1. FIRE BEHAVIOUR IN PINE PLANTATIONS IN SEVERE FIRE WEATHER CONDITIONS.

The literature of fire behaviour in pine plantations in severe weather conditions is comparatively sparse. Accordingly, brief case histories of some representative fires which have occurred in South Australia since 1958 have been prepared so that some specific points can be illustrated. All the fires described occurred in fairly similar weather conditions, but varying plantation ages, site qualities and thinning stages, coupled with varying levels of success as regards suppression action, resulted in fires of different size. They are summarised as follows:

No	Place/date		Plantation area burnt
1	Wandilo	5/4/58	320 ha
2	Glencoe	2/4/66	40 ha
3	Kongorong	29/3/71	328 ha
4	Glencoe	30/1/74	390 ha
5	Nangwarry	17/3/67	5.0 ha
6	Mt. Burr	19/1/73	0.6 ha
7	Penola	18/1/73	1.9 ha

It is worth noting that none of the above fires was spreading after midnight on the day of the fire. This situation is fairly general in South Australia. Good access and the considerable intermixing of pasture areas with the plantations both help to virtually ensure that pine fires are "24-hour-wonders."

a. Fuel Factors

The quantity, sizes and arrangement of fuels (as in all forest fires) are vitally important components in the complex of variables which influence fire behaviour in plantations.

All fuel factors change with the age and management stage of the plantation. After initially light ground fuels, a significant aerial fuel component develops as the green level rises then, when the first thinning removes half the stocking, ground fuels can become very heavy while patches of aerial fuels still remain if the plantation had not by then been pruned.

With still increasing age and further decreased stocking, ground fuels tend to become less of a hazard - at least to the extent that crown fire formation becomes less likely and the increased accessibility makes more possible a direct attack of the fire by fire tankers and line construction equipment.

Some of these points are illustrated by the 'case history' fires herein.

(i) Fire 2 Glencoe 2/4/66.

P.radiata 12-14 years old, mostly of middle to low quality and both unpruned and unthinned forest was involved. Topography was not a factor but crown fire development was virtually inevitable because of the readiness with which fire was lifted by the aerial fuels.

(ii) Fire 3 Kongorong 29/3/71.

Particular points demonstrated at this fire included -

- In old heavily thinned and pruned forest down to 200 trees/ha, crown fire did not develop in spite of very heavy fuel loadings of 60-80 tonnes/ha (estimated) while the fire progressed steadily on level ground.

- In young 6 year-old forest which had been grazed, ground fuels were light and sometimes discontinuous. The trees had not yet formed a green level. As a consequence the fire in this fuel was a low intensity and relatively slow-moving.

(iii) Fire 1 Wandilo 5/4/58.

Parts of the plantation burnt in this fire were of low site quality and carried significant quantities of natural dry sclerophyll shrubby growth in amongst the pines. The increased ground fuel quantities thus provided contributed to an accelerated rate of fire spread in those areas. While the silvicultural advantages of pruning are arguable, there is no doubt that pruning to say 3 m is a useful fire protection measure. The air barrier between ground fuels and crown certainly inhibits the chances of crown fire development. Fire No. 2, which was in unpruned forest, crowned readily.

b. Wind effects in plantations

Aside from the question of fire storms and other erratic fire behaviour involving wind movements, wind speed variations within, above, and around plantations are very relevant to fire behaviour.

Inside the average plantation, wind speed near the ground is of the order of one-fifth of the speed in open unforested land, but this varies, of course, with the density of the stand and the distance from the windward edge. It was noted at Fire No. 5, Nangwarry 17/3/67, that the wind speed was greater near the edge of this heavily thinned plantation than in the centre of the compartment and that rates of forward spread of the fire decreased there. In fires 6 and 7, where initial attacks were successful, both stands were densely stocked and the low ground wind speeds at the fire site undoubtedly contributed to the successful suppression.

On plantation edges - particularly against open pasture land - and where there are distinct breaks in the continuity of the forest canopy, wind effects can complicate fire behaviour.

On the windward side of sharp plantation edge (i.e. against open land), wind speeds at ground level commence to decrease in strength from about 5 x height, the reduction being about 30% at the pine edge itself. As a consequence of this ground level wind speed reduction, increases in strength occur above the tree crowns and also at ground level where the direction of the 'wall' of pines changes, particularly through any appreciable gap in the 'wall' and at corners of plantations. These, then, are locations where unexpected fire behaviour can occur.

Openings in the forest canopy of more than 5 x height of the trees (in the direction of the wind) enables the formation of eddies and increased windspeeds in these gaps and, when other conditions favour intermittent crowning, severe crown fires are common downwind of such breaks in the canopy.

It is noteworthy that one of the factors involved with the formation of the fire storm in Fire No. 1 (Wandilo, 5/4/58) was increased surface wind speed due to a tree-less swamp amid the plantation.

c. Flame Characteristics

As mentioned earlier, the structure of the forest - particularly its stocking - appears to influence the development, or at least the maintenance, of a three dimensional fire. But the chief factors affecting flame heights are the fuel characteristics and weather factors.

Flames of the most intense of the crown fires which occurred in the 'case history' fires, were of the order of 1½ to twice tree height. Ground-fire flames ranged from about 1 to about 15 metres. The depth of the burning zone varied according to fuel quantity and whether head or flank fire is involved, but even in the comparatively light fuels of Fire 5 (Nangwarry 17/3/67), the actively burning zone on the flanks of the fire was about 2 m wide and this required considerable quantities of water to control.

d. Spotting

Just as in eucalypt forests fires, the spotting process is a vitally important mechanism for spreading fires in pine plantations. But spotting distances tend to be significantly less.

For the 'case history' fires, spotting distances are shown below:

Fire	Location		Recorded Spotting Distances
1	Wandilo	5/4/58	400-600 m, 2000 m (after a fire storm)
2	Glencoe	2/4/66	400-600 m.
3	Kongorong	29/3/71	(100-200 m through canopy
			(800 m as a result of whirlwind
4	Glencoe	20/1/74	800 m.
5	Nangwarry	17/3/67	300 m.
6	Mt. Burr	19/1/73	240 m.
7	Penola	18/1/73	400 m.

If ground fuel quantities in all the above fires were 25 tonnes/ha, "eucalypt" spotting distances would have been of the order shown below (after McArthur 1966).

Fire	Spotting distance for eucalypt fires
1	2600 - 2900 m.
2	2600 - 4400 m.
3	3200 m.
4	3100 m.
5	4600 m.
6	2600 m.
7	3600 m.

This rough and ready comparison suggests that pine plantation fuels frequently exhibit spotting distances of less than a quarter of those common in eucalypt fuels.

Nevertheless, spotting is a significant suppression problem and the successful initial attacks carried out on Fire Nos. 5, 6 and 7 were only successful because spot fires, which were generated very early in the progress of each fire, were caught and extinguished.

Another point worth mentioning is that a ground fire can throw spots some 100 - 200 m. These fire brands apparently can pass through quite a dense canopy.

The longest throws of spot fires known to have emanated from pine plantations in South Australia in recent years range from 1600 - 2000 m. Umbos of cones have been noted as fire-brands.

Mass spotting from fire storms or fire whirlwinds occurred in both 'case history' fires 1 and 3. The latter was on a much smaller scale than with the former but, nevertheless, provided such a suppression problem that a big fire became inevitable in spite of the presence of substantial fire-fighting forces.

e. Rates of spread

For given quantities of continuous fuel of low moisture content within the forest and for given meteorological conditions outside it, rates of forward fire spread are largely related as to whether or not crown fires develop. Mechanisms triggering crown fire formation chiefly involve quantities of fuel and its distribution laterally and vertically, wind factors and atmospheric stability as well as topographical features.

The same factors affect the potential for long distance spot fire development and this certainly influences the rate of spread.

For the 'case history' fires, rates of fire spread were as follows:

Fire	Place		Rate of forward spread	
			Ground Fire	Crown Fire
1	Wandilo	5/4/58	600 m/hr	1200-1600 m/hr
2	Glencoe	2/4/66	600 m/hr	1200 m/hr
3	Kongorong	29/3/71	High forest 500-600 m/hr	-
4	Glencoe	30/1/74	High forest 600 m/hr	-
5	Nangwarry	17/3/67	280-440 m/hr	-
6	Mt. Burr	19/1/73	about 100 m/hr	-
7	Penola	18/1/73	about 80 m/hr	-

Of particular note are the relatively slow rates of spread initially (Fires 6 & 7). The rates of spread would undoubtedly have accelerated if the fire size had been permitted to increase.

Generally, rates of forward spread are comparable with those indicated for Eucalypt fuels, but the increased long distance spotting potential of the latter may lead to greater rates than for pine when fuel loadings are high.

f. Species differences

Most plantation fires experienced in South Australia have been in *P.radiata*. The only other species which have been burnt in any significant area are *P.pinaster, P.muricata* and some *P.canariensis*.

As far as fire behaviour is concerned, *P.pinaster and P.muricata* provide more problems than the others.

The very deep coarse needle litter of *P.Pinaster* burns very fiercely and the heavy clusters of needles caught in the 'elbows' of unpruned lower branches provide a very significant aerial fuel.

