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INSECT ATTACK IN FIRE-DAMAGED PLANTATION TREES AT BULOLO IN PAPUA NEW GUINEA*

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Abstract

The progression of insect attack in sample plots of fire-damaged *Araucaria cunninghamii* and *Eucalyptus* spp. was assessed. Fungi occurring on plot trees during the study were identified and listed.

In the 12 week period following the fire, ambrosia beetle attack (mainly *Diapus pusillimus* and *Xyleborus perforans*) was recorded on 77% of *A. cunninghamii* trees and 94% of *Eucalyptus* spp. trees. Highest attack occurred on burnt *Eucalyptus deglupta*. A total of 40% of *Eucalyptus torelliana* trees in the plots were severely damaged by the bostrychid *Xylothrips religiosus*, most attacks occurring in the first 5 weeks after the fire. Termite damage to *Eucalyptus* spp. was minimal 12 months after the fire but 44% of scorched *A. cunninghamii* were heavily attacked by *Coptotermes pamuae* during this period.

Extensive sapstain caused by *Botryodiplodia theobromae* was noted in *A. cunninghamii* and *E. deglupta* 3 weeks after the fire. The decay fungus *Schizophyllum commune* was found on all tree species 4 weeks after the fire but was most prevalent on *A. cunninghamii*.

Introduction

Since the establishment of forestry plantations began in the Bulolo-Wau area in 1949 there have been few severe fires. In 1965 at Bulolo 122 ha of *Araucaria cunninghamii* were destroyed. In September 1972, 833 ha of *Araucaria* spp., 74 ha of *Pinus* spp. and 4 ha of *Eucalyptus* spp., totalling 911 ha or 12% of established plantations in the Bulolo-Wau area were destroyed by fire following unusually low rainfall. Of this damaged area only 59 ha of *A. cunninghamii* were considered sufficiently mature to salvage.

Prior to the studies reported here, there was no information from these plantations on tree survival following fire or upon the development of degrade due to insect attack. Fire-damaged *Eucalyptus* spp. were included with *A. cunninghamii* (the main plantation species) in the study since consideration was being given at this time to the replanting of burnt areas with eucalypts, in particular *E. torelliana*.

Materials and methods

The site chosen for the study was at Heads Hump Logging Area, Bulolo, where 16 ha of mixed plantation species had been destroyed by a ground fire in September, 1972. Four weeks after the fire, sample plots of *A. cunninghamii*, *Eucalyptus torelliana*, *Eucalyptus grandis*, *Eucalyptus citriodora* and *Eucalyptus deglupta* were selected on the basis of severity of burn. Trees were rated as burnt (foliage completely destroyed), scorched (at least one-third of crown surviving with green foliage) and unburnt. Plots of 50 trees (0.02 ha) within each of the above categories were established for *A. cunninghamii* and *E. torelliana*‡. The number of *E. grandis*, *E. citriodora* and *E. deglupta* trees varied because of the initial small plantings of these species (Table 2). The trees were numbered, and the height and diameter of each tree recorded.

At weekly intervals, for a period of 8 weeks, the numbers of ambrosia and bostrychid beetle holes were counted on the main stem of each tree to a height of 2 m from the base. This height was chosen for convenience of counting and because the zone of burning and scorching above 2 m varied considerably between stems. A colour coding system was used to mark new holes each week. The bark on the trees was left intact where possible. Inspection for termite attack and a survival rating for all trees in the plots were made at intervals of 3, 6 and 12 months after the fire. Survival was judged

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‡One burnt tree misidentified as *E. torelliana* was subsequently excluded from the study (Table 2).

by the regeneration of crown foliage and where doubt existed cambial samples from the main stem were examined. Inspections for sap-stain and other fungi were made at approximately monthly intervals for 6 months following the fire.

Twelve weeks after the fire at least 1 tree from each plot was felled and examined for insect attack. The diameters of holes caused by ambrosia and bostrychid beetles were measured using a Peak Lupe scale (x7). The trees were then split and insects collected from beneath the bark and from tunnels in the wood. Predators and parasites of these insects were also collected.

Five sticky traps were positioned in and adjacent to the study area to collect insects in flight, traps 1-4 being associated with fire-damaged *Eucalyptus* spp. and trap 5 with fire-damaged *A. cunninghamii* (Table 3). Each trap consisted of a 1 m square plywood sheet (4.8 mm thickness) coated on both sides with Osticon[1], a sticky-banding material containing the insecticide Trichlorphon 15% W/W (Gray, 1973a). The top of each board was 2.5 m above the ground. The numbers and identifications of insects caught in the traps were recorded at weekly intervals.

Temperature and rainfall data for the 12 week period of intensive observation following the fire were obtained from the meteorological station at the Forestry College, Bulolo, 5 km from the study area. A total of 335.5 mm of rainfall was recorded, 84 mm falling during the first week of the study. Average mean maximum and mean minimum temperatures over the 12 week period were 31.4 °C and 17.94 °C respectively.

