

FIRE SECTIONQuarterly Report

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Temperature Measurements in Control Burning

A new method of reducing the destructive effects of bush fires is to burn the bush in spring and autumn: this reduces fuel concentrations and thus prevents dangerous fires from getting out of control in summer when they can cause great damage and loss of life. Ideally the "control" fires are mild and do not harm forest trees: therefore the method is most worthwhile, if it can be carried out inexpensively in a well organised fashion.

After the disastrous fires of 1961 the W.A. Forests Dept. has carried out such "area burning" on a large scale, and they aim to treat 10^6 acres each year as a result of their new policy of hazard reduction. Total costs are small (of the order of 4d per acre) and they have developed methods of burning large areas with a minimum of effort in a very short time. Inevitably there are people critical of this approach: they argue that even small fires must damage forest trees in some way, that the soil is harmed and erosion promoted, and that insect attack is more likely when the trees are injured by fire.

The experiments of the West Australians provided us with unique opportunities for measuring cambium temperatures under both fierce and mild fire conditions. This information is vital if sensible conclusions are to be reached regarding the deleterious effects of control burning upon forests. Final conclusions can be drawn only after growth measurements on the selected trees, and other general observations, have been made over a period of years: nevertheless it is evident from our present measurements that the temperature rise at the cambium is surprisingly small under

representative conditions of spring burning. Full details of all measurements are given below.

Techniques

Sheathed thermocouples were used to prevent tree o.m.f.'s being picked up. The couples were from Pyrotenax (.062" stainless steel sheath) and were sufficiently long to extend well away from the selected trees. Connection was made to an asbestos covered copper cable through a small junction box which was buried 1 ft below the forest floor: the cold junction temperature was measured with a mercury/glass thermometer and did not change appreciably even after a severe fire had passed over the box. With the most severe fires it was necessary to bury each thermocouple sheath a few inches below the soil surface, and to cover it with asbestos tape where it was exposed on the tree trunk: in this way it was possible to prevent the couples from being damaged.

Cambium (and soil) temperatures were measured on a Philips 12 point recorder, set up on a truck away from the fire. This was equipped with selector switches etc. and was powered by a portable 220V ac unit.

The thermocouples were placed in the trees as follows:-

A bark gauge was used to measure bark thickness at the appropriate spot, and a hole was then drilled through the tree with a series of metal drills (diam. 0.090" to provide easy clearance for the thermocouples). A thin wooden plug (equal in length to the bark thickness as measured above) was introduced to the hole and the couple was pushed in from the other side of the tree until it touched the plug: in this way the exact location of the couple at the cambium was assured. The couple was then bent over and tacked in place so that it could not move.

Results

Measurements were carried out on Pinaster pines which are reasonably fire sensitive. The season was early spring (September) after prolonged rain, so that the sandy soil in the plantation was very wet.

In consequence the burns were mild, but the conditions were representative of those considered necessary for burning under pines.

Later in the spring season (at the end of November) measurements were repeated on Jarrah which is a most fire resistant eucalypt. The weather was hot and dry and in most cases the trees had been intentionally surrounded by heavy piles of dead saplings and dried leaves, roughly 3 ft high and twelve feet in diameter. The trees were thus subjected to intense heat over extended periods of time.

During the mild pine burns cambium temperatures were rarely above 40°C , and in the jarrah, where the trees have a thick layer of dry bark around them, the corresponding temperature rise was even less. In these circumstances it seems likely that little damage results from burning — at least as far as direct temperature effects are concerned.

In the hot jarrah burns with exceptionally heavy fuel, the temperature rise at the cambium was greater and depended upon bark thickness. In general:- With $\frac{3}{4}$ " bark, the temperature was $<55^{\circ}\text{C}$: rising to about 60°C with bark $\sim\frac{1}{2}$ " thick. With bark $<\frac{1}{4}$ " thick, temperatures of $65-75^{\circ}\text{C}$ were obtained, and with thinner bark still, the temperatures were even higher.

In these extreme conditions the smaller trees might well be damaged.

Detailed Results for Pine Burns

21-9-64

First burn. Soil temps ($< \frac{1}{2}$ " below sand surface) rose no more than 15°C above ground temperature.

22-9-64

Third burn. The equipment misbehaved but cambium temperature of different trees rose no more than a few degrees. The soil temperature (below wet duff) similarly rose no more than a few degrees C.