P.muricata appears to have a very great spotting potential. It is probable that the very high numbers of persistent stem cones common on this species provides a fertile source of fire brands.

The main point to bear in mind is that different pine species do exhibit different characteristics with regard to fire and sometimes tactical allowances must be made on account of them.

g. Fire whirlwinds and erratic fire behaviour

Erratic fire behaviour occurred in 'case history' fires 1 and 3. In both cases ground fires quite rapidly built up into significant fire whirlwinds with flames reaching well above tree top height. In Fire 1 the diameter of the area immediately affected was up to 300 metres while in Fire 3, the diameter appeared to be smaller, probably about 50 m, but more than one whirlwind appeared to have developed and these occurred at slightly different locations and times.

Apart from suppression difficulties brought about by massive spotting etc., the sudden development of fire whirlwinds can present a danger to personnel. These two instances appear to indicate that seemingly small changes in conditions can trigger what appears to be a relatively stable and safe-looking situation into something quite the reverse.

It appears likely that fire whirlwind formation in fairly heavy fuel situations is more likely to occur in a conditionally stable or unstable atmosphere. With this atmospheric condition -

- changes of slope,
- changes of ground wind speed,
- merging fires,
- increases of fuel quantity (especially aerial fuels,

each may help initiate fire whirlwinds.

h. Conclusion

For this discussion of fire behaviour aspects in pine plantations, topographic factors and time, have been mentioned only incidentally but, of course, their influences on fire behaviour are extremely important and frequently dictate fire suppression tactics.

2. FIRE SUPPRESSION IN PINE PLANTATIONS IN SEVERE FIRE WEATHER CONDITIONS.

a. Suppression Objectives

While there are possible exceptions, it is perhaps almost universal that a basic strategical objective is to keep the area of pine plantation burnt by wild fire to an absolute minimum. For individual situations, tactical reasons may demand that certain plantation areas be 'sacrificed' but such a tactical decision will usually be taken within the framework of an overall strategical 'minimal loss' objective.

Strategy, then, is general in its ambit and widespread in its implications. Tactical considerations, on the other hand, are more specific but can only be applied within an already-determined strategical framework.

This section of the notes concerns tactics more than strategy, but both are inevitably involved.

b. Initial Attack

In Australia's worst fire weather situations fires in pine plantations nearly always are either comparatively large or quite small. The difference usually is related to the success or failure of the initial attack.

"Initial attack" is defined as the attack initiated by the first fire crew(s) to arrive and attack the fire, while "subsequent attack" is defined as the attack which is deliberately mounted when the initial attack has failed and when the number and nature of all supporting fire crews and equipment is known well enough and when the particular fuel, topographic and access conditions in the area of the fire itself (and of the area into which the fire is burning) are also knwon well enough.

In severe fire weather the initial attack in pine plantations can usually be regarded as having failed if the forward spread has not been halted within about an hour (or at the most 1½ hours) after ignition.

What then is needed to achieve a successful initial attack? The following are believed to be the main requirements -

- Sufficient fire crews,
- Who arrive quickly enough,
- With sufficient fire suppressant (water or retardant)
- Which the crews apply to the fire edge quickly and effectively,
- Find and suppress spot fires as soon as they are generated,
- Take advantage of such "lucky breaks" that occur.

Enough fire crew working time must be provided within this 1-1½ hour period so that fire perimeter can be suppressed at a greater rate than it is being formed by the spreading fire. Ever since fire brigades began, it has been recognised that the earlier an attack on a fire begins the better the chances are of success. So there is nothing new about this, and the last 2 decades in Australia has seen a lot done in the provision of better detection equipment and access so that earlier and stronger initial attacks can be mounted. But initial attacks still fail more often than they succeed. Perhaps some of the reasons for this are due to either too many attacks being too small and too late, and/or faulty decisions made at the time of the initial attack.

(i) Assembly of fire crews

If a fire crew comprises 5 men who operate a fire truck of 3000 l capacity, equipped with a heavy duty pump, 400 m of delivery hose and other appropriate ancillary equipment, then successful initial attack is usually possible in pine plantations in Very High - Extreme fire weather if crews so equipped arrive at the fire and commence working within the following time scale:

Numbers of crews	Minutes after fire detection
2 - 3	15
5 - 6	30
7 - 8	45
8	60

Of course even this rate of assembly of fire crews may not be successful if local difficulties of access, fuel types, topography etc., either restrict or prevent the amount of suppression work which can actually be done immediately. And the reverse can happen too - too much equipment for too little fire - but this is hardly a problem.

(ii) Decisions

Efficient fire suppression is intimately tied to good decision-making. Decisions about the initial attack have got to be made by the leader of the first crew to arrive.

He must decide:

- Whether to attack immediately or to wait for further assistance.
- If immediate attack is decided upon, where and how to mount this attack.

The correct decisions depend on the circumstances of the place and time but rarely is it justified not to take immediate action of some sort. Provided that access is possible and appropriate equipment is available, the first attack crews (no matter how small) can at least commence action on holding the heel of the fire, viz. that part clearly near its origin.

If water cannot be brought to bear, hand tool work is almost always possible. The initial attack crew should almost always attack the fire directly. Rarely, if ever, is indirect action of any sort by a lone initial attack crew justified. A decision to mount a direct attack on the head fire by a lone initial attack crew is a difficult one. The intensity of the fire, its rate of spread, its present size, its direction of movement, the fuels it is heading for, and the accessibility, all must be balanced against the calibre and capability of the men and equipment available to make the attack.

There are, perhaps, two guiding principles:

(1) Never attack the head fire unless:

- the whole fire can be seen all the time,
- or access is very good and high value assets may be saved by a vigorous 'hot-spotting' attack.

(2) Never put men into a situation where they are at undue risk by attacking a head fire.

Accepting these limitations, there frequently are many occasions when head fire attack is a proper tactic. Sometimes the decision to go ahead with this attack will depend upon the sure knowledge that help will be available within a known (short) time.

Accordingly, it is wise to advise the forces still assembling at the fire that a head fire attack is being attempted and that certain help is necessary at a nominated location. While no-one decries the need for positive and vigorous fire-fighting, there is no place for the dare-devil and when fire suppression 'capability' and the assessment of the potential of the fire is in balance, or when the leader of the initial attack crew is unsure of himself, his crew, or his equipment, then there is little doubt that the proper course is to neglect the head fire and commence the essential job of anchoring the heel of the fire. And this must be done by direct attack if at all possible.

If direct action is impossible then it is probably best to await reinforcements and, while doing so, to recce the fire so providing information to better direct the activities of the assembling suppression forces, particular attention being paid to watching out for spot fires.

The success or not of an initial attack thus depends upon the decision made by the first leader to arrive at the fire. This leader may be very junior and, accordingly, adequate training must be carried out to ensure that these vital decisions are good decisions.

c. The subsequent Attack

The decisions for the 'subsequent attack' are usually made by the 'Fire Boss' of the fire who may, or may not, have led the unsuccessful initial attack.

The first requirement is to set up an appropriate command organisation and to decide upon the basic suppression tactics to be adopted.

Appropriate tactics chiefly depend upon:

- the fuels in which the fire is burning and towards which it is moving,
- topographic and access considerations,
- weather conditions and changes anticipated,
- the particular crews and equipment available to put plans into effect,
- logistic and co-ordination problems.

An early decision is needed as to whether a direct attack should be implemented, or whether a containment policy is to be attempted. The latter may well be the almost only option open in areas of steep topography or where access is very limited but, where access to the fire edge is good, a direct attack has many advantages.

In plantation fire suppression direct attack methods should generally be preferred to indirect methods if the choice is really available as less burnt area usually results.

d. Logistics

(i) Provision of adequate water supplies

Direct attack methods in severe conditions in pine plantations almost inevitably require the use of either large volumes of water or, alternatively, fire retardants to aid suppression. To date, little is known of the latter and are not discussed in this section.

For planning purposes, it can be assumed that a satisfactory rate of suppression of fire perimeter can usually be achieved with 200 - 600 litres of water per 20 metres of fire perimeter per working minute.

Water supplies need to be made available such that the available 'fire crew working time' is fully utilised. This, of course, represents the best chance of either achieving a successful initial attack, or alternatively managing a subsequent attack which is economical in terms of burnt area.

(ii) Provision for line construction

After knock-down by water, the essential physical separation of burnt and unburnt fuels may be achieved by :

- men with hand tools
- bull-dozers, etc.

Ideally the assembly of men and/or equipment, putting them to work, and their rate of line production, should be such that a mineral earth fire-line can commence to be established no more than 10 minutes after knockdown by water. (With retardants this time may be 30 minutes or longer; but research is needed to confirm this).

If initial attack has been successful, anything up to 6 - 8 km of line may have to be constructed.

Hand tools:

In light fuels a 6 - man crew using rakhos can achieve 1000 - 1400 m per hour for the first hour, decreasing over longer work periods. In moderate-heavy slash these values may be halved.

Using flail-trenchers, a crew of 4 comprising two flail trenchers and two assistants can construct 1500 - 2500 m/hour. Slower rates are inevitable with very heavy slash needing a chain-saw to lead the flail-trencher crew.

