Table 2. Characteristics of oven-dry specimens of the species used together with their ignition delay times at 400ºC.

Family	Genus	Species	Ave. Weight (g)	Ave. Thickness (mm)	Ave. Length (cm)	Ave. Width (cm)	Ave. Area (cm^2)	Ave. Ignition delay time (sec)	Ave. Surface area/ volume ratio (mm^{-1})
Oven dry specimens									
Asteraceae	Olearia	argophylla	0.333	0.257	10.04	3.90		4.03	7.78
Casuarinaceae	Allocasuarina	distyla	0.061	0.890	9.90	0.89	0.35	12.75	4.49
Casuarinaceae	Casuarina	glauca	0.050	0.596	10.55			10.53	6.71
Euphorbiaceae	Beyeria	viscosa	0.065	0.155	5.97	0.97	3.64	4.60	12.90
Fabaceae	Bossiaea	scolopendria	0.100	0.266	8.86	0.43	2.86	9.80	7.52
Fabaceae	Daviesia	arborea	0.073	0.150	10.95	0.84	5.69	4.18	13.33
Haemodoraceae	Anigozanthos	flavidus	0.057	0.165	10.76	0.46	3.97	3.51	12.12
Loranthaceae	Amyema	cambagei	0.044	0.932	8.15	0.93	0.25	8.53	4.29
Loranthaceae	Amyema	miquelii	0.932	0.663	9.85	1.90	13.60	10.96	3.02
Mimosaceae	Acacia	implexa	0.151	0.211	11.74	0.91	8.01	5.55	9.48
Mimosaceae	Acacia	melanoxylon	0.146	0.204	9.01	1.29	6.94	5.07	9.80
Mimosaceae	Acacia	podalyrifolia	0.094	0.192				4.35	10.42
Myoporaceae	Myoporum	acuminata 1	0.150	0.176	10.54	1.98	12.08	3.39	11.36
Myoporaceae	Myoporum	acuminata 11	0.089	0.190	7.57	1.24	4.87	3.29	10.53
Myrtaceae	Acmena	smithii	0.235	0.181	7.77	3.74	16.71	3.77	11.05
Myrtaceae	Angophora	costata	0.362	0.265	13.27	2.27	18.06	4.14	7.55
Myrtaceae	Callistemon	citrinus	0.094	0.325	5.52	0.80		7.46	6.15
Myrtaceae	Callistemon	sp.	0.165	0.329				6.81	6.08
Myrtaceae	Eucalyptus	cinerea	0.233	0.220	6.43	3.13	13.37	3.57	9.09
Myrtaceae	Eucalyptus	dives	0.267	0.236	10.15	2.25	13.88	3.36	8.47
Myrtaceae	Eucalyptus	elata	0.150	0.180	13.10	1.20	10.27	3.22	11.11
Myrtaceae	Eucalyptus	grasbyi	0.372	0.298	11.58	2.81	22.40	5.22	6.71
Myrtaceae	Eucalyptus	grossa	1.082	0.455	8.77	4.65	22.74	6.40	4.40
Myrtaceae	Eucalyptus	mannifera	0.191	0.219	11.92	1.37	10.05	3.18	9.13
Myrtaceae	Eucalyptus	neglecta	0.773	0.294	8.43	6.11	36.91	4.05	6.80
Myrtaceae	Eucalyptus	parramattensis	0.262	0.248	10.58	1.84	12.15	4.43	8.06
Myrtaceae	Eucalyptus	serraensis	0.865	0.527	8.29	3.68	20.55	6.96	3.80
Myrtaceae	Eucalyptus	sideroxylon	0.354	0.317	9.75	2.55	15.31	4.27	6.31
Pittosporaceae	Pittosporum	undulatum	0.232	0.182	8.62	3.21	17.43	3.59	10.99
Podocarpaceae	Podocarpus	elatus	0.137	0.252	7.96	0.93	4.84	12.05	7.94
Proteaceae	Banksia	paludosa	0.248	0.398	9.05	1.67	8.96	5.61	5.03
Proteaceae	Grevillea	shirlessii	0.153	0.206	10.41	1.65	10.43	3.28	9.71
Proteaceae	Hakea	cristata	0.374	0.470	6.93	3.46		12.54	4.26
Proteaceae	Hakea	macreana	0.062	1.024	8.95		0.43	10.90	3.91
Proteaceae	Hakea	multilineata	0.298	0.509	14.49	0.78	7.45	12.96	3.93
Proteaceae	Hakea	petiolaris	0.621	0.477	10.34	3.71	20.17	8.15	4.19
Proteaceae	Hakea	salicifolia	0.147	0.258	10.88	1.29	8.30	3.84	7.75
Proteaceae	Lomatia	arborescens	0.284	0.264	8.22	3.19		4.39	7.58
Proteaceae	Persoonia	levis	0.314	0.353	6.84	3.43	13.70	7.94	5.67
Proteaceae	Telopea	sp. (hybrid)	0.392	0.345	15.85	2.19	17.45	5.49	5.80
Rhamnaceae	Pomaderds	apetala	0.262	0.356	8.33	3.02	18.28	3.70	5.62
Rutaceae	Asterolasia	hexapetala	0.063	0.186	5.08	1.35	4.14	5.42	10.75
Rutaceae	Correa	lawrenciana	0.096	0.235	5.07	2.08	6.05	5.96	8.51
Rutaceae	Eriostemon	myoporoides	0.082	0.221	6.39	0.81	3.49	8.78	9.05
Rutaceae	Geijera	parviflora	0.084	0.150	9.80	0.57	4.21	5.88	13.33
Sapindaceae	Dodonaea	viscosa	0.039	0.152	7.45	0.55	2.27	3.84	13.16
Sterculiaceae	Brachychiton	populneus	0.129	0.137	8.09	3.31	13.20	3.31	14.60
Sterculiaceae	Lasiopetalum	macrophyllum	0.340	0.304	9.55	3.55	22.64	3.51	6.58
Winteraceae	Tasmannia	insipida	0.143	0.154	8.80	2.09	10.03	5.70	12.99
Xanthorrhoeacae	Lomandra	longifolia	0.152	0.315	11.02			11.13	6.36

Casuarina glauca and *Allocasuarina distyla*. Two populations of *Myoporum acuminata* (Myoporaceae) were sampled.

Specimens exposed at 400ºC

Fresh samples varied in moisture content (expressed as a percentage of oven-dry weight) from 74 to 412% (summarized in Table 3 from Table 1). During the experiments fresh weights declined by an average of 3.6%. The ratios of average maximum value to average minimum value for fresh specimen average weights and areas were greater than 20 while those for lengths, surface area to volume ratios and thicknesses were between 3 and 10 (Table 3). For oven-dry specimens, ratios of maximum value to minimum value followed the same trends but the ratio for average areas had substantially higher values due to a much lower minimum value (summarized in Table 4 from Table 2) because of the shrinking of the terete leaves of Amyema cambagei upon drying (Table 2). Reactions to drying varied making some specimens impossible to measure for area, width and even length because of the wrinkling, buckling and bowing (Table 2). Changes in moisture content during the experiments with oven-dry material were negligible (maximum about 2%).