23-9-64

Burn 4. [Cambium temp. rises to $\sim 40^{\circ}\text{C}$ a few minutes after flames have passed.]

Tree 2. Thermocouples in E side (bark $1\frac{1}{2}$ cm thick) and W side (bark 1 cm), both ~ 1 ft from ground. Flames lasted $\frac{1}{4}$ min going to max. height of 3 to 4 ft. W side rose $\sim 10^{\circ}\text{C}$ just after flames ceased, and E side rose the same amount some 3 min later, with a further small rise some minutes after that.

Tree 3. This tree had fairly dense fuel around it, but did not burn well, even so. Flames were 3 ft high (max.) and burnt for 3 min. W side temp. rose above 40°C very quickly and then to a max. of $\sim 50^{\circ}\text{C}$ (wooden plug possibly had crack in it): bark was $\frac{1}{4}$ cm thick and couple 10" above ground. The E side was protected by grass, and temp. did not rise greatly.

Tree 4. Couples on E and W side were 1 ft above ground and bark was 1 cm thick. Two foot flames were around tree for about $2\frac{1}{2}$ min. On W side temperature rose to 35°C 5 min after flames had passed, and E side behaved in same way 1 minute later.

Tree 1. Couple on W side 15" from ground (bark 1 cm thick), and there was a lot of resin about hole which burnt thoroughly for ~ 5 sec. Flames were ~ 2 ft. in height and burnt for 4 min. Temp. rose to $< 35^{\circ}\text{C}$ shortly after flames had passed.

In a subsequent test with fuel piled about the same tree, 3 ft. flames persisted for 3 min. The temp. rose to $< 45^{\circ}\text{C}$ when flames were on the tree.

Duff Temperature. A couple was placed in the thick pine litter $\sim \frac{1}{2}$ inch above the wet sand surface. The temp. rose to $> 400^{\circ}\text{C}$, and remained in the region of 100°C for ~ 4 min.

24-2-64

Burn 8 (Packham's experiment of heat profile with felled tree). Very hot conditions: thermocouples introduced from top of stump.

Cambium temperature (2 ft. from ground, bark $1\frac{1}{2}$ cm thick) rose to 37°C ; temperature within thick dry bark roughly 1 cm away was as high as 47°C — achieved about 3 min earlier. The air temperature 25" above the ground was not much greater than 150°C , even though equipment was immersed in flames.

Water Effect. In this experiment a peculiar effect was noted for the first time. More particularly when the temperature rise at the cambium is large, water seems to be moved within the living bark so that a sudden cooling is achieved. Whether this is a positive response on the part of the tree is not clear: it may be only a side effect associated with damage to the tree cells. The effect was noticed quite often, with both pine and jarrah burns.

Typical moisture contents:

- a Outer dry bark $\sim 25\%$ of dry weight.
- b Inner dry bark $> 50\%$.
- c Living bark 250-300%.

Burn 7. (Hotter burn than No. 4). Two trees with thicker bark did not rise in temp. above 40°C ; but small tree with thin bark had cambium rise to $\sim 65^{\circ}\text{C}$. Good water effects (see above) were observed with all trees, but especially the small one.

Tree 1. Couples on E and W side 1 ft from ground (bark 1 cm thick). Flames lasted 3 min. with max. height of 4 ft. Temp. rose after flames had passed, rising to a max. of $\sim 40^{\circ}\text{C}$, approx. 5 min. later.

Tree 2. Couples on E and W side 1-1½ ft from ground (bark ¾ cm thick). Same results as for Tree 1: flames were initially 4 ft high, but mainly at the 2-3 ft level.

Tree 3. Couples on E and W side 1 ft from ground. (A small tree with bark only ¼ cm thick). Flames were 3 ft high and lasted 5 min (duff at base of tree). On W side temp. rose to ~ 65°C (max.) immediately flame had passed, and temp. remained high for further 10 min. On E side temp. rose (while flames were still burning) to 55°C max. and remained high for 10 min.

Soil temperatures. Two couples were placed ½ cm below sand surface near tree 1, and an extra amount of fuel was thrown over duff. As flames passed over the couples temp rose by no more than 10°C. Just after the flames had gone the couples were removed to the hot surface: under a thin layer of hot duff, temp. was ~ 500°C immediately above the sand surface, and in a thick pile of glowing duff ~~was~~ the temp. rose to 700°C.