Bull-dozers:

Light tracked bull-dozers with a hydraulic angle-tilt blade working through thinned stands can operate at 800 - 1600 m/hour in lighter fuels. Fitted with a special V-blade, similar machines can operate at 2000 - 3200 m/hour.

3. PLANTATION MANAGEMENT ASPECTS AFFECTING FIRE SUPPRESSION

a. Introduction

So many plantation management aspects affect fire suppression strategies that it is fair enough to say that fire protection should not be regarded as a separate discipline. Rather it should be looked upon as a part of every facet of plantation management from initial establishment right through to final clear felling.

This general policy is reflected in South Australia by not having separate Fire Protection Plans for Districts but, instead, Fire Protection Works and Works Proposals are integral parts of each District's Forest Working Plan which is up-dated each 5 years.

Before going further it is necessary to mention the important place that adequate fire detection facilities have with respect to fire suppression strategies. It is not much good to provide top quality access, fire suppression crews and specialised vehicles for them, if fire detection standards are considerably less than reasonable. With respect to fire detection it is worth remembering too, that smoke on Very-High-Extreme days often stays below crown height for 10-15 minutes and, consequently, a delay of this order between ignition and report is common-place in a fixed fire tower detection system.

Most relevant management aspects which affect fire suppression fall into the following headings:

- Fuels,
- Access and firebreaks,
- Native forest areas.

b. Fuels

(i) Clearing standards

The degree to which the previous crop has been removed prior to the establishment of the new crop can have long term consequences. Tree stumps left within the compartment can create mop-up problems if the area is subsequently burnt. While sometimes it is necessary to accept this (e.g. in second rotation pine areas) it may often be possible to prescribe site clearing criteria which lay down a maximum number of stumps per unit area which may be left. Stumps left on access tracks and firebreaks are another matter. All should be removed to avoid recurring problems of track maintenance. (It is of particular note that old decaying pine stumps of a first rotation readily ignite and are difficult to extinguish - this is relevant to any within-the-stand burning that may be contemplated.)

(ii) Competition control inside stands

For the first years (sometimes up to five) of the new plantation, the control of herbaceous and shrub competition by either mechanical or chemical means has big advantages in terms of better pine growth. This procedure concomitantly provides a higher level of fire protection.

(iii) Grazing

Grazing is generally unacceptable in P.radiata until the trees are about 2½ m high because of the damage which the stock may cause. From this stage onwards, however, grazing can fulfil a useful fire protection function in reducing ground fuel quantities. Of course, as canopies close, there is little to attract stock inside the stand until much later in the rotation.

(iv) Low pruning

Pruning provides an air barrier between ground and aerial fuels so lessening the chances of crown fire formation. While complete pruning over all areas of plantation may seem desirable for these reasons, cost considerations may preclude pruning to this extent. In South Australia, priority is given to prune plantations adjoining:

- grassland,
- significant areas of native forests,
- well-trafficked roads.

All are pruned for 20 - 100 m from the vulnerable edge. The pruned width varies according to:

- travel time from Forest H.Q. to the area
- topography and nature of the adjoining fuels,
- location on the ground in relation to the most fire dangerous winds.

Pruning is to a height of 3 m and commences after green level formation.

(v) Spatial Distribution

In their earliest years young plantations can be relatively safe from fire and can, in fact, impart a measure of safety to older stands which may surround them. Between the ages of about 5 and 15 years, though, most stands are very vulnerable and can look to a measure of protection from older stands about them, especially if by then these older stands have been thinned twice or more. It follows that it is good protection practice to attempt to spread young plantations amongst older stands wherever possible.

(vi) Crown-fire-free areas

Experience has clearly shown (vide 'case-history' fires) that old well thinned stands can be made, or become, "crown-fire-free" in all, or almost all, fire weather situations. Such areas can be created following the reduction to anything below about 370 trees/hectare, low pruning of all stems, and a modest removal or (even re-arrangement) of ground fuels.

Crushing of slash by tracked tractor and roller has been shown to be effective, while cleaner but much more expensive jobs of heaping and 'winter' burning have been carried out in some areas.

The locations of crown-fire-free areas vary from area to area and from decade to decade. A general principle is applied of giving preference to:

1. areas which surround high value capital assets (towns, mills, etc)
2. areas which are more remote and to which fire suppression forces take longer than normal to assemble,
3. areas alongside open paddocks and well-trafficked roads,
4. areas which tend to be used by recreationists (legal and illegal).

When stockings come below 300 - 320 tree/hectare persistant regeneration is prone to become established in many areas. The presence of this regeneration can compromise crown-fire-free intentions for an area and it may have to be removed. If this becomes necessary then treatment at an age when rotary slashers can be effective is desirable if costs are to be kept to a reasonable level.

(vii) Harvesting

Good fire protection practice is a necessary part of all logging operations. The extent to which such practices can be carried out may vary between different operations, however. The removal of pulpwood from trees which already have provided sawlog is a case in point. Maximum pulpwood removal reduces the overall slash hazard but is not always an attractive proposition for the logging contractor.

Supervision of logging contractors is necessary to ensure the carrying out of such aspects as:

- placing all hanging trees and limbs on the ground,
- heaping of slash etc. left on firebreaks,
- clearance of slash etc. from tracks.

The increasing development of log extraction systems involving double handling of material may call for special fire control provisions. The keeping of harvesters, forwarders, fork lifts, etc. 'in the bush' for lengthy periods tends to result in maintenance work being carried out there rather than in a workshop. Not only are machines greased and oil-changed but such activities as welding also take place.

c. Access and Firebreaks

Fire suppression is assisted by the provision of as much access for vehicles as it is economically possible to provide and access, per se, is considered to be of greater value than firebreaks, as such.

In South Australia firebreaks are either of 7 m or 20 m in width and all must be negotiable to vehicles. Compartments are usually not larger than about 20 ha and these are surrounded by a firebreak. In steep topography tracks (5 m wide) are established on negotiable ridges and spurs not in use for firebreaks, and gullies are provided with tracks on both sides of any creek which cannot be crossed by vehicles. All tracks must have outlets at each end or have a turn-around.

d. Native Forest areas

Areas of native forest within or adjoining plantations areas usually must be managed according to some agreed upon plan.

Very often low intensity prescribed burning is possible in these areas and this hazard reduction can be a valuable protection to the exotic plantations. Burning of such areas though must also usually be planned in relation to aspects other than just plantations fire protection, i.e.,

- wild life consideration
- recreation consideration
- noxious weed spread etc.

CASE HISTORY NO. 1

THE WANDILO FIRE OF 5/4/58

(Woods and Forests Department Plantation)

1. ORIGIN

The fire started in Sec. 346, Hd. Young, in an area of natural eucalypt forest adjoining pine plantations. This area carried ground fuel quantities ranging from 10-40 tonnes/ha. From this natural forest, the fire entered plantations of *P.pinaster* (10-11 m high, unthinned and unpruned with ground and aerial fuels estimated at 25-35 tonne/ha) and *P.radiata* (low quality unthinned stands 5-10 m high to high quality thinned forest 30 m high with ground fuel quantities to 50 tonnes/ha).

2. METEOROLOGICAL CONDITIONS

At 12.30 p.m. maximum temperature 33°C was reached at which time the relative humidity was 29%.
Surface wind speeds 37-42 k.p.h. with gusts higher.
Atmosphere conditionally unstable early in day, considered certain to be unstable at time of fire.
Forest Fire Danger Index 33 - Very High.

3. FIRE SPREAD AND BEHAVIOUR (in plantation)

The fire entered the *P.pinaster* area at 1230 hours on a 10° upslope and rapidly crowned to throw spot fires 400-600 m downwind. Rate of forward spread at this time was 1200-1600 m/hr. After this 'surge'. the rate of spread slowed to about 600 m/hr (mostly ground-fire) in *P.radiata* forest until a combination of circumstances involving a break in the plantation canopy, changes of slope and merging forks of headfire led to the development of an intense fire storm. Massive spotting occurred over an area extending 2 km downwind. The area receiving this massive spark shower 'crowned' immediately. The total area of plantation burnt was 320 ha.

4. MECHANICS OF THE FIRE STORM

- At 1500 hours the fire perimeter was to the west and north of what became the fire storm area. The eastern edge of the fire perimeter in the pine plantation had just entered the northern end of a long treeless swamp which was aligned in a NNW-SSE direction.

- To the west of this open swamp, there was dense, bushy Pinus radiata with a very heavy fuel accumulation on rising ground. To the east of the swamp a distinct knoll carried a poor 'spindle' stand of pine and intermixed eucalypt coppice and heavy ground vegetation. This 'valley', being roughly orientated with the gradient wind direction, allowed the formation of a strong wind-funnel effect which accelerated the spread of the fire through the swamp.