Table 3. Summary of the characteristics of the fresh specimens.

Characteristic	Maximum value	Minimum value	Mean	Range
Weight (g)	2.470	0.090	0.549	2.380
Length (cm)	16.49	5.17	9.91	11.32
Width (cm)	6.11	0.63	2.31	5.48
Thickness (mm)	1.323	0.184	0.429	1.139
Area (cm^2)	38.46	0.65	13.24	37.81
Moisture (% odw)	412	74	136	338
Ignition delay time (sec)	57.07	11.57	24.34	45.5
Surface area/volume ratio (mm^{-1})	10.87	2.03	6.06	8.84

Table 4. Summary of the characteristics of oven-dry specimens.

Characteristic	Maximum value	Minimum value	Mean	Range
Weight (g)	1.082	0.039	0.248	1.043
Length (cm)	15.85	5.07	9.33	10.78
Width (cm)	6.11	0.43	2.11	5.69
Thickness (mm)	1.024	0.137	0.322	0.887
Area (CM^2)	36.91	0.25	11.15	36.66
ignition delay time (sec)	12.96	3.18	6.11	9.79
Surface area/volume ratio (mm^{-1})	14.60	3.02	8.12	11.58

For fresh material, there were statistically significant correlations between specimen weights, widths and areas ($P<0.01$) and a correlation between weight and surface area to volume ratio ($P=0.001$). The result was similar for oven-dry material but surface area to volume ratio was correlated with both weight and area ($P<0.05$). Lengths were independent of other measures. Because of the strong correlations between ignition delay times and surface area to volume ratio ($P<0.001$), the lack of correlation

Table 5. Mineral contents ('major' elements) of the specimens used in the tests.

Family	Genus	Species	Sodium %	Magnesium %	Phosphorus %	Sulphur %	Chloride %
Asteraceae	Olearia	argophylla	0.057	0.094	0.154	0.087	0.218
Casuarinaceae	Allocasuarina	distyla	0.054	0.102	0.068	0.153	0.293
Casuarinaceae	Casuarina	glauca	0.053	0.280	0.087	0.119	0.495
Euphorbiaceae	Beyeria	viscosa	0.009	0.235	0.143	0.274	0.258
Fabaceae	Bossiaea	scolopendria	0.025	0.167	0.059	0.185	0.509
Fabaceae	Daviesia	arborea	0.064	0.111	0.060	0.135	0.090
Haemodoraceae	Anigozanthos	flavidus	0.220	0.383	0.066	0.670	0.959
Loranthaceae	Amyema	cambagei	0.091	0.297	0.109	0.152	1.119
Loranthaceae	Amyema	miquelii	0.018	0.204	0.188	0.134	0.828
Mimosaceae	Acacia	implexa	0.019	0.208	0.107	0.194	1.019
Mimosaceae	Acacia	melanoxylon	0.062	0.196	0.102	0.162	0.332
Mimosaceae	Acacia	podalyrifolia	0.024	0.218	0.134	0.176	0.487
Myoporaceae	Myoporum	acuminata 1	0.382	0.314	0.211	0.425	1.483
Myoporaceae	Myoporum	acuminata 11	0.311	0.349	0.284	0.578	1.919
Myrtaceae	Acmena	smithii	0.062	0.246	0.110	0.286	0.249
Myrtaceae	Angophora	costata	0.107	0.293	0.083	0.092	0.034
Myrtaceae	Callistemon	citrinus	0.044	0.103	0.073	0.116	0.193
Myrtaceae	Callistemon	sp.	0.026	0.123	0.105	0.122	0.275
Myrtaceae	Eucalyptus	cinerea	0.018	0.135	0.120	0.131	0.095
Myrtaceae	Eucalyptus	dives	0.012	0.247	0.148	0.141	0.365
Myrtaceae	Eucalyptus	elata	0.131	0.238	0.205	0.147	0.662
Myrtaccae	Eucalyptus	grasbyi	0.068	0.247	0.370	0.110	0.133
Myrtaceae	Eucalyptus	grossa	0.045	0.112	0.458	0.138	0.309
Myrtaceae	Eucalyptus	mannifera	0.009	0.124	0.171	0.138	0.333
Myrtaccae	Eucalyptus	neglecta	0.019	0.131	0.155	0.131	0.236
Myrtaceae	Eucalyptus	parramattensis	0.049	0.317	0.087	0.118	0.145
Myrtaceae	Eucalyptus	serraensis	0.161	0.207	0.065	0.092	0.331
Myrtaceae	Eucalyptus	sideroxylon	0.008	0.187	0.458	0.119	0.439
Pittosporaceae	Pittosporum	undulatum	0.133	0.285	0.089	0.157	0.288
Podocarpaceae	Podocarpus	elatus	0.014	0.098	0.207	0.110	0.013
Proteaceae	Banksia	paludosa	0.249	0.111	0.057	0.162	0.249
Proteaceae	Grevillea	shirlessii	0.051	0.145	0.060	0.161	0.091
Proteaceae	Hakea	cristata	0.127	0.082	0.045	0.126	0.175
Proteaceae	Hakea	macreana	0.124	0.103	0.037	0.115	0.140
Proteaceae	Hakea	multilineata	0.055	0.101	0.115	0.103	0.100
Pro ' teaceae	Hakea	petiolaris	0.243	0.260	0.078	0.231	0.239
Proteaceae	Hakea	salicifolia	0.324	0.258	0.046	0.091	0.242
Proteaceae	Lomatia	arborescens	0.006	0.105	0.091	0.125	0.234
Proteaceae	Persoonia	levis	0.090	0.135	0.056	0.094	0.185
Proteaceae	Telopea	sp. (hybrid)	0.004	0.095	0.038	0.088	0.024
Rhamnaceae	Pomaderris	apetala	0.017	0.164	0.110	0.105	0.452
Rutaceae	Asterolasia	hexapetala	0.119	0.251	0.249	0.271	0.509
Rutaceae	Correa	lawrenciana	0.054	0.128	0.084	0.174	0.387
Rutaceae	Eriostemon	myoporoides	0.080	0.139	0.098	0.152	0.681
Rutaceae	Geijera	parviflora	0.030	0.222	0.149	0.121	0.557
Sapindaceae	Dodonaea	viscosa	0.026	0.289	0.181	0.206	0.262
Sterculiaceae	Brachychiton	populneus	0.016	0.272	0.139	0.203	0.047
Sterculiaceae	Lasiopetalum	macrophyllum	0.024	0.097	0.062	0.173	0.208
Winteraceae	Tasmannia	insipida	0.089	0.254	0.078	0.184	0.048
Xanthorrhoeacae	Lomandra	longifolia	0.023	0.132	0.080	0.226	0.6341