25-9-64

Burn 9. This burn gave excellent traces for both tree and ground temperatures. The flames approached trees 1 and 2 from the East, and in both cases the cambium temperatures were higher on the E side than on the W side - 10°C hotter for tree 1 and 15°C hotter for tree 2. The E side temps were just > 35°C for Tree 1, and just < 45°C for Tree 2: these max. temps were achieved immediately after flames had passed.

Ground temperatures were as follows (the ground temp, as given at cold junction being 15°C):-

- a 45°C, below a layer of wet duff not completely consumed.
- b 20°C, just below sand surface, when thin pile of duff above had been completely burnt.
- c 65°C, ½" below sand surface which was strongly heated by a large pile of well burnt duff.

Burn 9A. Peckham's air temp. measurements showed only slight temp. rise, even directly above hot fire.

Conclusions

Cambium temperatures, under these spring burning conditions, rarely rise above 40°C, and it would be surprising if the pines were damaged greatly except in special circumstances. The rise in ground temperature, even close to the surface, is generally small, and pine feeder roots are not likely to be affected.

Detailed Results for Jarrah Burns

10-11-64

Burn 1. Plot 21. ↑ Ground (cold junction) temps were 20°C at base in all these measurements.]

Tree 3. > 1 ft diam. Bark on E side $\frac{1}{2}$ in thick.

Bark on W side < $\frac{1}{2}$ in thick.

Couples about 2 ft from ground: flames were 20 ft high (max) for about 1 min and were very hot for ~5 min altogether. Cambium temp began to rise as flames were dying.

W side rose at ~3°C/min to max of 67°C after 22 min.

E side " " 2°C/min for 16 min, to max of 53°C after 19 min.

Both couples fell at 0.2°C/min. —

E side to 50°C after $\frac{1}{4}$ hr: and then to 30°C after $1\frac{1}{2}$ hr.

W side " 62 $\frac{1}{2}$ °C " " " " " 40°C " " "

Tree 2. Only 9 ins diam. Bark on E side $\frac{3}{4}$ " thick.

" " W " $\frac{1}{4}$ " "

Couples 2 $\frac{1}{2}$ ft from ground. Flames (20 ft high max.) persisted at lower levels for 4-5 mins. Cambium temp. began to rise as flames were playing on tree.

W side rose at 25°C/min for 3 min to 95°C (max) after 5 min. After further 3 min it dropped suddenly to 82°C, * rose again, and fell at $\frac{2}{3}$ °/min to 63° after $\frac{1}{4}$ hr. (32 $\frac{1}{2}$ °C after $1\frac{1}{2}$ hrs).

E side rose at 6°C/min for 7 min to 68°C (max) after 18 min: then fell to 60°C at $\frac{1}{4}$ hr, and 45°C at $1\frac{1}{2}$ hrs.

Tree 4. (Burn was a bit hotter than previous ones).

15 ins diameter. Bark on E side < $\frac{1}{2}$ in thick.

" " W " > $\frac{1}{2}$ in thick.

Couples 3 ft from ground: flames 20-30 ft high (max.) soon burnt down and continued at lower levels for 5 mins. Temp began to rise as flames were on tree.

* Possible water effects (see earlier).

E side rose at $12\frac{1}{2}^{\circ}/\text{min}$ for 4 min to 75°C (max) after 7 min — and gave sudden drop* like W side of Tree 2.

W side rose at $4^{\circ}/\text{min}$ for 8 min: then slowly to 50°C after 20 min.

Both couples fell to 46°C after 1 hr.

Soil temps close to fuel pile.

a 1" down: rose 15°C in 10 min (2 min after flames overhead) then fell $2\frac{1}{2}^{\circ}\text{C}$ in next hour.

b 1 $\frac{1}{2}$ " down: rose slowly 8 mins after flames overhead. Rise was 17° after $\frac{1}{2}$ hr and continued to 20° after 1 hr.

Burn 2 plot 22.

Tree 4. >15 ins diameter. Bark on E side $>\frac{1}{4}$ " thick.

" " W " $\frac{3}{4}$ " "

Couples were ~ 3 ft above ground: flames were > 30 ft. high after 1 min, 20 ft high at 2 min and were dying down after 5 min. At 7 min only glowing embers on ground were left. Cambium temp did not rise until after 8 mins had elapsed.

W side rose at $3^{\circ}/\text{min}$ for ten min, to $\sim 53^{\circ}\text{C}$ (max) after 20 min.

E side rose at $3^{\circ}/\text{min}$ for 10 min: then slowly to 50°C after 25 min.