Results

Insect attack

A. *Platypodidae and Scolytidae*

All tree species in the study area damaged by fire were attacked by ambrosia beetles (Table 1). At the first inspection, 5 weeks after the fire, ambrosia beetle attack was noted on 109 *Eucalyptus* spp. trees in the plots but no attack was found on burnt and scorched *A. cunninghamii* trees. The first ambrosia beetle holes in *A. cunninghamii* were recorded 6 weeks after the fire, 18 trees being attacked. Over the 12 week period following the fire, attack was recorded on 199 of the 212 fire-damaged *Eucalyptus* spp. trees in the plots and on 77 of the 100 *A. cunninghamii* trees. No attack occurred on the unburnt trees. Of the fire-damaged trees not attacked, most of the smaller ones had died and dried out rapidly while some others had been only lightly scorched and were alive 12 months after the fire. No attack was noted on these trees during subsequent inspections at 6 and 12 months after the fire.

The average number of holes per tree (i.e. on the basal 2 m of the stem) for each tree species in the burnt and scorched plots is shown in Figs. 1 and 2 respectively. The highest weekly count of new attacks was recorded 6 weeks after the fire for all tree species except *A. cunninghamii*. The increase was most noticeable for *E. deglupta* where an average of 22 new attacks per tree were counted (Fig. 1). Peak attack on scorched and burnt *A. cunninghamii* occurred at 10 and 11 weeks after the fire respectively. For all species, few new attacks were recorded 12 weeks after the fire.

The results of statistical analyses of the data for burnt and scorched plots are presented in Table 2. Bartlett's test for the homogeneity of variances was not significant at the 1% level. In the burnt plots after 12 weeks the mean number of attacks per tree on *E. deglupta* was significantly higher than for any other tree species. There was no significant difference between the number of attacks on *E. torelliana*, *E. grandis* and *E. citriodora* in both burnt and scorched plots. *Araucaria cunninghamii* trees had significantly fewer attacks than all other scorched trees and all burnt trees except *E. citriodora*. There was no significant difference (B = 2.86) between the number of attacks on burnt and scorched trees for all species except *E. deglupta* (There were no scorched trees for comparison). No evidence was found of a species x burn interaction using Scheffé's method at the 5% level.

[1] Osticon was developed by Imperial Chemical Industries for use in Papua New Guinea to control the cacao weevil *Pantorhytes szent-ivanyi* Marshall.

TABLE 1

SPECIES OF TIMBER BORING BEETLES COLLECTED DURING THE STUDY FROM STICKY TRAPS AND IN FIRE-DAMAGED STANDING TREES AT HEADS HUMP LOGGING AREA, BULOLO. PREVIOUS HOST RECORDS FOR SEVERAL OF THESE INSECTS ARE LISTED FOR COMPARISON.

Species	Sticky-trap	*Araucaria cunninghamii*	*Eucalyptus citriodora*	*Eucalyptus deglupta*	*Eucalyptus grandis*	*Eucalyptus torelliana*
Platypodidae						
Crossotarsus biconcavus Schedl		R	X			
Crossotarsus kuntzeni Schedl	X	R				X
Diapus pusillimus Chapuis	X	R		X	X	
Platypus chevrolati Chapuis	X	R				
Platypus excedens Chapuis	X	R				
Platypus jansoni Chapuis	X	R				X
Platypus pallidus Chapuis	X					
Platypus solidus Walker	X			X		
Platypus sp. n.					X	
Scolytidae						
Arixyleborus canaliculatus Eggers	X	R				
Hylesinus porcatus Chapuis	X					
Hylurdrectonus piniarius Schedl		X				
Poecilips philippinensis Eggers	X					
Poecilips vulgaris Eggers	X					
Xyleborus artestriatus Eichhoff	X					
Xyleborus perforans Wollaston		X	X			X
Xyleborus recidens Sampson				X		
Xyleborus similis Ferrari	X					
Xyleborus subagnatus Eggers	X					
Xyleborus sp.						X
Webbia pabo Sampson	X					
Bostrychidae						
Dinoderus minutus (Fabricius)	X					X
Xylopsocus gibbicollis Macleay						X
Xylothrips religiosus Boisduval						X
Cerambycidae						
Dihammus australis (Boisduval)		X				
Pterolophia sp.		X				
Curculionidae						
Sympiezoscelus sp. nr. *spencei* Waterhouse		X				
Illacuris laticollis (Pascoe)		X				
Aesiotes notabilis Pascoe		X				

X = Collected during study　　R = Recorded previously from this host at Bulolo, but not found in trees sampled during study.

TABLE 2

COMPARISON OF AMBROSIA BEETLE ATTACK ON 5 TREE SPECIES IN THE BURNT PLOTS AND 4 IN THE SCORCHED PLOTS. DIFFERENCES AT THE 5% LEVEL[1] AMONG MEANS IN EACH COLUMN ARE INDICATED BY DIFFERENT LETTERS.