Table 5 (continued)

Family	Genus	Species	Potassium %	Calcium %	Silicon %	Nitrogen %
Asteraceae	Olearia	argophylla	1.427	0.728	0.127	0.974
Casuarinaceae	Allocasuarina	distyla	0.872	0.501	0.057	1.361
Casuarinaceae	Casuarina	glauca	0.468	1.830	0.085	1.370
Euphorbiaceae	Beyeria	viscosa	0.964	1.193	0.081	1.785
Fabaceae	Bossiaea	scolopendria	0.674	0.449	0.038	1.526
Fabaceae	Daviesia	arborea	0.833	0.285	0.087	1.733
Haemodoraceae	Anigozanthos	flavidus	2.083	1.944	1.537	1.902
Loranthaceae	Amyema	cambagei	3.002	2.509	0.069	1.496
Loranthaceae	Amyema	miquelii	2.709	1.482	0.032	1.132
Mimosaceae	Acacia	implexa	1.538	0.556	0.086	2.304
Mimosaceae	Acacia	melanoxylon	0.795	0.522	0.050	2.126
Mimosaceae	Acacia	podalyrifolia	0.998	0.677	0.029	2.818
Myoporaceae	Myoporum	acuminata 1	2.893	2.269	0.087	2.147
Myoporaceae	Myoporum	acuminata 11	2.554	2.013	0.061	1.747
Myrtaceae	Acmena	smithii	0.848	0.547	0.118	1.212
Myrtaceae	Angophora	costata	0.487	1.139	0.056	1.027
Myrtaceae	Callistemon	citrinus	0.821	0.532	0.161	0.996
Myrtaceae	Callistemon	sp.	0.982	0.519	0.053	1.345
Myrtaceae	Eucalyptus	cinerea	0.633	0.714	0.089	1.311
Myrtaceae	Eucalyptus	dives	0.655	0.457	0.067	1.311
Myrtaceae	Eucalyptus	elata	0.713	0.637	0.071	1.373
Myrtaceae	Eucalyptus	grasbyi	0.437	0.726	0.050	0.970
Myrtaceae	Eucalyptus	grossa	1.221	1.244	0.048	1.324
Myrtaceae	Eucalyptus	mannifera	1.099	0.723	0.047	1.476
Myrtaceae	Eucalyptus	neglecta	0.819	1.811	0.095	1.373
Myrtaceae	Eucalyptus	parramattensis	0.625	2.506	0.068	1.065
Myrtaceae	Eucalyptus	serraensis	0.225	0.929	0.069	0.796
Myrtaceae	Eucalyptus	sideroxylon	1.863	1.246	0.072	1.047
Pittosporaceae	Pittosporum	undulatum	1.739	1.608	0.063	1.419
Podocarpaceae	Podocarpus	elatus	0.499	2.191	0.101	0.921
Proteaceae	Banksia	paludosa	0.335	0.592	0.067	1.153
Proteaceae	Grevillea	shirlessii	0.773	0.647	0.071	0.907
Proteaceae	Hakea	cristata	0.747	0.297	0.017	0.826
Proteaceae	Hakea	macreana	0.378	0.237	0.061	0.728
Proteaceae	Hakea	multilineata	0.383	1.326	0.090	0.482
Proteaceae	Hakea	petiolaris	0.579	0.549	0.026	0.586
Proteaceae	Hakea	salicifolia	0.404	0.467	0.040	0.814
Proteaceae	Lomatia	arborescens	0.925	2.299	0.072	1.049
Proteaceae	Persoonia	levis	0.518	0.259	0.084	0.989
Proteaceae	Telopea	sp.(hybrid)	0.518	0.563	0.042	0.646
Rhamnaceae	Pomaderds	apetala	1.011	1.312	0.213	1.263
Rutaceae	Asterolasia	hexapetala	0.992	1.588	0.166	1.721
Rutaceae	Correa	lawrenciana	1.500	1.728	0.296	1.421
Rutaceae	Eriostemon	myoporoides	1.288	1.001	0.066	1.392
Rutaceae	Geijera	parviflora	2.072	1.560	0.206	1.771
Sapindaceae	Dodonaea	viscosa	1.217	0.485	0.239	1.377
Sterculiaceae	Brachychiton	populneus	1.414	1.527	0.154	1.647
Sterculiaceae	Lasiopetalum	macrophyllum	1.024	0.861	0.116	1.021
Winteraceae	Tasmannia	insipida	0.687	0.978	0.155	1.356
Xanthorrhoeacae	Lomandra	longifolia	1.048	1.321	0.182	1.163

Table 6. Mineral contents ('minor' elements) of the specimens tested.