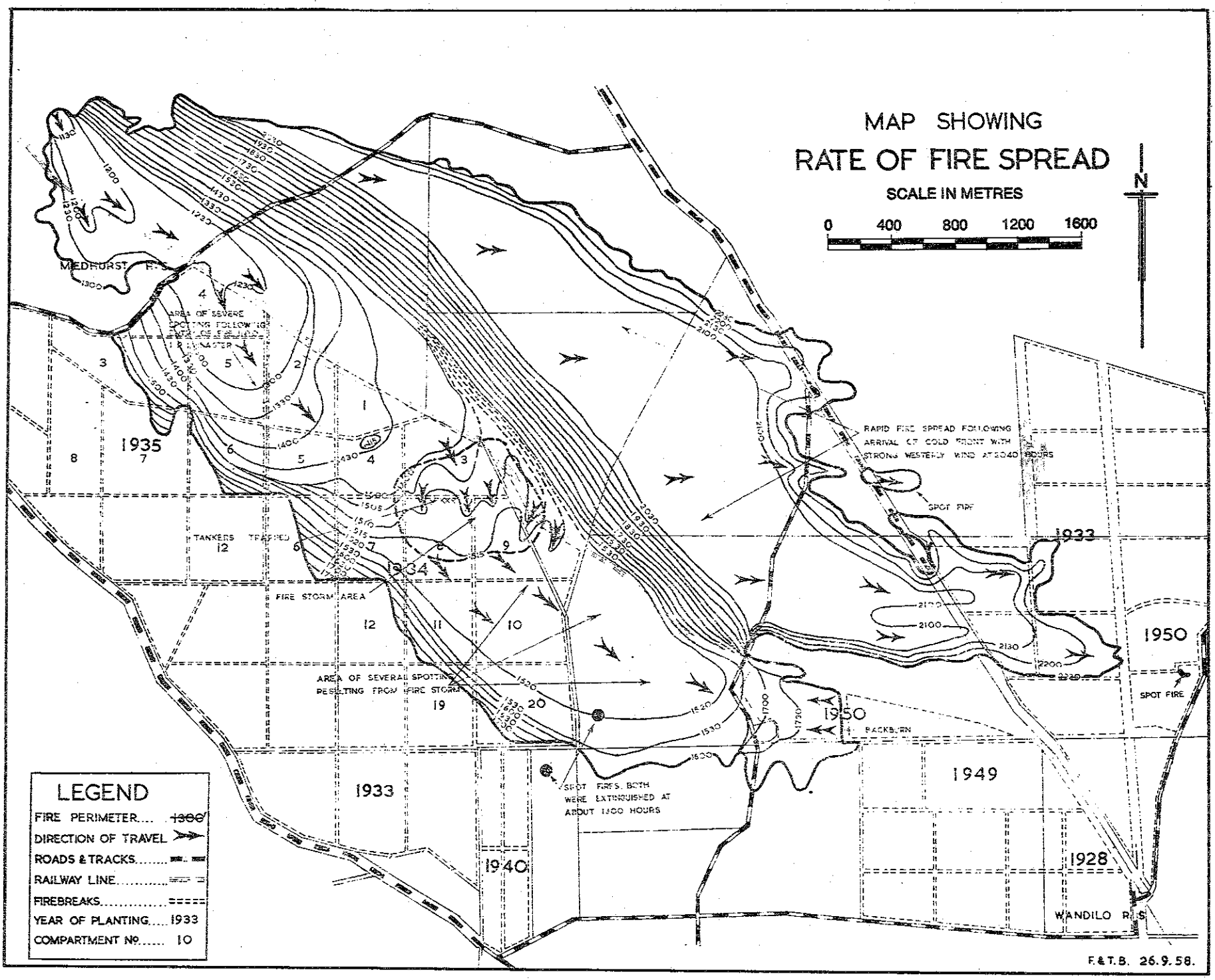
- The rapid spread through the open swamp induced a severe crown fire in the fringing spindle and dieback stands, and the intense fire created a strong convectional indraught which drew in the previously quiet main fire to the north and west. Another head-fire prong was thus formed and this also crossed the break between compartments 3 and 8 some 200-300 m to the west of the first head-fire.

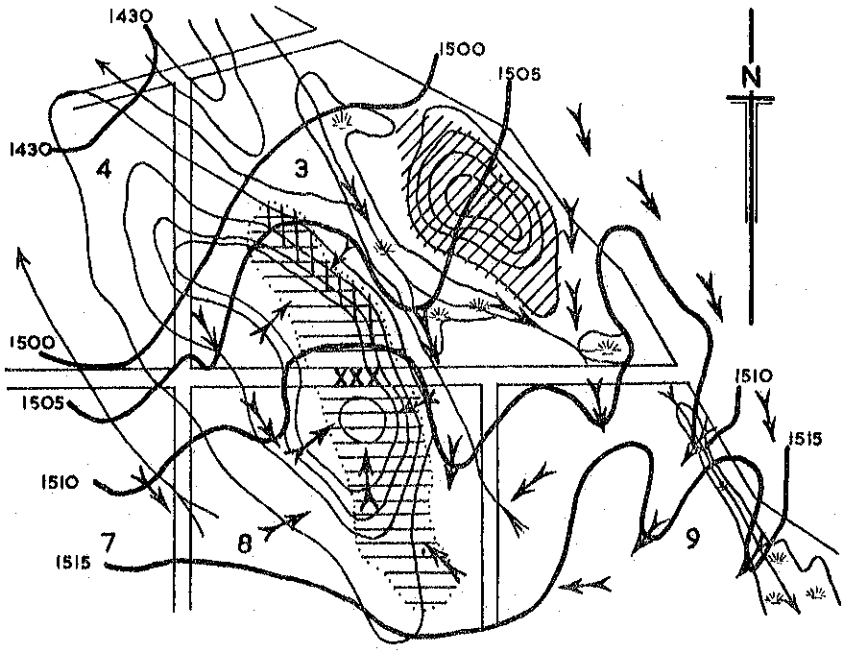
- These two headfires, each on either side of a distinct sand dune, converged and formed a junction zone at about 1512 hours reaching its greatest intensity at the head of the knoll in Compartment 8. Vehicles and fire-fighters were trapped directly in this junction zone only 40-60 m north of the knoll. 8 men died.

- The effect of the strong convectional indraught, caused by the crown fire on the area fringing the swamp and the two accelerating headfires, extended also to the previously quiet fire perimeter in the hardwood area to the east of the plantation. This then spread rapidly in a south-easterly direction along the pine edge and, drawn towards the developing storm centre, entered the pines in Compartment 9 and soon became a vigorous crown fire.

- The energy released by these converging crown fires caused a very strong convection column to form.

- The strong convection up-draught and the strong winds aloft initiated immediate and heavy 'spotting' over a wide area south-east of the storm centre for a distance of some 2 km and resulted in the almost simultaneous ignition of approximately 240 ha of Pinus radiata. This area was practically burnt out by 1530 hours.


MAP SHOWING
RATE OF FIRE SPREAD
SCALE IN METRES
0 400 800 1200 1600
N
MEDHURST R.S.
AREA OF SEVERE SPOTTING FOLLOWING PASSAGE OF FIRE MASTER
TANKERS TRAPPED
FIRE STORM AREA
AREA OF SEVERAL SPOTTING RESULTING FROM FIRE STORM
RAPID FIRE SPREAD FOLLOWING ARRIVAL OF COLD FRONT WITH STRONG WESTERLY WIND AT 2040 HOURS
SPOT FIRE
SPOT FIRES, BOTH WERE EXTINGUISHED AT ABOUT 1300 HOURS
PACKBURN
WANDILO R.S.
1935
1934
1933
1950
1949
1940
1928
LEGEND
FIRE PERIMETER.... 1300
DIRECTION OF TRAVEL
ROADS & TRACKS.....
RAILWAY LINE.....
FIREBREAKS.....
YEAR OF PLANTING.... 1933
COMPARTMENT No..... 10
F.&T.B. 26.9.58.



LEGEND

FIRE PERIMETER AT 5 MINUTE INTERVALS	1505
MAIN THRUSTS OF FIRE	
JUNCTION ZONE BETWEEN MAIN THRUSTS	
FORM LINES	
GULLIES	
SWAMP AREAS (UNPLANTED)	
SPINDLE STANDS 9m HIGH	/////
DIEBACK STANDS	
POSITION OF BURNT TRUCKS	XXX
COMPARTMENT N°'S	3

SCALE IN METRES

0 200 400 600

CASE HISTORY NO. 2

GLENCOE FIRE OF 2/4/66

(Woods and Forests Department Plantation)

1. ORIGIN

The fire started at about 1250 hours near the north-west corner of Cpt. 2 1954 plantation.

2. FUEL TYPES AND ACCESS

Adjacent eucalypt scrub fuels were poor quality swamp gum and stringybark over teatree and bracken. This area had not been burnt since April 1957 as far as is known.

The Pinus radiata plantations planted in 1954, 1956 and 1958 were generally of low, with parts of medium, site quality. All plantations were unpruned and in the lower qualities ground vegetation was dense and was estimated as exceeding 25 tonnes per ha.

3. WEATHER OF THE DAY

The day was hot with fresh to strong north-west winds. The cool change, expected late in the afternoon, arrived at the fire area earlier than anticipated at about 1320 hours after which the temperature fell, the humidity increased and the wind strength decreased noticeably.

Weather statistics are as follows:

- Temperature - Noon temperature 31°C with maximum of near 33°C occurring at about 1300 hours. The cool change was established by 1500 hours when temperature fell to about 21°C.

- Relative Humidity - Values of 20% were recorded at noon.

- Wind Velocity - Winds in the area were well indicated by those from Mount Edward fire tower.