Tree Species	Burnt Plots		Scorched Plots	
	No. of Trees	Mean No. attacks/ Tree ± S.E.	No. of Trees	Mean No. attacks/ Tree ± S.E.
E. deglupta	20	64.50a ± 10.79	—	
E. torelliana	49	16.86b ± 2.22	50	9.68d ± 1.57
E. grandis	50	11.82b ± 1.36	5	26.00d ± 5.89
E. citriodora	24	15.33bc ± 5.26	13	15.31d ± 3.39
A. cunninghamii	50	4.86c ± 0.97	50	3.36e ± 0.69

[1] Analyses of variance and "S method" of multiple comparison (Scheffé, 1959) after data subjected to transformation $\log_{10}(x + 1)$.

Attack on fire-damaged *E. deglupta* and *E. grandis* trees was primarily due to *Diapus pusillimus* Chapuis while *Xyleborus perforans* Wollaston was the main ambrosia beetle recorded from the other tree species. Several scorched *E. citriodora* trees were attacked by the large platypodid *Crossotarsus biconcavus* Schedl 4 weeks after the fire. All attacks were unsuccessful as the beetles were drowned by the copious resin flow exuded by these trees (Fig. 3). Holes of *Platypus solidus* Walker and *Platypus jansoni* Chapuis were common on *E. deglupta* and *E. torelliana* trees respectively. Only a few specimens of the remaining ambrosia beetles listed in Table 1 were collected from attacked trees during the study.

Of a total of 151 ambrosia beetles collected from the sticky traps during the period 1st November-19th December, 1972, 125 or 82.7% were *P. solidus*. Peak numbers of *P. solidus* were recorded 9 weeks after the fire (Table 3). Over the study period, the highest

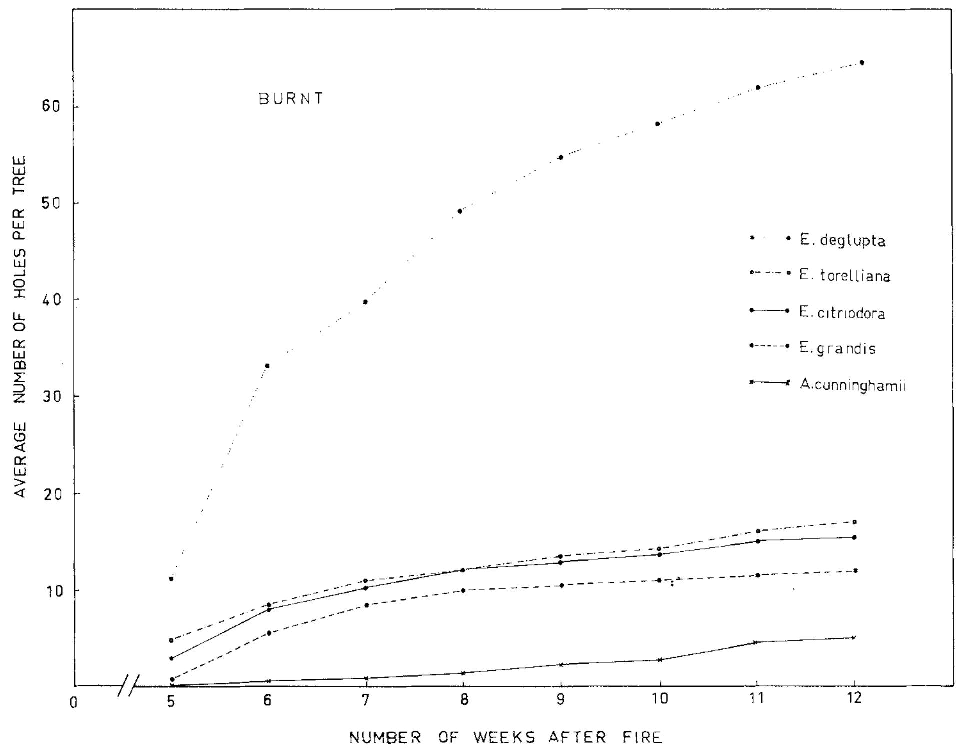


FIG. 1.—Ambrosia beetle attack on burnt trees at Heads Hump Logging Area, Bulolo.

TABLE 3

NUMBERS OF *PLATYPUS SOLIDUS* WALKER COLLECTED EACH WEEK FROM 5 STICKY TRAPS* AT HEADS HUMP LOGGING AREA, BULOLO.