Family	Genus	Species	Aluminium ppm	Manganese ppm	Iron ppm	Copper ppm	Zinc ppm
Asteraceae	Olearia	argophylla	119	596.9	74.6	5.3	55.4
Casuarinaceae	Allocasuarina	distyla	29	311.6	57.4	5.0	19.7
Casuarinaceae	Casuarina	glauca	26	494.0	56.5	4.0	20.7
Euphorbiaceae	Beyeria	viscosa	91	342.9	95.4	11.2	68.9
Fabaceae	Bossiaea	scolopendria	21	266.8	32.1	3.5	16.5
Fabaceae	Daviesia	arborea	93	121.9	88.5	1.0	82.0
Haemodoraceae	Anigozanthos	flavidus	78	2948.6	106.1	5.7	80.8
Loranthaceae	Amyema	cambagei	81	158.6	163.5	12.0	20.0
Loranthaceae	Amyema	miquelii	46	864.7	68.6	13.2	67.0
Mimosaceae	Acacia	implexa	68	232.3	71.4	5.7	19.6
Mimosaceae	Acacia	melanoxylon	79	238.9	84.0	4.6	10.8
Mimosaceae	Acacia	podalyrifolia	<10	138.4	75.4	7.7	30.3
Myoporaceae	Myoporum	acuminata 1	95	63.6	101.9	10.0	66.2
Myoporaceae	Myoporum	acuminata 11	58	55.3	84.0	19.3	39.7
Myrtaceae	Acmena	smithii	69	415.6	79.4	4.4	15.2
Myrtaceae	Angophora	costata	96	760.9	55.7	2.1	47.0
Myrtaceae	Callistemon	citrinus	210	903.5	94.9	4.6	17.0
Myrtaceae	Callistemon	sp.	82	758.8	56.1	5.2	16.0
Myrtaceae	Eucalyptus	cinerea	162	660.0	118.0	4.6	16.9
Myrtaceae	Eucalyptus	dives	110	364.0	84.4	5.3	11.1
Myrtaceae	Eucalyptus	elata	144	288.8	120.8	4.3	16.0
Myrtaceae	Eucalyptus	grasbyi	65	662.0	68.6	4.2	46.9
Myrtaceae	Eucalyptus	grossa	67	225.6	82.4	7.1	52.9
Myrtaceae	Eucalyptus	mannifera	43	527.4	60.2	5.4	20.6
Myrtaceae	Eucalyptus	neglecta	92	1519.2	58.3	7.9	23.5
Myrtaceae	Eucalyptus	parramattensis	80	983.7	54.8	5.0	48.9
Myrtaceae	Eucalyptus	serraensis	63	261.3	51.9	6.1	13.2
Myrtaceae	Eucalyptus	sideroxylon	96	420.7	86.7	9.8	21.2
Pittosporaceae	Pittosporum	undulatum	54	350.1	63.3	8.8	378.3
Podocarpaceae	Podocarpus	elatus	68	36.8	67.8	3.0	9.2
Proteaceae	Banksia	paludosa	283	109.8	73.9	4.6	10.3
Proteaceae	Grevillea	shirlessii	171	246.5	66.7	3.0	9.5
Proteaceae	Hakea	cristata	46	39.0	32.1	3.4	5.0
Proteaceae	Hakea	macreana	95	151.2	34.0	0.1	9.0
Proteaceae	Hakea	multilineata	157	97.0	111.1	1.8	6.8
Proteaceae	Hakea	petiolaris	41	185.8	45.8	2.8	10.7
Proteaceae	Hakea	salicifolia	71	387.8	43.1	2.5	10.3
Proteaceae	Lomatia	arborescens	74	2445.7	55.7	5.1	13.3
Proteaceae	Persoonia	levis	133	489.9	76.1	1.9	65.3
Proteaceae	Telopea	sp. (hybrid)	72	1342.3	31.6	1.8	6.8
Rhamnaceae	Pomaderris	apetala	284	90.6	222.3	6.3	34.0
Rutaceae	Asterolasia	hexapetala	161	105.3	156.3	3.5	15.1
Rutaceae	Correa	lawrenciana	86	395.7	105.9	6.6	14.8
Rutaceae	Eriostemon	myoporoides	44	154.6	69.7	2.9	15.3
Rutaceae	Geijera	parviflora	93	141.6	88.4	5.1	92.3
Sapindaceae	Dodonaea	viscosa	263	182.4	210.8	15.9	221.2
Sterculiaceae	Brachychiton	populneus	175	55.1	173.7	4.3	24.3
Sterculiaceae	Lasiopetalum	macrophyllum	213	355.8	189.3	4.7	19.5
Winteraceae	Tasmannia	insipida	127	1436.5	87.1	6.9	121.0
Xanthorrhoeacae	Lomandra	longifolia	106	1433.1	81.8	5.7	15.1

Table 7. Mineral contents (aggregated) of the specimens used in the tests

Family	Genus	Species	Total mineral - nitrogen	Total mineral - silicon	Total mineral %
Asteraceae	Olearia	argophylla	2.977	3.824	3.951
Casuarinaceae	Allocasuarina	distyla	2.142	3.446	3.503
Casuarinaceae	Casuarina	glauca	3.477	4.762	4.847
Euphorbiaceae	Beyeria	viscosa	3.218	4.922	5.003
Fabaceae	Bossiaea	scolopendria	2.140	3.628	3.666
Fabaceae	Daviesia	arborea	1.704	3.350	3.437
Haemodoraceae	Anigozanthos	flavidus	8.184	8.549	10.086
Loranthaceae	Amyema	cambagei	7.392	8.819	8.888
Loranthaceae	Amyema	miquelii	5.701	6.801	6.833
Mimosaceae	Acacia	implexa	3.767	5.985	6.071
Mimosaceae	Acacia	melanoxylon	2.263	4.339	4.389
Mimosaceae	Acacia	podalyrifolia	2.769	5.558	5.587
Myoporaceae	Myoporum	acuminata 1	8.098	10.158	10.245
Myoporaceae	Myoporum	acuminata 11	8.095	9.781	9.842
Myrtaceae	Acmena	smithii	2.524	3.618	3.736
Myrtaceae	Angophora	costata	2.387	3.358	3.414
Myrtaceae	Callistemon	citrinus	2.166	3.001	3.162
Myrtaceae	Callistemon	sp.	2.297	3.589	3.642
Myrtaceae	Eucalyptus	cinerea	2.031	3.253	3.342
Myrtaceae	Eucalyptus	dives	2.149	3.393	3.460
Myrtaceae	Eucalyptus	elata	2.861	4.163	4.234
Myrtaceae	Eucalyptus	grasbyi	2.226	3.146	3.196
Myrtaceae	Eucalyptus	grossa	3.618	4.895	4.943
Myrtaceae	Eucalyptus	mannifera	2.710	4.139	4.186
Myrtaceae	Eucalyptus	neglecta	3.567	4.845	4.940
Myrtaceae	Eucalyptus	parramattensis	4.032	5.029	5.097
Myrtaceae	Eucalyptus	serraensis	2.119	2.846	2.915
Myrtaceae	Eucalyptus	sideroxylon	4.455	5.430	5.502
Pittosporaceae	Pittosporum	undulatum	4.447	5.803	5.866
Podocarpaceae	Podocarpus	elatus	3.251	4.071	4.172
Proteaceae	Banksia	paludosa	1.870	2.956	3.023
Proteaceae	Grevillea	shirlessii	2.049	2.885	2.956
Proteaceae	Hakea	cristata	1.629	2.438	2.455
Proteaceae	Hakea	macreana	1.224	1.891	1.952
Proteaceae	Hakea	multilineata	2.310	2.702	2.792
Proteaceae	Hakea	petiolaris	2.234	2.794	2.820
Proteaceae	Hakea	salicifolia	1.924	2.697	2.737
Proteaceae	Lomatia	arborescens	4.116	5.093	5.165
Proteaceae	Persoonia	levis	1.498	2.403	2.487
Proteaceae	Telopea	sp.(hybrid)	1.517	2.121	2.163
Rhamnaceae	Pomaderris	apetala	3.448	4.498	4.711
Rutaceae	Asterolasia	hexapetala	4.189	5.744	5.910
Rutaceae	Correa	lawrenciana	4.411	5.537	5.833
Rutaceae	Eriostemon	myoporoides	3.534	4.860	4.926
Rutaceae	Geijera	parviflora	4.959	6.524	6.730
Sapindaceae	Dodonaea	viscosa	2.994	4.132	4.371
Sterculiaceae	Brachychiton	populneus	3.815	5.308	5.462
Sterculiaceae	Lasiopetalum	macrophyllum	2.643	3.548	3.664
Winteraceae	Tasmannia	insipida	2.651	3.852	4.007
Xanthorrhoeacae	Lomandra	longifolia	3.810	4.791	4.973

between other specimen dimensions and ignition delay time and the inter-relationships of weight, area and width, all specimen dimensions excepting surface area to volume ratio were considered no further.