1300 hours	335°	43 km/hr
1400 "	290°	29 " "
1500 "	275°	31 " "
1600 "	260°	23 " "
1700 "	255°	15 " "

- Atmospheric stability - Conditionally unstable early in day Believed to be unstable at time of fire.

- F.F.D. - 49 Very High at time of maximum temperature.

4. FIRE PROGRESS AND BEHAVIOUR

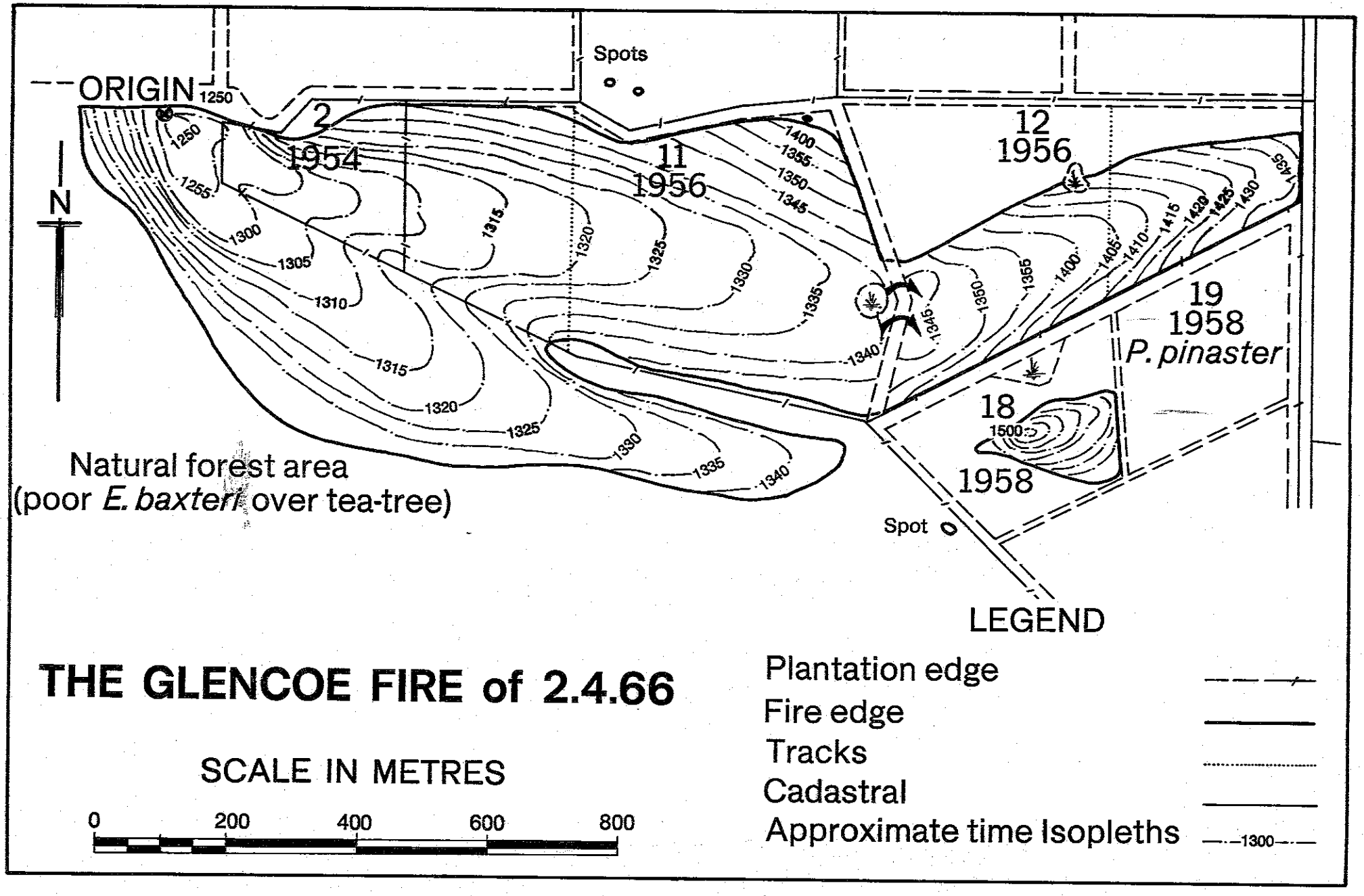
The fire spread rapidly from the outset and the spread was almost certainly accelerated by spotting.

The fire entered the pines at about 1250 hours and completed its ESE'ly run through compartments 2/1954 and 11/1956 at 1440 hours. This represented a rate of forward progress of just over 1200 m/hr. During this run spotting ahead of the fire occurred and, in particular, a spot ignited in compartment 18/1958 at about 1500 hours. The progress of the main head fire was marked by a full crown fire in the 6-10 m high unpruned trees. Maximum spotting distance was 400-600 m.

After jumping into Compartment 12/1956, the wind changed to WSW and decreased in strength. The humidity also rose in sympathy with a decreasing temperature. As a result the rate of spread halved to about 600 m /hr. This relatively slow rate of spread was accompanied, of course, by a decrease in flame height and a lower fire intensity. This relatively low fire intensity was also evidenced by the fact that the right flank burnt out itself against the 20 m between 12/1956 and 18 and 19/1958 with no help whatsoever from suppression units.

The spot fire in 18/1958, which occurred after 1500 hours, also spread relatively slowly in spite of heavy ground fuels in the poor quality Pinus radiata stand. The fire burnt out itself on to the 10 m break adjoining 19/1958 and, although a few trees in this compartment were scorched by radiant heat no ignition occurred, and also the fire did not spot over.

Area of plantation burnt was 40 ha.


ORIGIN
1250
Spots
2
1954
11
1956
12
1956
19
1958
P. pinaster
18
1500
1958
Spot
N
Natural forest area
(poor E. baxteri over tea-tree)
LEGEND
THE GLENCOE FIRE of 2.4.66
SCALE IN METRES
0
200
400
600
800
Plantation edge
Fire edge
Tracks
Cadastral
Approximate time Isopleths
1300

CASE HISTORY NO. 3

THE FIRE OF 29/3/71 - SOFTWOOD HOLDINGS' PLANTATIONS KONGORONG, SOUTH AUSTRALIA.

(Permission by the Company to include this data in this series is acknowledged).

1. LOCATION, ORIGIN, CAUSE AND AREA BURNT

The fire occurred in parts of Sections 312, 492, 493, 494 and 533, Hd. Kongorong on 29th March, 1971.

The origin was near the north west corner of Sec. 493, just inside the pine plantation (cpt. P20) adjacent to a large roadside borrow-pit (quarry).

The plantation in question was 29 years of age, thinned to 200 trees/ha, and carrying heavy thinning slash estimated to range from 10-40 t/ha.

The cause is unknown.

The area burnt (figures provided by Softwood Holdings Ltd.) is as follows:

1942 pltn.	229	acres
1960 Nat. Reg.	28	"
1964 P	120	"
1965 P	91	"
1966 P	290	"
Slash	53	"
Total	811	" (328 ha).

2. WEATHER OF THE DAY

Max. Temp. 33°C R.H. % 23% Average wind speed 35 km/h. Wind direction N-NNW. Forest Fire Danger 38 Very High.

The wind was very gusty and it is certain that the fire danger reached 40-45 i.e. nearing Extreme. The weather Bureau advised that the atmosphere was very unstable up to 2400 m.

The Byram-Keetch Drought Index value for Mt. Gambier Forest on 29/3/71 was 420, which is considerably higher than normal.

3. PROGRESS OF THE FIRE (vide attached map)

1100-1200 hours: The fire burnt through the slash in cpt. P20 as a ground fire. After jumping into P23 it crowned on a small knoll just south of the intervening break.

1200-1230 hours: Two heads appear to have proceeded through P23 and raced towards the NE-SW break separating P23 from P24 and T13. P23 is partly thinned to 200 trees per ha while parts are out-row-only thinned. Apart from the knoll mentioned earlier, the fire remained on the ground.

During this period, flank fires still burnt strongly in P20 and it appears that fire jumped at about 1215 hours from the S.W. corner of P20 across the break into the N.W, corner of 108/1966P to start a new head in this young stand. This head appears to have continued on a southerly course until the whole fire was contained late in the afternoon.

1230-1300 hours: Early in this period, the fire (crowned and behaved erratically,) and a large loss became inevitable from this time onwards. Just after jumping into T13, which is an unthinned compartment (Stocking 1250 trees/ha) having several patches of die-back affected trees (often on shallow-soiled knolls), it appears certain that a group of large fire whirlwinds developed. From this small "fire storm", fire brands were thrown downwind and numerous ignitions must have occurred in cpts. 109 and 110, 1960 plantation. The dry grass ground fuel in this 2.3 m high stand was variable but ranged up to 2-3 tonnes (estimated) per ha in quantity and was sufficient to carry a fire intense enough to scorch and kill most of the plantation.

Just after the fire storm occurred, the main wind direction changed from N to nearer N.W. (probably as a result of a coastal influence), and the main head fire proceeded through T12 and threw shots in the clear felling slash of T11 before reaching the firebreak.