Date	Trap 1		Trap 2		Trap 3		Trap 4		Trap 5		Total	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
7. xi.1972	2	5	3	1	0	1	1	2	0	0	6	9
14. xi.1972	0	0	1	0	1	0	3	2	0	0	5	2
21. xi.1972	2	2	0	1	3	3	3	1	2	0	10	7
28. xi.1972	2	3	1	2	9	6	9	12	1	0	22	23
5.xii.1972	0	0	2	0	6	2	6	4	0	0	14	6
12.xii.1972	4	2	2	2	2	1	1	2	0	1	9	8
19.xii.1972	0	0	0	0	1	0	0	2	1	0	2	2
Total	10	12	9	6	22	13	23	25	4	1	68	57

*Trap position 1 and 2: Along roadway approximately 200 m and 50 m respectively from fire-damaged *Eucalyptus* spp. plots.
3 and 4: Within fire-damaged *Eucalyptus* spp. plots.
5: Within fire-damaged *A. cunninghamii* plots.

numbers of *P. solidus* were collected from traps 3 and 4 in the fire-damaged *Eucalyptus* spp. plots, while few were recorded from trap 5 in the *A. cunninghamii* plots. There was no significant difference between the numbers of male and female *P. solidus* collected from the traps each week. Despite the abundance of *D. pusillimus* and *P. jansoni* on fire-damaged trees in the plots only a few specimens of each were recorded from the traps. Similar findings for these species in sticky trap collections at Bulolo were reported by Gray (1974). No *X. perforans* were collected from the traps.

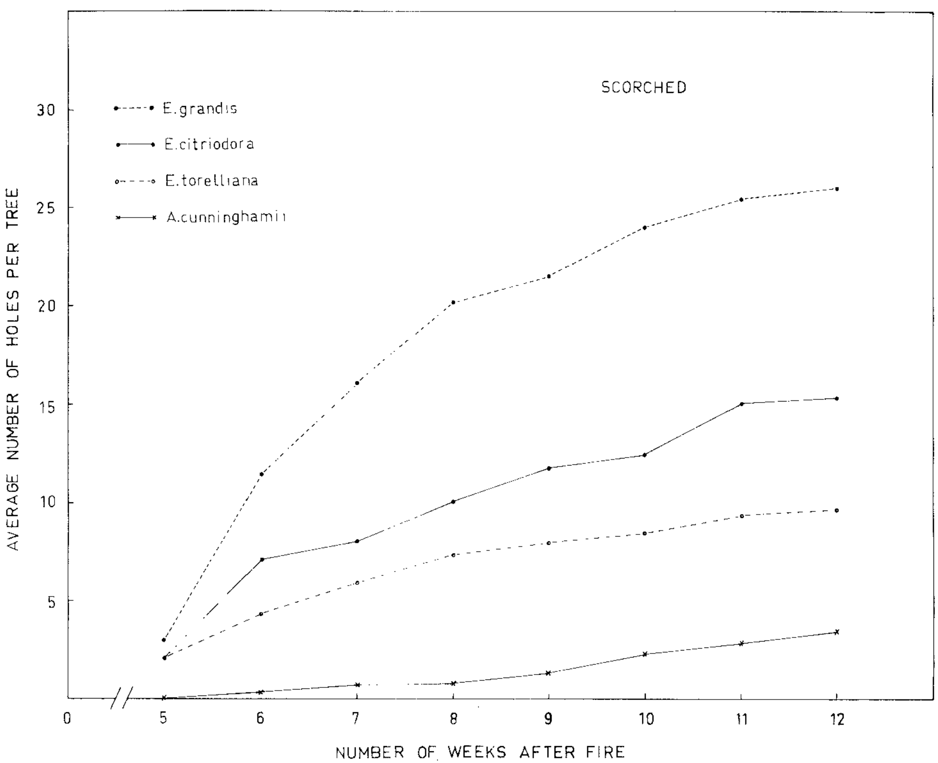


FIG. 2.—Ambrosia beetle attack on scorched trees at Heads Hump Logging Area, Bulolo.

Six scorched *A. cunninghamii* trees were attacked by the bark beetle *Hylurdrectonus piniarius* Schedl 3 months after the fire. This insect is commonly found on moribund *A. cunninghamii* trees in the Bulolo/Wau plantations and is of little economic consequence (Gray, 1973b).

Large numbers of adult *Phaenomerus* sp. (Curculionidae) and several *Nematidium posticum* Pascoe (Colydiidae) and *Cyphagogus elongatus* Kleine (Brenthidae) adults were collected from ambrosia beetle holes during the study. Members of these genera are all known predators of ambrosia beetles (Beeson, 1941).

B. *Bostrychidae*

Three species of Bostrychidae were found attacking *E. torelliana* subsequent to the fire: *Xylothrips religiosus* Boisduval, *Xylopsocus gibbicollis* Macleay and *Dinoderus minutus* (F.). No other tree species was attacked by these insects.

Adults of *X. religiosus* were found boring in the main stems of 56% of the trees in the burnt plot and 24% of the trees in the scorched plot. Holes of *X. religiosus* were easily distinguished by their size (2.8-3.4 mm diameter) from those of the ambrosia beetles present (0.5-1.8 mm diameter). The sapwood of most attacked trees was almost completely destroyed by larval and adult tunnelling (Figs. 4, 5).