Details of the results of the mineral analyses are shown in Tables 5, 6 and 7 and summarized in Table 8. For Cl, Cu, Na, Mn, Si, and Zn the ratios of maximum value to minimum value ranged from 75 (Zn) to 148 (Cl). The same ratio for other elements varied from near 5 (Mg) to 28 (Al). There were statistically significant intercorrelations ($P<0.05$) between contents of Ca, Cl, Cu, K, Mg and S ("group 1 elements"), and between Al and Fe ("group 2 elements"). Nitrogen content was correlated with all the elemental concentrations of group 1 except Ca. Similarly, Na concentration was correlated with concentrations of Cl, Mg and S, and P with Cu and K but not with the remainder of elements in group 1. Si concentrations were correlated with those of Mg, Mn and S (Table 9).

Table 8. Summary of the mineral contents of the specimens used in the tests.

Mineral	Maximum value	Minimum value	Mean	Range
Calcium (%)	2.509	0.237	1.082	2.272
Chloride (%)	1.919	0.013	0.391	1.906
Potassium (%)	3.002	0.225	1.066	2.777
Magnesium (%)	0.383	0.082	0.192	0.301
Nitrogen (%)	2.818	0.482	1.314	2.336
Sodium (%)	0.382	0.004	0.081	0.378
Phosphorus	0.458	0.037	0.131	0.421
Sulphur (%)	0.67	0.087	0.174	0.583
Silicon (%)	1.537	0.017	0.12	1.52
Aluminum (ppm)	284	10	101.8	274
Copper (ppm)	19.3	0.1	5.7	19.2
Iron (ppm)	222.3	31.6	86.4	190.7
Manganese (ppm)	2948.6	36.8	516.4	2911.8
Zinc (ppm)	378.3	5	41.4	373.3
Total minerals (%)	10.245	1.952	4.626	8.293
Total minerals – silicon (%)	10.158	1.891	4.506	8.267
Total minerals – nitrogen (%)	8.184	1.224	3.312	6.960

Table 9. Correlation half matrix for the mineral contents of the specimens used.

	Al	Ca	Cl	Cu	Fe	K	Mg	Mn	N	Na	P	S	Si
Ca	-0.117												
Cl	-0.206	0.411											
Cu	0.017	0.396	0.620										
Fe	0.695	0.195	.0.138	0.325									
K	-0.130	0.521	0.762	0.685	0.296								
Mg	-0.130	0.397	0.481	0.443	0.196	0.393							
Mn	-0.104	0.266	-0.050	-0.027	-0.180	0.012	0.071						
N	-0.168	0.161	0.510	0.362	0.223	0.458	0.378	-0.077					
Na	-0.045	0.100	0.463	0.124	-0.131	0.194	0.441	-0.105	0.016				
P	-0.060	0.239	0.247	0.421	0.166	0.320	0.153	-0.163	0.135	-0.052			
S	-0.074	0.322	0.669	0.442	0.174	0.504	0.567	0.241	0.453	0.511	0.110		
Si	0.094	0.239	0.202	0.039	0.231	0.247	0.330	0.573	0.205	0.159	-0.102	0.632	
Zn	0.060	0.117	0.008	0.377	0.158	0.275	0.353	0.035	0.166	0.064	0.043	0.115	0.137

Total minerals (the sum of percentage compositions), nitrogen-free minerals and silicon-free minerals were strongly correlated with each other and with the group 1 elements ($P<0.001$). These three aggregate values were not correlated with Al, Mn or Zn. Of these three two were not correlated with P content but total mineral content was correlated with P content ($P<0.05$).

Filter papers, used as standards, had a naturally more circumscribed range of values than the 50 species of plants. Oven dry weight averaged 0.34g; diameter was designated as 7 cm by the manufacturer giving an average area (measured) of 37.7 cm^2; average thickness air dry was 0.171 mm and oven dry was 0.168 mm. Moisture content, air dry, averaged 6.4%.

Air temperatures in the furnace room for the fresh-specimen runs averaged 23.Oº C (s.e. = 1.8ºC) and oven-dry runs averaged 22.9ºC (s.e. = 2.6ºC). Metered furnace temperatures averaged 398.6 ºC (s.e. = 2.5ºC) for the fresh-specimen runs and 399.8 ºC for the dry (s.e. = 1.5ºC). [Standard errors, s.e., were calculated as the standard deviations of the means for each run.]

The average ignition delay times for each species, at 400ºC , varied from 11.6 to 57.1 sec. for fresh specimens (Table 3) and 3.2 to 36.9 sec for the same species as oven-dry material (Table 4). Air-dry filter papers ('fresh') had ignition delay times averaging 5.61 sec (s.e. = 0.44) and oven-dry times of 4.90 sec (s.e. = 0.60).

There were qualitative differences in behaviour of species in the muffle furnace. Some specimens remained passive on the cradle during heating whereas others rolled, curled or bowed. Some specimens jumped about, actions that were accompanied by the production of 'pops' and 'bangs' and sparks. Specimens of such species had to be restrained by holding them at the proximal end with long-handled forceps. Some specimens produced large volumes of smoke before ignition, others little. Some specimens charred and glowed but did not flame. The proportion of specimens that did ignite by flaming is shown in Table 10. The species with specimens showing poor ignition by flaming were retested at 500ºC (see later, below).

A graph of the ignition delay time when specimens were fresh against the ignition delay time when specimens were dry reveals the range of response and its distribution amongst the 50 species (Fig. 3). Three species were relatively quick to ignite when fresh but slow when dry (two *Hakea sp.* and *Podocarpus* - Group A) and 10 species fell into the category of slow to ignite whether fresh or dry (Group B). Two of the latter were mistletoes, two were *Hakea* spp. and two were Casuarinaceae. Most species fell into the category with short ignition delay times for both fresh and dry material (74%, Group C). Four species - including two *Myoporum* collections and *Anigozanthos* - were slow to ignite when fresh but quick when oven dry (Group D).

Specimens from Groups A and B species were moist when fresh and often had low surface area to volume ratios (Table 1). The two *Myoporum* collections and the *Anigozanthos* material in Group D had the highest water contents and the highest total mineral contents of all species sampled (Tables 1 and 7).