1330-1430 hours: The main head fire proceeded through the western half of the slash of cpt. T11 and jumped into the 1964 and 1960 N.R. compartments. This latter crowned vigorously and is probably the source of spot fires thrown across the public road into cpt. 67/1962P. These spots were extinguished. The fire in the 1966 plantation continued and the man ignition sources emanating from the fire storm coelesced with the head fire resulting from the 1215 hours jump from cpt. P20.

1430 hours+: The main aspect here was the ignition of the green slash of the clear-felled portion of cpt. P24 and the burning of parts of cpts. 95, 96 1965P.

Secondary minor head fires occurred in this area while much of the area was burnt by flank fire from the main head.

The rate of progress of the fire generally decreased after 1500-1600 hours and little forward spread took place after 1700 hours when the large mopping-up job commenced.

4. SIGNIFICANT POINTS CONCERNING THE FIRE BEHAVIOUR

- In the old high forest thinned to 200 stems per ha, the fire remained on the ground notwithstanding very unstable atmospheric conditions and very heavy fuel accumulations, (which are estimated at 10-40 t/ha, with the heaviest quantities alongside alternate E-W access rows).

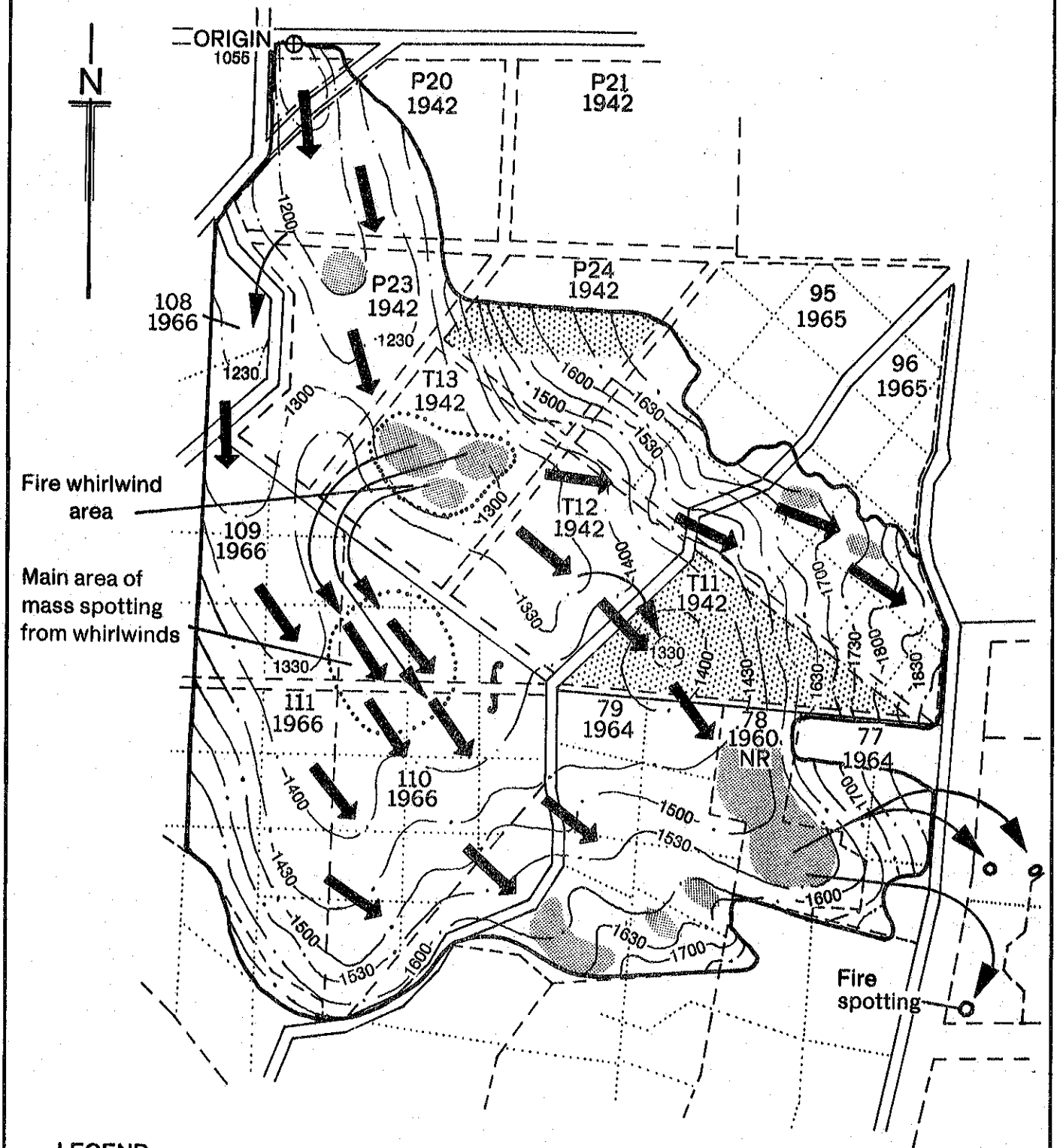
- Once the first attack had failed to confine the fire to P20 and P23 by about 1230 hours, a large fire became inevitable because of the subsequent fire whirlwind development and the mass spotting resulting therefrom.

- The meteorological and fuel conditions of the day were such that only slight changes in conditions were required to elevate a ground fire into the crowns. Small topographic variations, with or without changes in the distribution of aerial fuels, were all that was needed to do this.

- In high forest the rate of forward spread of principle head fires was up to 70 m/hr. In young forests 2-5 m high the rates of spread was about 80 m/hr where ground fuels were continuous.

- Spotting was a common phenomenon. Spotting distances from the fire whirlwind appear to have been of the order of 800 m. Spots from ground fires beneath high forest were of the order of 100-200 m. From the 1960 natural regeneration, which crowned vigorously, spots were thrown some 600 m.

THE SOFTWOOD HOLDINGS
KONGORONG FIRE of 29.3.71



LEGEND

Fire edge

Direction of main fire heads

Approximate time Isopleths —1500—

Areas of complete Crown Fire

Areas of clear-felling slash

SCALE IN METRES

0 400 800 1200

NOTE: Cpts. P20, P23, T12 and T13—28 year-old plantations
Other plantations all less than 10 years of age

CASE HISTORY NO. 4

THE GLENCOE FIRE OF 30/1/74
(Woods and Forests Department Plantation)

1. ORIGIN

The fire commenced shortly before 1300 hours near the eastern edge of Lake Edward, burnt slowly at right angles to the wind direction along heavy grass beneath a fence-line and, reaching a more exposed area, then jumped a track with fire brands lodging in the needle litter of Compartment 4, 1935 Plantation, from where it spread rapidly in ground fuels averaging about 20 t/ha. The cause of the fire is unknown

2. METEOROLOGICAL CONDITIONS

Mt. Gambier Forest Reserve Headquarters

1200 hrs.	Temp.	31.7°C	RH 36%	Wind (Mt. Edward)	54 km/hr
1500 hrs.	Temp	33.5°C	RH 31%	Wind (Mt. Edward)	50 km/hr

At Mt. Gambier Airport surface wind velocities ranged from 40-50 k.p.h. (with maximum gusts to 75 k.p.h.) and directions ranging from 330° - 060°, mean being mostly about 020° between 1300 and 1800 hours. Average values of Forest Fire Danger (McArthur Index) ranged between 34 and 37 (Very High) but moving into the lower levels of extreme as the wind gusts exceed 65 k.p.h.

At 0900 hours, the environmental lapse rate was noticeably less than the dry adiabatic lapse rate and the atmosphere was thus stable. Except, possibly, for the lowest 30 meters or so, the atmosphere can be safely assumed to have been stable during the course of the fire. This is a relatively unusual situation and undoubtedly was a factor which limited the rate of spread, the spotting distance, and the crowning of the fire.

3. FIRE SPREAD AND BEHAVIOUR

The total area burned was approximately 370 ha and the spread pattern of the fire is shown on the attached plan.

Particular points are:-

- In the areas of P.radiata of reasonable quantity, crown fire development was minimal. Between 1330 and 1400 hours, an intense crown fire developed on a quite steep upslope run in 4/1935. This undoubtedly caused significant spotting into 2/1933, 13/1932 and 4/1932 - all of which compartments were of failed plantation, dense with low quality eucalypt and/or teatree with fuel quantities estimated to be 60-80 t/ha.