No *X. religiosus* adults were collected from the sticky traps during the period of study. The main invasion flight of this insect probably occurred in the first 5 weeks after the fire prior to the erection of the traps. During this period, 94 and 22 holes were counted on the stems to a height of 2 m in the burnt and scorched plots respectively. Only 10 attacks were recorded subsequently in the burnt plot and 5 attacks in the scorched plot. The last new attack by *X. religiosus* occurred 9 weeks after the fire in the burnt plot and the first emergence holes were noted approximately 15 weeks after the fire. The pattern of attack is similar to that noted for bostrychids on *Eucalyptus maculata* billets in Australia (Erskine, 1965).

One burnt *E. torelliana* tree (height 12.0 m, diameter 12.1 cm), on which 10 initial attacks of *X. religiosus* had been recorded, was felled 4 months after the fire. A total of 62 first generation emergence holes were counted on the basal 2 m of the stem. A second tree (height 12.2 m, diameter 15.0 cm) was felled in the same plot 8 months later. *Xylothrips religiosus* holes on the basal 2 m of the stem numbered 240 (18 initial attacks) and on the remainder of the stem 250. Many of these holes were probably caused by first generation adults reinfesting the stem.

Xylothrips religiosus is the commonest powder post borer in Papua New Guinea (Gray and Wylie, 1974). It also occurs in Irian Jaya and has a wide range over the Pacific Islands and tropical Australian regions (Froggatt, 1927; Kalshoven, 1963).

A few *D. minutus* adults were found in the smaller branches of *E. torelliana* after the fire but little damage was caused. This was the only bostrychid collected from the sticky traps, one specimen being recorded from each of traps 1, 2 and 3 at 7, 10 and 11 weeks respectively after the fire. *Dinoderus minutus* is primarily a pest of bamboo in Papua New Guinea and many other tropical countries but has also been recorded from other plant species (Gray and Wylie, 1974; Beeson, 1941). It is very common in bamboo in the Wau/Bulolo area.

Xylopsocus gibbicollis was found only in the smaller branches of burnt *E. torelliana* trees and damage was minor. A similar preference for infesting the smaller branches of trees was reported by Kalshoven (1963) for *Xylopsocus capucinus* F. in Java. In Australia *X. gibbicollis* is common but it has been recorded only once previously from Papua New Guinea in 1947 (T. Fenner, pers. comm., 1973).

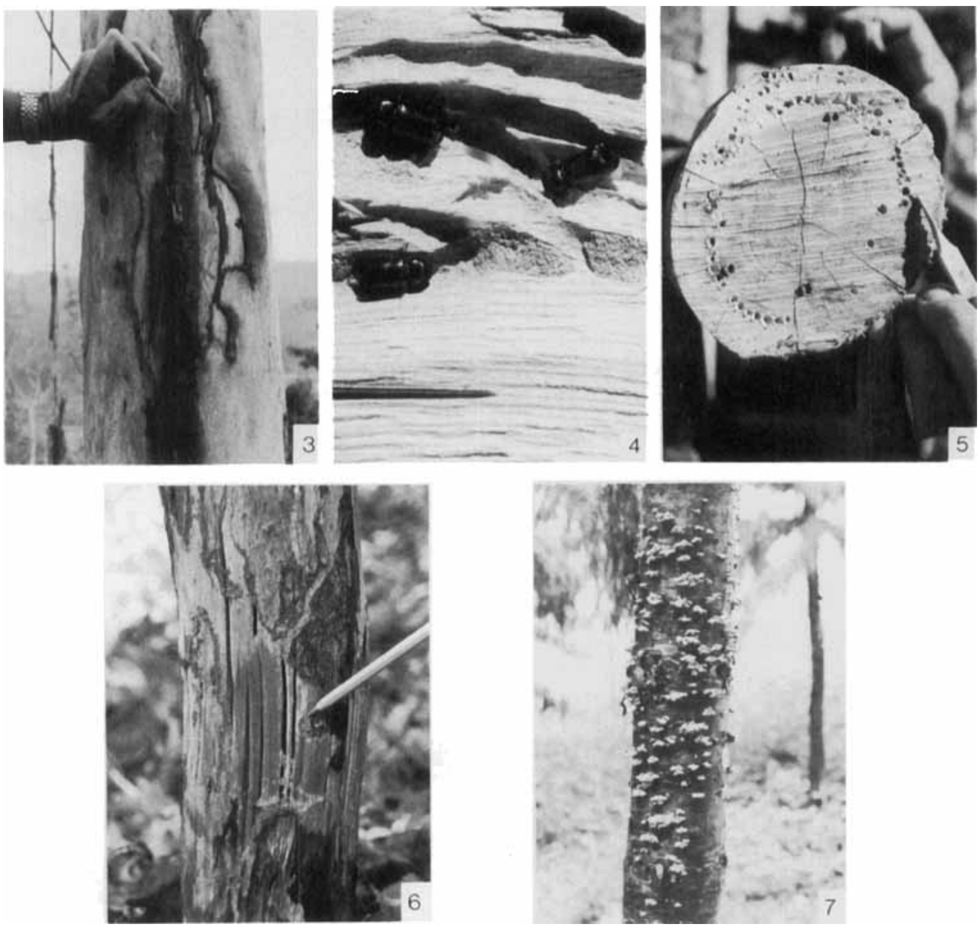
Several species of insects predacious on Bostrychidae were collected during the study. The passandrid *Hectarthrum heros* (F.), which is a common predator of wood boring larvae in many tropical countries and a known predator of bostrychid larvae in India (Beeson, 1941), was found in large numbers in holes of *X. religiosus*. The colydiid *Bothrideres nocturnus* Pascoe, the histerid *Teretriosoma somerseti* (Marseul), and the clerids *Cylidrus cyaneus* (F.), *Cylidrus* sp. and *Tenerus* sp. were also numerous in *X. religiosus* holes.