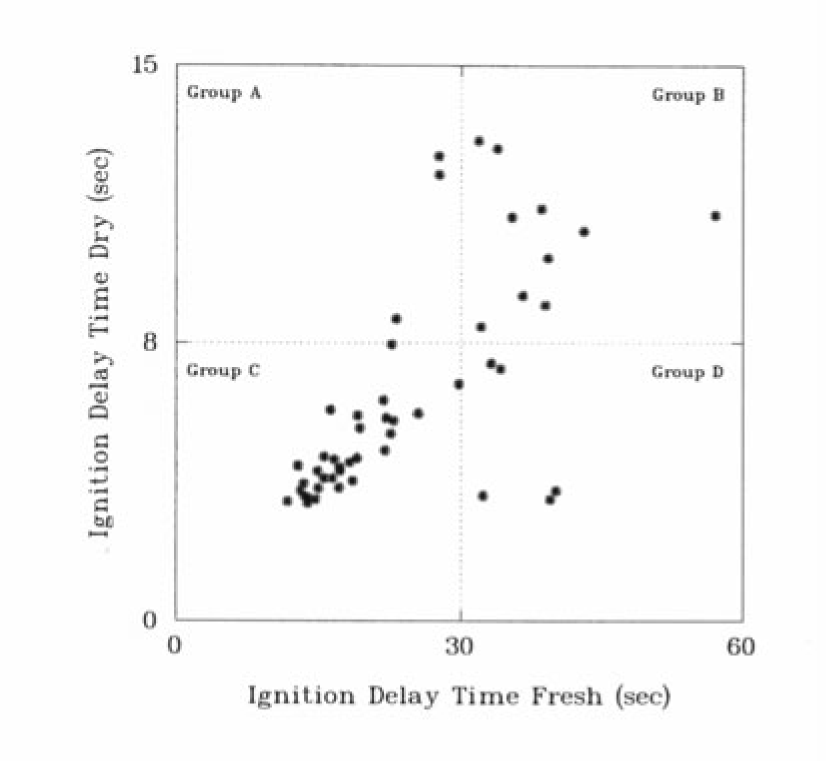

Figure 3. Average ignition delay times of specimens of all species when fresh and dry.

In our analyses of the data we tried a number of models seeking both a good fit and relative simplicity using independent variables. Firstly we examined the relationships for the dry materials then the fresh and finally the combined data set.

Hypothesizing that the oven-dry material would be most sensitive to mineral matter, we examined the data for any correlation between mineral contents and ignition delay time. All correlation coefficients of untransformed data between mineral contents and ignition delay time were negative - an unexpected result - and only four coefficients were statistically significant, viz. those for Al, Fe, Mg and N. Of these Mg gave the highest correlation coefficient ($r = -0.383$,.$P<0.01$). Contents of Al and Fe were correlated as were those of Mg and N (as above). Logging the mineral contents increased the statistical significance of the correlation coefficients a little (to near or less than $P = 0.01$ except for log [Al]). Logging values of mineral contents and those of ignition delay times also gave higher correlation coefficients than those found with untransformed data; the resulting regression using the transformed variables gave an r^2 value of 0.233.

Turning to the data for surface area to volume ratios in relation to ignition delay time we found a correlation coefficient of -0.594 ($P< 0.001$) for ignition delay and surface area to volume ratio. Using the logged data the correlation coefficient was -0.648 ($P<0.001$). The surface area to volume ratio, transformed or not, was related to the concentrations of Fe and Mg in the materials whether transformed or not (with highest probabilities equal to 0.001). Thus the mineral contents as variables were not independent of the surface area to volume ratio so considerations of minerals were held in abeyance at this point.

For the oven-dry specimens the average ignition delay times at 400ºC, y sec, were related to average surface area to volume ratio, x mm^{-1} by:

$y_f = 27.393 - X_d^{-0.766}$ [Equation 11

where the subscript refers to 'dry'. The relationship is shown in Fig.4 (r^2 =0.426, P<0.001).

For fresh material moisture content and total mineral content were highly correlated (P < 0. 001). Because of this, and the relationship of the mineral content of dry material to surface area to volume ratio (see above), mineral contents were not considered further.

Curves were fitted to the average ignition delay times at 400 ºC, y sec, versus average surface area to volume ratio, x mm^{-1}, and moisture content, w percent. oven-dry weight, for the fresh specimens:

$y_f = (340.2 + w)(0.194x_f^{-0.802})$ [Equation 2]

where the subscript refers to 'fresh' ($r^2 = 0.754$). Linking the two data sets gives:

$y = (111.3 + w)(0.375x^{-0.850})$ [Equation 3]

$r^2 = 0.831$

Fig. 4 shows the observed versus expected results. The apparent outliers toward the top of the graph are for *Anigozanthos* and one of the *Myoporum* collections.

Repeating the above process using the ratios of average ignition delay time for the specimens over the average ignition delay time for the filter papers during the same run standardizes the ignition delay times according to conditions at the times of the experiments. The analysis explained slightly less of the variation than equation 3.

Specimens exposed at 500ºC

The ignition rates for specimens of some species were particularly low at 400ºC, especially *Geijera parviflora* at 0% (Table 10), so a further collection of specimens of these species were exposed to furnace temperatures of 500ºC. Confirmed was the low rate of ignition of specimens of fresh *Geijera parviflora.*

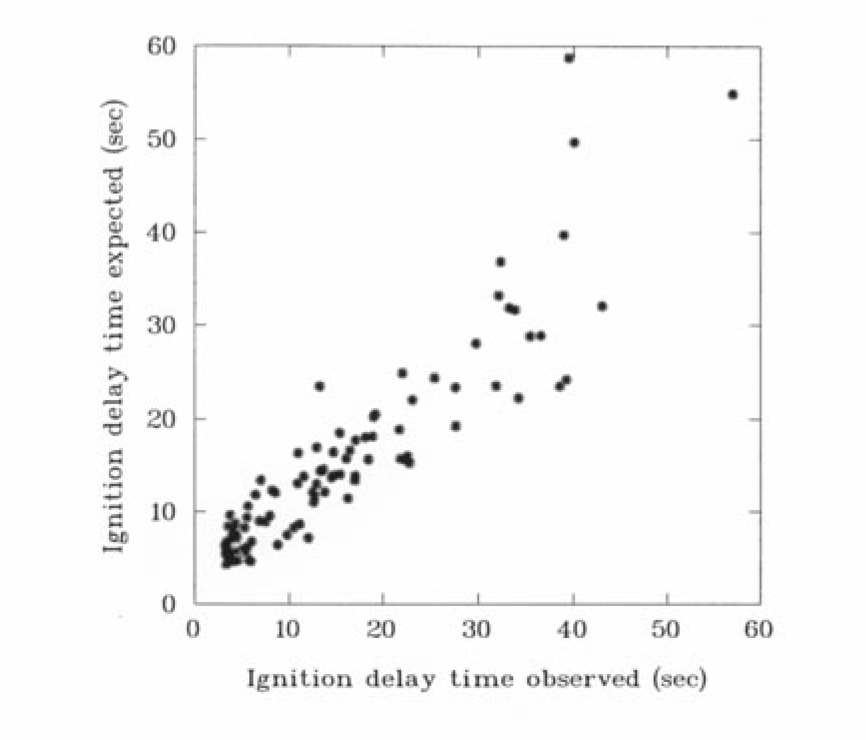

Figure 4. The ignition delay time as predicted from equation (3) as a function of the observed ignition delay time.