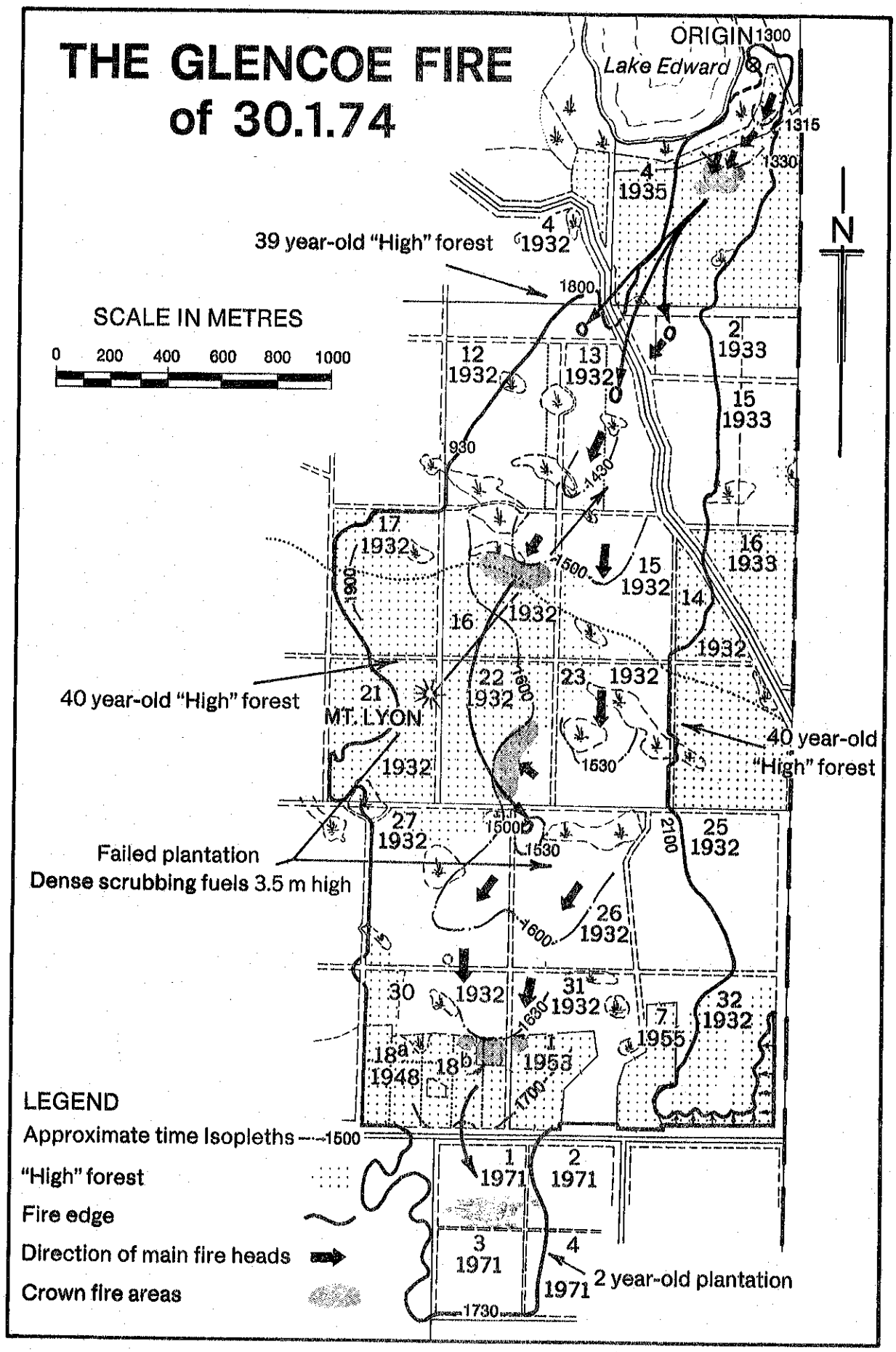
  Crown fires also developed in 16/1932 and 22/1932, both areas on the edge of swampy areas in which fires burnt intensely. Also compartment 18b/1948 (P.pinaster) crowned vigorously.

- About two-thirds of the total area burnt was failed or very low quality plantation, and it was in these areas that the most intense fires developed. Here, rates of spread were approximately 1200m/hour.

- In the initial run in pruned 'high forest' in 4/1935, and in other areas of good plantation, rates of spread were approximately 600 m/hour.

- Two well authenticated examples indicated that maximum spotting distances were about 800 metres. Heavy spotting over lesser distances occurred at various stages during the main run of the fire.

- Within high forest, flank fires spread slowly at about 200 m/hour.


THE GLENCOE FIRE
of 30.1.74
ORIGIN 1300
Lake Edward
1315
1330
4
1935
4
1932
39 year-old "High" forest
1800
SCALE IN METRES
0 200 400 600 800 1000
N
12
1932
13
1932
2
1933
15
1933
930
1430
17
1932
1500
15
1932
16
1933
16
1932
14
1932
40 year-old "High" forest
21
MT. LYON
1932
22
1932
23
1932
1530
40 year-old
"High" forest
27
1932
1500
1530
25
1932
Failed plantation
Dense scrubbing fuels 3.5 m high
1600
26
1932
30
1932
31
1932
1630
7
1955
32
1932
18a
1948
18b
1
1953
1700
LEGEND
Approximate time Isopleths 1500
"High" forest
Fire edge
Direction of main fire heads
Crown fire areas
1
1971
2
1971
3
1971
4
1971
2 year-old plantation
1730

CASE HISTORY NO. 5

NANGWARRY FIRE OF 17/3/67
(Woods and Forests Department Plantation)

1. ORIGIN

The fire started at about 1225 hours in a waste sawdust dump and spread into the immediately adjoining plantation. The exact cause is unknown.

2. WEATHER

Maximum temperature 34°C
Relative humidity 18%
Wind Speed 40 k.p.h. in open, gusting to 56 k.p.h.
Atmosphere unstable between the surface and at least 2500 m
Forest Fire Danger Index (McArthur) 51 - Extreme.
Frontal passage at 1330 hours with wind swinging from NW round to W and SW.

3. FOREST FUELS

The 35 fuels old P.radiata plantation was of average site quality and had been thinned to 400 trees per hectare and completely low pruned. Tree heights approximated 37-39 m and green crowns covered some 40% of the holes.

The compartment formed portion of a planned "crown-fire-free" zone and a strip 100 m wide on the northern and southern edges of the compartment had been cleared of all slash to a "needles only" state about two years previously, while the slash on remainder of the area had been reduced by a very complete removal of pulpwood following the last thinning.

Quantities of slash fuels (needles and twigs to 12 mm diameter) measured at representative locations after the fire were as follows:-

(i) Area with slash fully removed - 7.5 tonnes/ha
(ii) Area with all pulpwood removed - 17.5 - 22.5 tonnes/ha

The area in which the slash was not completely removed also contained heavy fuel components, viz. branches greater than 12 mm diameter, stemwood, cones etc. The quantity of these heavier components of the fuel was about 25 tonnes/ha, and obviously

affected the intensity of the fire and the width of the burning zone but was not considered to have influenced the rate of forward spread of the fire.

4. FIRE BEHAVIOUR

The rate of forward spread of the fire was relatively rapid near the compartment edge because of the greater wind speed there, but towards the centre of the compartment the rate of spread decreased. The rate of forward spread varied from 440 to 280 metres per hour.

Except for one or two flares, the fire remained as a ground fire throughout. Flame heights varied from 1½ to 2 m while bark was blackened on the lee side of trees for 3-7 m, occasionally higher. One tree only "crowned out".

The pine fire spotted short distances ahead occasionally. One spot fire, extinguished 35 minutes after the start of the fire and then some 300 m from the head fire, may have come from the burning chip heap rather than from the fire in the pines.

Factors contributing to the fact that a crown fire did not develop are believed to be:-

- the relatively low quantities of ground fuel;
- the complete low pruning of the stand;
- the comparatively low stocking of the stand.

It is relevant that the conditions of atmospheric instability were conducive to crown fire formation.