Cylidrus cyaneus was observed attacking an adult *X. religiosus* at the entrance of its hole. This predator is widely distributed in the Oriental and Australasian regions and has been recorded previously as a predator of both *Xylothrips* and *Xylopsocus* (Beeson 1941; Froggatt 1927; Kalshoven 1963).

C. *Isoptera*

Five species of termites, *Coptotermes elisae* (Desneux), *Coptotermes pamuae* (Snyder), *Microcerotermes biroi* (Desneux), *Nasutitermes* sp. and *Schedorhinotermes sanctaecrucis* (Snyder) were found attacking fire damaged trees in the study area. All species except *S. sanctaecrucis* have been collected previously in the Wau/Bulolo area (Gray and Wylie, 1974). The percentage of trees in the various plots attacked by termites is shown in Table 4.

Scorched *A. cunninghamii* trees were extensively damaged by *C. pamuae* (Fig. 6). After 12 months the lower stems of many of the attacked trees had been completely hollowed out and a few trees had fallen to the ground. No *C. pamuae* attack was found in the adjacent plot of burnt *A. cunninghamii*, but 2 trees were attacked by *S. sanctaecrucis*. Damage caused by this termite was slight and was confined to the roots



FIGS. 3-7.—(3) Copious resin flow exuded by scorched *E. citriodora* tree in response to attack by the platypodid *Crossotarsus biconcavus* Schedl. (4) Adults of *Xylothrips religiosus* Boisduval in stem of burnt *E. torelliana* tree at Heads Hump Logging Area, Bulolo. (Adult length approximately 7 mm). (5) Cross section of the stem of a burnt *E. torelliana* tree showing tunnels of *X. religiosus* in the sapwood. (6) Damage caused to the stem of a scorched *A. cunninghamii* tree by *Coptotermes pamuae* Snyder at Heads Hump Logging Area, Bulolo, 4 months after the fire. (7) Fruiting bodies of *Schizophyllum commune* on the stem of a scorched *A. cunninghamii* tree.

TABLE 4

PERCENTAGE OF TREES IN FIRE-DAMAGED PLOTS ATTACKED BY TERMITES AT 3, 6 AND 12 MONTHS AFTER THE FIRE

Tree species	Fire damage rating	No. of trees in plot	Percentage of trees attacked														
			Coptotermes elisae (Desneux)			*Coptotermes pamuae* (Snyder)			*Microcerotermes biroi* (Desneux)			*Nasutitermes* sp.			*Schedorhinotermes sanctaecrucis* (Snyder)		
			3	6	12	3	6	12	3	6	12	3	6	12	3	6	12
A. cunninghamii	Burnt	50	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
,,	Scorched	50	—	—	—	4	24	44	—	—	—	—	—	—	—	—	—
E. torelliana	Burnt	49	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—
,,	Scorched	50	—	—	—	—	—	2	—	—	—	—	—	2	—	—	2
E. grandis	Burnt	50	—	—	—	2	2	10	34	42	42	—	—	—	—	—	—
,,	Scorched	5	—	—	—	—	—	—	—	20	20	—	—	—	—	—	—
E. citriodora	Burnt	24	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,,	Scorched	13	—	—	8	—	—	—	—	—	—	—	—	—	—	—	—
E. deglupta	Burnt	20	—	—	—	—	—	—	—	30	30	—	—	—	—	—	5

and stem beneath the ground. Termite damage to *Eucalyptus* spp. trees was minimal after 12 months. Galleries of *M. biroi* were found in the outer sapwood of *E. grandis* and *E. deglupta* trees and the root systems of several trees were slightly damaged. Similar minor damage to *Eucalyptus* spp. was recorded for the other termite species listed.

Workers and soldiers of *Pericapritermes schultzei* (Holmgren) were found in the soil around the roots of 4 scorched *E. torelliana* trees and in a cavity in a "soft" stone at the base of another tree. No damage to the timber was observed. *Pericapritermes* appear to feed only on decayed and weathered material, possibly humus, and there are no records from sound wood (J. A. L. Watson, pers. comm., 1974). *Pericapritermes (Capritermes) schultzei* has not been recorded previously from Bulolo although it is known in Highland areas and the Sepik District (Barrett, 1965; Hill, 1942).