Surprisingly, rates of ignition of oven-dry specimens of *Amyema cambagei* were lower than fresh specimens at both temperatures. Rates of ignition of all specimens of the other three species were high at the higher temperature. There was no species that was not ignitable.

Discussion

The method used in this study was found to be very satisfactory. The choice of 400 ºC for the temperature and the use of a spark gun for ignition represented a compromise. If the temperature chosen was too high then there would have been little discrimination between times. If the temperature was too low then no ignition would have occurred. Through the use of the pilot (the spark from the spark-gun) a relatively low temperature could be used - to achieve discrimination - while still achieving ignition.

Table 10. Percentage of specimens fresh or oven-dry igniting at the designated temperatures (n= 10).

Family	Genus	Species	Fresh @ 400ºC	Oven dry @ 400ºC	Fresh @ 500ºC	Oven dry @ 500ºC
Asteraceae	Olearia	argophylla	100	100		
Casuarinaceae	Allocasuarina	distyla	100	60		
Casuarinaceae	Casuarina	glauca	40	90	100	100
Euphorbiaceae	Beyeria	viscosa	90	80		
Fabaceae	Bossiaea	scolopendria	100	100		
Fabaceae	Daviesia	arborea	100	100		
Haemodoraceae	Anigozanthos	flavidus	70	100		
Loranthaceae	Amyema	cambagei	80	10	100	50
Loranthaceae	Amyema	miquelii	100	100		
Mimosaceae	Acacia	implexa	100	100		
Mimosaceae	Acacia	melanoxylon	90	100		
Mimosaceae	Acacia	podalyrifolia	100	100		
Myoporaceae	Myoporum	acuminata 1	50	100	90	100
Myoporaceae	Myoporum	acuminata 11	70	100		
Myrtaceae	Acmena	smithii	100	100		
Myrtaceae	Angophora	costata	100	100		
Myrtaceae	Callistemon	citrinus	90	100		
Myrtaceae	Callistemon	sp.	100	100		
Myrtaceae	Eucalyptus	cinerea	100	100		
Myrtaceae	Eucalyptus	dives	100	100		
Myrtaceae	Eucalyptus	elata	100	100		
Myrtaceae	Eucalyptus	grasbyi	100	100		
Myrtaceae	Eucalyptus	grossa	100	100		
Myrtaceae	Eucalyptus	mannifera	100	100		
Myrtaceae	Eucalyptus	neglecta	100	100		
Myrtaccae	Eucalyptus	parramattensis	100	100		
Myrtaceae	Eucalyptus	serraensis	100	100		
Myrtaceae	Eucalyptus	sideroxylon	100	100		
Pittosporaceae	Pittosporum	undulatum	100	100		
Podocarpaceae	Podocarpus	elatus	100	100		
Proteaceae	Banksia	paludosa	100	100		
Proteaceae	Grevillea	shirlessii	100	100		
Proteaceae	Hakea	cristata	90	90		
Proteaceae	Hakea	macreana	90	80		
Proteaceae	Hakea	multilineata	90	100		
Proteaceae	Hakea	petiolaris	100	100		
Proteaceae	Hakea	salicifolia	100	100		
Proteaceae	Lomatia	arborescens	100	100		
Proteaceae	Persoonia	levis	100	100		
Proteaceae	Telopea	sp. (hybrid)	100	100		
Rhamnaceae	Pomaderris	apetala	100	100		
Rutaceae	Asterolasia	hexapetala	70	100		
Rutaceae	Correa	lawrenciana	90	70		
Rutaceae	Eriostemon	myoporoides	20	100	100	100
Rutaceae	Geijera	parviflora	0	100	40	100
Sapindaceae	Dodonaea	viscosa	100	100		
Sterculiaceae	Brachychiton	populneus	70	100		
Sterculiaceae	Lasiopetalum	macrophyllum	100	100		
Winteraceae	Tasmannia	insipida	100	100		
Xanthorrhoeacae	Lomandra	longifolia	80	80		

Although the range in the range of values of the explanatory variables was large the only statistically significant variables used in the analysis were moisture content and surface area to volume ratio. While these variables are important components of the structure of those models of fire spread in the field using generalized fuel models (Rothermel 1972) there seems to have been no previous laboratory study of ignition delay time in relation to these variables together.

Ascertaining the reasons for the results obtained is obfuscated by intercorrelations between potential explanatory variables. There were intercorrelations between the dimensions of the specimens and there were correlations between specimen dimensions and element concentrations.

Montgomery and Cheo (1971) found a semi-logarithmic relationship between ignition delay time and surface area to volume ratio for 32 species tested in North America (including one Australian species) but we found that the power function model gave an appropriate fit to our data. Trabaud (1976) found a hyperbolic relationship between ignition delay time and moisture content while our results were statistically significant using a linear relationship. If there was no inhibition of water loss associated with the anatomy of different specimens then a linear relationship would be expected given exposure to an environment of constant temperature. Details of methods used and the types of specimens sampled (shoots or leaves for example) are likely to affect the nature of the relationships obtained.

Some specimens of some species in our experiments did not ignite at 400 °C on all occasions. Most specimens of these species ignited at 500 °C. Of particular interest were specimens of *Amyema cambagei* which showed a greater frequency of ignition when fresh rather than when oven dry. This phenomenon was evident at both the higher and lower furnace temperatures. We have no explanation for this. It is a phenomenon worthy of further study.

The *Myoporum* species which have very thick moist leaves when fresh were slow to ignite but readily ignited when dry. Dry leaves were relatively thin. This suggests that litter of these plants may be relatively easy to ignite while the canopy remains difficult to ignite. This observation is important in relation to a choice of low flammability species because it is the litter that is more likely to ignite first and carry the fire. The ideal difficult-to-ignite species would have litter that was hard to ignite (and easily decomposed and light) as well as having foliage that was hard to ignite when fresh.

Conspicuous among the slowest specimens to ignite both in a fresh state and when oven dry (Fig. 3) were species of *Hakea,* Casuarinaceae *(Casuarina* and *Allocasuarina)* and *Amyema.* The *Hakea spp.* in this category had relatively low moisture contents while the Casuarinaceae and *Amyema* spp. had relatively high moisture contents (Table 1). The surface area to volume ratios of all of these species were relatively low (Tables 1 and 2).