19-11-64

Burn 2A. Packham's tests with cut down tree, with thermocouples introduced from top of stump. Strong wind had cooling effect. Tree was little more than 9 ins diam where couples were placed — ~ 4 ft from ground: flame height was not large and flames persisted for less than 5 min. Bark was $\frac{1}{4}$ " thick on S side and $>\frac{1}{2}$ in. on E side: (even though tree was small, bark was not consumed by small flames as much as in other burns).

S side

Couple 1 was in dead bark and rose to 120°C in $3\frac{1}{2}$ min, falling to 50°C at 35 min.

Couple 2 was in living bark and rose to 55°C in $3\frac{1}{2}$ min. then to 57°C (max) at 12 min: it fell to 47°C at 35 min.

* Possible water effects (see earlier).

Couple 3 was at cambium and did not start to rise till flames had virtually gone. Temp. reached 45°C after 21 min and then fell slowly to 43°C at 35 min.

E side.

Couple 4 — in dead bark — [flames blown away from E side of tree] started to rise at 2 min, reached 55° at 6 min, and fell to 43°C at 35 min.

Couple 5 — in living bark — started to rise at $3\frac{1}{2}$ min, reached 43°C at 7 min and fell to 40°C at 35 min.

Couple 6 — at cambium — started to rise at $4\frac{1}{2}$ min, reached $32\frac{1}{2}^{\circ}\text{C}$ at 10 min and continued to 38°C at 35 min.

Burn 2B Very hot burn, again with cut down tree.

Tree 1 ft diam. with couples 4 ft from ground. Flames were almost 40 ft high after 1 min and continued at 15 ft after 2 min: they persisted for 5 min.

N side. Couple 1 was placed at interface between dead and living bark. It rose to 95°C after 5 mins and fell to 60°C after 35 min. Couple 2 was in living bark $\frac{1}{8}$ " from cambium. It rose to 65°C after $6\frac{1}{2}$ min and fell to 55°C at 35 min. Total bark thickness was $\frac{3}{4}$ in after flames had gone.

S side. Couple 3 was located in same way as Couple 2 (above): it rose to 70°C at minute five, and then fell exactly as couple 2.

Couple 4 was in outer bark: it went to 200°C after almost 1 min and then jumped out, rising to beyond 600°C .

Total bark thickness was just less than $\frac{3}{4}$ " at end of test.

20-11-64

Burn 3. Plot 23. (Apparent flame temp measured as $900-950^{\circ}\text{C}$)

Tree 1. < 1 ft diam: termites were in this tree.

E side (couple 2 ft from ground) bark $\frac{1}{8}$ " thick.

W side (" 3 " " ") " $>\frac{1}{8}$ " "

Flames were 20 ft high after 1 min and continued for further minute — then 10 ft flames for 2 minutes, and small flames for another 2-3 mins. Cambium temp began to rise after 2 min. E side went to 45°C at 15 min and then slowly to max of 52°C at 26 min. Final temp 60°C after 40 min. W side rose more quickly to 52°C at 14 min and max of 60°C at 20 min. Final temp 50°C after 40 min.

Tree 2 and Tree 4 were grouped together in a large combined "birdsnest."

Couples were 2 ft from ground. Flames were 25 ft high after 1 min and continued at 20 ft for further $1\frac{1}{2}$ min; flames died at 3 min and were quite gentle at 6 min except on Tree 2.

Tree 2. W side: thermocouple in living bark $< \frac{1}{4}$ " from burning surface. Began to rise after $\frac{1}{2}$ min reaching 125°C at 4 min. At 7 min it rose to 145°C and fell rapidly to 120°C in $\frac{1}{2}$ min (water effect?). There it stayed for $1\frac{1}{2}$ min, then fell steadily to 75° at 20 min and 60° at 40 min.

Tree 4. E side. bark $\frac{3}{4}$ " thick. Temp began to rise as flames were dying and reached 45°C after $\frac{1}{4}$ hr continuing to a max of 52°C after 40 min. W side bark $> \frac{1}{2}$ " thick. Temp rose while flames still at their height and reached 45°C after $\frac{1}{4}$ hr. Max temp was 50°C at 27 min, ending at 46°C after 40 min. (Very similar to E side behaviour).

23-11-64

Burn 4 Plot 5.

Tree 5. < 9 ins. diam: Couples 2 ft from ground. After burn mild flames continued for long period to ~ 10 min.