5. SUPPRESSION

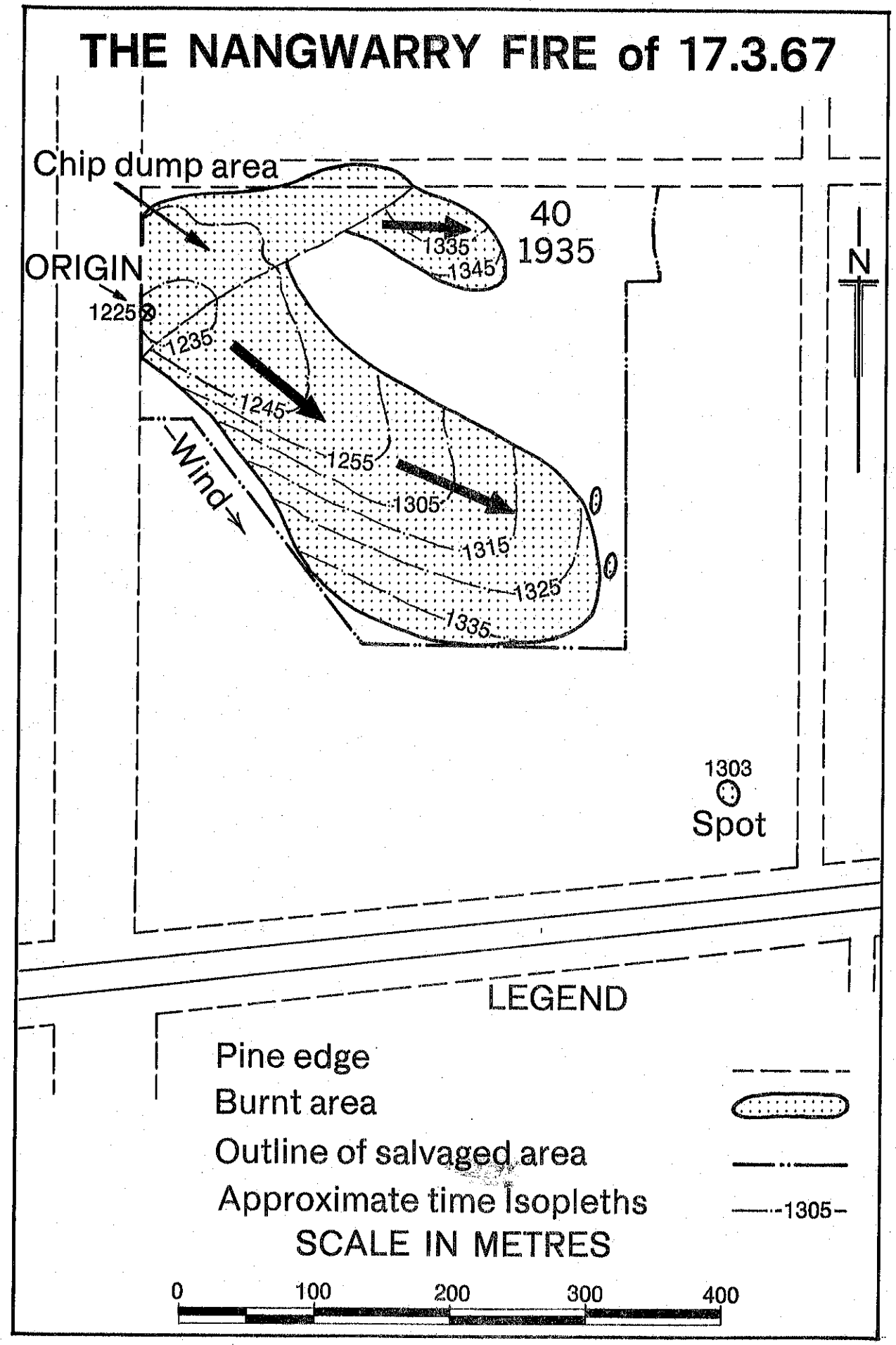
The forward movement of the fire was halted at 1335 hours and full control achieved shortly afterwards.

In view of the imminence of the expected wind change, the bulk of the suppression forces was directed to the eastern flank of the fire and six units, worked on this flank.

From 1245 until 1335 hours some 500 m of fire perimeter were extinguished by 6 fire trucks working in sectors. They used approximately 1800 litres of water in this time, i.e. 36 litre/m and 360 litre/min.

Because of the heavier fuel components, the fire edge was wetted down for a width of about 2 m, and a raked line followed this. The line so produced held throughout.

The area of plantation burnt was 5 hectares.


THE NANGWARRY FIRE of 17.3.67
Chip dump area
ORIGIN
1225
1235
1245
1255
1305
1315
1325
1335
1345
40
1935
Wind
N
1303
Spot
LEGEND
Pine edge
Burnt area
Outline of salvaged area
Approximate time Isopleths
1305
SCALE IN METRES
0
100
200
300
400

CASE HISTORY NO. 6

MT. BURR FIRE OF 19/1/73
(Woods and Forests Department Plantation)

1. ORIGIN

The fire commenced at 1040 hours on the edge of a 21 year old P.radiata plantation as yet unthinned, height about 21 m and ground fuels about 20 tonnes per ha.

2. METEOROLOGICAL CONDITIONS

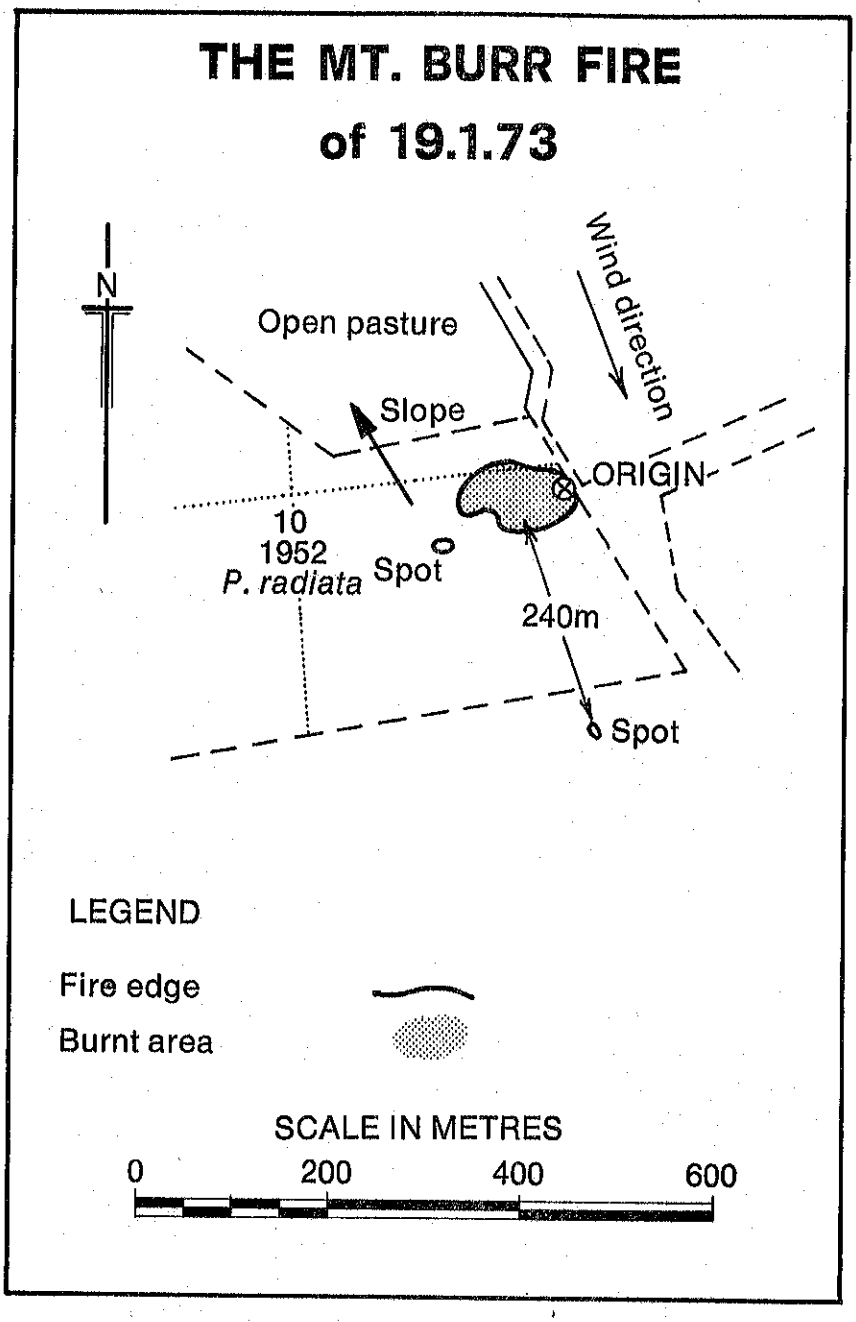
Temperature 34°C est. (33% at 0900 hours, 38° at noon)
Relative humidity 30% est. (38% at 0900, 22% at noon)
Wind speed 35 k.p.h.
Forest Fire Danger Index 30 V. High 21 at 0900 hours
No data on atmospheric stability available but unstable conditions considered likely.

3. FIRE SPREAD AND BEHAVIOUR

Ground fire throughout but a small group of trees 'flared' to the crowns. Spot fires occurred and were extinguished - longest spotting distance 240 m.

4. SUPPRESSION

Rapid and effective initial attack enabled total burnt area to be confined to 0.6 ha. Initial attack commenced at 1055 hours, control being achieved by 1107 hours. The final perimeter was 180 metres and 2700 litres of water were used (i.e. 15 litres/m and 225 litres/min).


THE MT. BURR FIRE
of 19.1.73
N
Open pasture
Slope
Wind direction
ORIGIN
10
1952
P. radiata
Spot
240m
Spot
LEGEND
Fire edge
Burnt area
SCALE IN METRES
0
200
400
600

CASE HISTORY NO. 7

PENOLA FIRE OF 18/1/73

(Woods and Forests Department Plantation)

1. ORIGIN

The fire commenced at about 1300 hours on the edge of a small dry peaty swamp within a pine plantation.
Cause - a camp fire not properly estinguished.
The fire moved across the peat swamp and entered P.radiata exceeding 30 m high and with ground fuel quantities 25-30 tonnes/ha.

2. METEOROLOGICAL CONDITIONS

Temperature 38^{0}C
Relative humidity 17%
Wind speed (average) 16-24 km/hour, gust to 40 km/h
Forest Fire Danger Rating 40 - Very High
No data on atmospheric stability, but unstable atmosphere considered very likely.

3. FIRE SPREAD AND BEHAVIOUR

Ground fire throughout with one or two trees 'flaring' into the crown. One spot fire detected, and immediately extinguished, 400 m from the fire.

4. SUPPRESSION

Rapid and effective initial attack enabled total burnt area (pines and swamp) to be confined to 3 ha of which the plantation area was 1.9 ha. Initial attack commenced at 1320 hours and fire rounded up by 1415 hours. Perimeter when extinguished 600 m and water used to this stage approximately 10000 litres (about 17 litres/m and 180 litre/min).