Microcerotermes biroi was present in the study plots prior to the fire. Abandoned galleries were noted on the stems of 4 burnt *E. grandis* trees immediately after the fire and 1 gallery was later reoccupied by *M. biroi.* No evidence was found of pre-fire infestation of plot trees by the other termite species although this may have occurred. Of note is the low incidence in plot trees of *C. elisae*, the dominant termite species in the Bulolo-Wau *A. cunninghamii* plantations (Gray and Buchter, 1969) and the abundance of *C. pamuae*, previously regarded as uncommon in the area.

The ant *Pheidole* sp. was the main predator of the termites when their galleries and nests were disturbed.

D. *Other insects*

Seven scorched *A. cunninghamii* trees were severely damaged by the large cerambycid *Dihammus australis* (Boisduval). Up to 3 exit holes, 1.0-1.5 cm in diameter, were counted on the main stem of each tree to a height of 2 m from the base. The holes were first noted during an inspection 12 months after the fire. *Dihammus australis* has a life cycle of 7-8 months (B. Gray, pers. comm., 1973). Larval tunnelling caused grooves up to 1.0 cm wide and 4.0 mm deep in the outer sapwood. Vertical pupal chambers 6-8 cm long and 1.0-1.5 cm in diameter were excavated at a depth of approximately 5 cm in the sapwood. *Dihammus australis* is extremely common in the *A. cunninghamii* plantations at Bulolo and Wau in slash during thinning operations (Gray and Wylie, 1974) and will attack moribund standing trees.

Two scorched *A. cunninghamii* trees were attacked by the cerambycid *Pterolophia* sp. Larval tunnelling grooved the outer sapwood of both trees and a pupal chamber was found just below the sapwood surface. An exit hole approximately 4.0 mm in diameter was noted 6 months after the fire. Two adult *Pterolophia* sp. were collected on the bark of another tree in the plot.

Adults and larvae of the curculionid *Sympiezoscelus* sp. nr. *spencei* Waterhouse were found under bark and tunnelling in the sapwood of 16% and 24% of *A. cunninghamii* trees in the burnt and scorched plots respectively. Larval tunnels averaged 3 mm in diameter and extended into the sapwood to a depth of 3-4 cm. Tunnels were numerous on most attacked trees, giving the timber a "wormy" appearance. A few larvae, pupae and adults of 2 other curculionids, *Illacuris laticollis* (Pascoe) and *Aesiotes notabilis* Pascoe were also collected from scorched *A. cunninghamii.*

A mass emergence of the cicada *Diceropyga* sp. occurred in all plots 10 weeks after the fire. A similar emergence of cicadas after fire was reported by French and Keirle (1969) in New South Wales.

A few adult *Eucorynus* sp. (Anthribidae) were found sheltering in holes of *Xylothrips religiosus* in scorched *E. torelliana* trees.

Fungal attack

Extensive sapstain caused by *Botryodiplodia theobromae* was noted in fire-damaged *A. cunninghamii* and *E. deglupta* 3 weeks after the fire. The timing of the attack was similar to that found for *Diplodia* species in fire-damaged *P. radiata* in New

South Wales (French and Keirle, 1969), and Victoria (Wright and Grose, 1970). *Botryodiplodia theobromae* is the dominant sapstaining fungus in Papua New Guinea (Levy, 1969).

At least 2 heterothallic species of the saprophytic fungus *Neurospora* were found on all fire-damaged trees in the plots. Only the conidial stages of the genus *Monilia* were observed (J. Simpson, pers. comm., 1972). A pink form of *Neurospora* sp. appeared within 3 weeks of the fire and was succeeded by an orange form 8 weeks after the fire. *Neurospora* ascospores must have been present in the area prior to the fire since generally they do not germinate readily and must be heat shocked to achieve any significant percentage of germination (Dwidjoseputro, 1961; Shear and Dodge, 1927).

A saprophytic fungus *Schizophyllum commune*, which causes whiterot of sapwood (Duncan and Lombard, 1965) was found on all tree species 4 weeks after the fire but was particularly prevalent on *A. cunninghamii* (Fig. 7). Decay caused by *S. commune*, once considered inconsequential, is known to reduce the strength of wood (Boyce, 1961). Another decay fungus, *Pycnoporus* sp., was found on *A. cunninghamii* 4 months after the fire. This is in contrast to the situation in fire-damaged *P. radiata* in New South Wales where no decay was found on standing trees and *S. commune* was first discovered on burnt stumps 11 months after the fire (French and Keirle, 1969). However, the heavy rain at Bulolo immediately following the fire would have contributed to the rapid spread of decay fungi whereas, in New South Wales, French and Keirle note that "the climate during the study period was drier than usual".