N side bark $< \frac{1}{2}$ " thick. Temp started rising after 3 min, rose to 45°C at $\frac{1}{4}$ hr and a max of 55°C at $\frac{1}{2}$ hr: fell to 45°C at 65 min.

S side bark $> \frac{1}{4}$ " thick. Temp rose after 2 min, to 45° at 7 min. Was at 68°C (max) after 20 min, and fell to 50°C at $\frac{1}{2}$ hr.

Soil temperatures immediately beneath "birdsnest" pile.

S side. Couple 1 was 1" below soil surface. Started rising at 7 min and went to 70°C at 35 min. At 40 min temp was 80°C (max), falling to 68°C at 65 min.

Couple 2 was immediately under No. 1, $2\frac{1}{2}$ " beneath soil surface. Started to rise at 15 min and went to 45°C at 65 min.

N side. Couple 3 was 1" below surface. Started rising at 3 min and continued linearly to 58°C at 10 min. At 30 min temp was 80°C (max) falling to 68°C at 65 min — i.e. very similar behaviour to couple 1.

Couple 4, placed beneath No. 3, rose in same way as No. 2, but then became exposed.

Burn 5 Plot 29.

This was only burn without birdnests around trees. It was a typical spring control fire, though a certain amount of fuel was placed at the tree bases to ensure hot flames. The couples were 1 ft from the ground, or less.

Tree 4. > 9 ins diam: Bark on E side $\frac{1}{2}$ " thick.

" " S " < $\frac{1}{2}$ " thick.

Flames as they passed were 2 ft high after $\frac{1}{2}$ min, and 3 ft after 1 min. Flames continued hot until they died after 3 min.

E side Temp rose to $27\frac{1}{2}^{\circ}\text{C}$ (max) at $\frac{1}{2}$ hr. and cooled only 2° in further $\frac{1}{2}$ hr.

S side Temp rose to 25°C (max) otherwise identical.

Tree 5. 9 ins diam or less: Bark on N side < $\frac{1}{2}$ " thick

" " S " $\frac{1}{2}$ " "

This was a hotter burn. There were 2-3 ft flames for 2 min, but these had died by $3\frac{1}{2}$ min.

N side Temp began to rise very slowly after 2 min, reaching 37°C in 10 min: maximum of 40°C at 15 min and 35°C after $\frac{1}{2}$ hr.

S side Temp rose to 35°C (max) in 10 min, and fell to 34°C after $\frac{1}{2}$ hr.

Soil temperatures. Couples were both < 1" below soil surface in an open position and small piles of litter were placed immediately above them: they burned fiercely for 2-3 min leaving hot ash.

Couple 1. Temp began to rise after 2 mins, rose to 34°C (max) at 10 min and cooled to 29°C after ½ hr.

Couple 2. Began to rise after 2 min reaching 37°C at 10 min and 40°C (max) after ¼ hr: fell to 33°C after ½ hr.

Summary for Spring Conditions

a. Typical moisture content measurements for the jarrah showed:-

	Wt.	Oven dry wt.	MC
Dead bark	24.63 gm	18.78 gm	31.1%
Live bark	53.06	18.87	182.2%

b. Soil temperatures more than a few inches below the surface were scarcely affected. One inch below the surface with a mild burn, and 2½ inches below the surface with an intense burn, the temp. rose ^{to} not much more than 40°C.

c. With typical burning conditions cambium temperatures of less than 40°C are to be expected even in stands of small jarrah.

d. Max cambium temperatures and related bark thicknesses, for the birdenest experiments, were as follows:-

	Tree	Bark Thickness (ins.)	Max. Cambium Temp. °C
Burn 1	3 W	< ¼	67
	E	¼	53
	2 W	¼	95
	E	> ¼	68
	4 W	> ¼	50
	E	< ¼	75
Burn 2	4 W	¾	53
	E	> ¼	58
Burn 2B	S	< ¾	70 (not cambium
	N	¾	65 (but "living bark" temps.

	Tree	Bark Thickness (ins.)	Max. Cambium Temp. °C
Burn 2A (Cooler burn)	E	$> \frac{1}{4}$	40
	S	$\frac{1}{4}$	45
Burn 3	1 W	$> \frac{1}{4}$	60
	E	$\frac{1}{4}$	62
	4 W	$> \frac{1}{4}$	50
	E	$\frac{1}{4}$	52
Burn 4	5 N	$< \frac{1}{4}$	55
	S	$> \frac{1}{4}$	68