Using only surface area to volume ratio and moisture content as explanatory variables explained over 80% of the variance in ignition delay time. Increasing moisture increased ignition delay time while increasing the surface area to volume ratio decreased it. Higher mineral contents tended to decrease ignition delay time, surprisingly (cf. Broido and Nelson 1964). We did not set out to test whether or not volatile oils affected ignition delay time but note that Mutch (1964) found that volatiles reduced the ignition delay time when samples were exposed in a furnace with a pilot but not at all when samples were allowed to ignite spontaneously.

Conclusion

High moisture contents of 'leaves' and low surface area to volume ratios increased the ignition delay time when specimens were placed in a muffle furnace with a pilot ignition source. The relationships between these three variables can be described mathematically in a statistically significant way. The high percentage of the variance that is described suggests that the mathematical relationships can be used to predict ignition delay time of non-tested materials within the data-domains of the present study.

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5. GENERAL DISCUSSION AND RECOMMENDATIONS

Recommendations for plantings in fire-prone areas

There are numerous lists of 'recommended' species for plantings (e.g. Bellamy, 1993, documents 17 lists) but there is little scientific evidence to support the choices. The research reported here, and that referenced, provides evidence for the sorts of leaves that are desirable but does not take into account the many other factors that are relevant from a plant point of view (Chapter 3). For determining leaf flammability, we recommend the use of piloted ignition of single-leaf samples in the muffle furnace at 400ºC as a screening technique but for other plant parts qualitative guidelines can be given, e.g. avoid the use of plants which support large proportions of dead leaves (e.g. *Xanthorrhoea spp.* and some *Dryandra* spp.), dead twigs (e.g. some *Melaleuca spp.),* dead bark (e.g. some *Melaleuca* spp. and many *Eucalyptus* spp.) or produce copious quantities of litter in the local fire season (e.g. pines often shed dead needles in the autumn and winter; deciduous trees in southern Australia shed leaves in autumn but they remain as litter until spring and eucalypts usually shed leaves in summer in temperate areas). This guideline can then be qualified by saying that maintenance can reduce these negative attributes of plants growing in fire-prone areas. Simply removing dead materials will reduce the risk of ignition.

We suggest as an area for further work that an hierchical approach be used to the categorizing of plant flammability, building on the work of Rudolph (1993b). Rudolph summed the number of attributes (maximum of 14) that increased flammability (as opposed to those that decreased it or had no affect). In the following key, the presence or absence of certain properties is recognized as affecting others (further down in the key). The score is prematurely ended if flames cannot reach the canopy for example. We do not claim that the key is comprehensive. Rather it is a step towards a flexible, plant-based (not species-based) system that allows for seasonal, yearly and life-stage variation with or without management effects.

Towards a flammability score

The higher the score in the key below the more flammable is the plant considered to be. Note that there are caveats on this system as mentioned above. The system is crude and not very explicit at this point but illustrates the idea. It is perhaps obvious that more work needs to be done. The system would assign a value of zero or one for each attribute but this assignation could be backed by quantitative assessments. The attributes we consider here (sometimes indirectly) are: fuel load beneath the plant (litter, organic mulch, other plants), the nature of the bark on the plant (flammable or not), the height of the base of the crown of the plant (from zero in short plants to many metres for some trees), canopy presence or absence, amount of dead material in the crown of the plant, and thickness of the finest parts of the crown (leaves, phyllodes etc.) - converted to surface-area-to volume ratio - and live moisture content of the finest materials of the crown (the last two being considered together).

Key:

(1) If fuel is continuous to the plant in question from the main source of fires (e.g. adjacent bushland) then score one point and go to (2). If fuel otherwise do not score a point and go to (2).

(2) If bark present and flammable add one point and go to (3). If bark not present or nonflammable then do not increase the flammability score and move on to (3).

(3) If there is continuity of fuel from the surface to the crown of the plant in question add one point to the score and go to (4). [Note that this increase can be due to the plant being herbaceous or a short shrub. If there is a lot of litter beneath the plant then the potential flame height can be great and flames could reach the canopy even if it was at a substantial height above the ground; a look-up table could be used to declare '.continuity' according to surface fuel loading and height of the crown base.] If there is no continuity (flames cannot reach the canopy of the plant) do not add to score and end count here.

(4) If a canopy is present and has substantial dead material (e.g. a cypress hedge, a long-unburnt *Xanthorrhoea* crown) add one point to the score and go to (6). If a canopy has little or no dead material (e.g. because it is deciduous and lost its leaves or is all green) do not add to the score and go to (5).

(5) If the canopy is absent (e.g. deciduous and lost its leaves or a cactus) or sparse do not add to score and end count. If a canopy is present do not add to the score and go to (6).

(6) If the ignitibility of 'leaves' is high (see Chapter 4) then add one to score and end count. If ignitibility is low then do not add to the score and end the count.

Thus the plant can receive a score up to 5 - its flammability rating. Again, we stress the tentative nature of this key and point out the vagueness of its definitions.

Recommendations of what species to plant are often made with little or no guidance to allow the user to determine its suitability for their area. Thus, a recommended species from a low flammability point of view, such as *Nerium oleander* (Oleander) (e.g. Bellamy 1993), may have attributes which are undesirable (e.g. Oleander may produce toxic smoke if burned (or be toxic if ingested) - Pearn 1987). Deciduous species could be problem species for carrying fires in some areas if the fire season coincided with the time that canopy-litter is on the ground and new canopies had not been restored (e.g. along the coast of New South Wales). Apart from these possible problems with recommended species there may be a need for other forms of guidance also. Because many species used in horticulture can be environmental weeds the user of lists of recommended species may inadvertently choose an environmental weed when choosing a 'less-flammable' species to plant. Examples of plants in this category are the Privets *(Ligustrum spp.)* (Ministry for Planning and Environment 1983, Francis and Tegart 1989), *Pittosporum* spp. (Ministry for Planning and Environment 1983, Bellamy 1993), Cootamundra Wattle (*Acacia baileyana*) (Francis and Tegart 1989, Bellamy 1993, SGAP 1995) and *Cotoneaster* sp. (Bellamy 1993). Other features of plants in lists of recommended species that may be worthy of note are: whether native or introduced (e.g. Francis and Tegart 1989) or all native (e.g. SGAP 1995); and, whether or not they pose a health problem. In the last respect are species recommended for planting in fire-prone areas, such as Ivy (*Hedera helix* - Francis and Tegart 1989 which may cause contact dermatitis -Dowling and Kleinschmidt 1987), or other health problems such as asthma (Bass undated).

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