The following species were also noted on *E. deglupta* 4 months after the fire: *Fusarium* sp., *Aspergillus* sp., *Penicillium* spp., and *Paecilomyces* sp. In a final inspection of all plots 6 months after the fire, *Pleurotus* sp., *Trametes* sp., and *Daldinia concentrica* were recorded on *A. cunninghamii*; *Stereum* sp. on *E. citriodora*; and *Merulius* sp. on *E. torelliana* and *A. cunninghamii*.

Survival

Three months after the fire, all stems were dead in the burnt *A. cunninghamii* plot and in the burnt and scorched *E. grandis* plots. In the scorched *A. cunninghamii* plot, 68% and 20% of stems were alive at 3 months and 12 months respectively after the fire. Of the 40 dead stems in the plot, 21 were attacked by the termite *C. pamuae*. Eight of the 24 stems which died subsequent to the 3 monthly count were attacked by *C. pamuae*. In the plot of burnt *E. deglupta*, 95% of the stems were dead after 3 months and all stems were dead after 12 months.

The fire susceptibility of *E. torelliana* was difficult to assess because of the heavy bostrychid attack sustained by most stems in the burnt plot (36 stems). However, all 13 stems in this plot not attacked by bostrychids were dead at the end of 6 months. Since no termite attack and below average ambrosia beetle attack were noted, the cause of death was almost certainly fire. All stems in the burnt plot were dead after 12 months, compared with a 54% survival in the scorched *E. torelliana* plot. Of the 23 scorched stems which died, 3 were attacked by termites and 9 others by bostrychids.

Eucalyptus citriodora exhibited the greatest fire resistance with 62.5% and 100% survival of stems in the burnt and scorched plots respectively, 12 months after the fire. The thick bark of *E. citriodora* probably contributed greatly to the survival of these trees.

Of the total of 73 dead stems recorded in the *E. torelliana* plots, 55 showed extensive coppicing from the base after 6 months. Coppicing was noted in 13 of the 55 dead *E. grandis* stems and in 6 of the 9 dead *E. citriodora*.

For all species, the mean diameter and height of trees rated as scorched was greater than that of trees in the burnt plots. However, after 12 months in all plots, a number of the larger trees had died while a few smaller trees survived. No relationship was found between tree size and survival after fire in the plots examined.

Discussion

Considerable timber loss and degrade occurred in all fire-affected tree species as a result of insect and fungal attack. Termites caused extensive damage to *A. cunninghamii*, many plot trees being almost completely destroyed after 12 months. Termite damage to *Eucalyptus* spp., although minimal at the completion of the study would increase subsequently as decay facilitated colony establishment. Surveys by Greaves *et al* (1965, 1967) in 3 eucalypt forest areas in New South Wales demonstrate the large losses by termites that may result from even relatively minor fire damage. Although few bostrychid beetle attacks were recorded initially on *E. torelliana* stems, the number of holes on the surface does not give an accurate picture of the degree of damage internally (i.e. to the sapwood). In the pole preservation industry, it is essential that the sapwood is undamaged to ensure a complete sheath of preservatives around the heartwood and generally any timber showing bostrychid attack is rejected for treatment (Erskine, 1965). Ambrosia beetle attack, while not seriously reducing the strength of timber, except when galleries are close and decay fungi are established (Neumann and Harris, 1974), presents an unsightly appearance and infested timber is usually down-graded or rejected for commercial use. Similar reduction in timber value is caused by the presence of sapstain while decay fungi cause direct timber loss and provide conditions for termite establishment.

When considering salvage operations following fire, it is important to know how long the standing tree remains free from significant degrade. For example, in fire-damaged *Pinus radiata* in New South Wales, French and Keirle (1969) note that sapstain on standing trees was not serious until 7 months after the fire and no insect attack had occurred after 8 months. In Victoria, 3 years after fire in mountain ash (*Eucalyptus regnans*) forests, Hogan (1944) reports that trees left standing were not damaged to any important extent by borers (mainly platypodids) and observes that salvage could be delayed until physical deterioration commenced.

At Bulolo, insect and fungal attack was extensive on all tree species studied within 3 months of the fire. Although no salvage was attempted because of the immaturity of most fire-damaged trees, in the event of future fires salvage operations (e.g. clear felling and protective storage of logs) should commence immediately to prevent significant degrade and timber loss.

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References

BARRETT, J. H. (1965).—The occurrence of termites in the New Guinea Highlands. *Papua New Guin. agric. J.*, **17**(3): 95-98.

BEESON, C. F. C. (1941).—"The ecology and control of the forest insects of India and the neighbouring countries" (Vasant Press 1st reprint 1961: Dehra Dun).

BOYCE, J. S. (1961).—"Forest Pathology" (Ed. 3. New York, McGraw-Hill Book Company, Inc.: Toronto and London).

DUNCAN, C. G. and LOMBARD, F. F. (1965).—Fungi associated with principal decays in wood products in the United States. *U.S. Forest Service Research Paper* W. 0-4, 31 pp.
DWIDJOSEPUTRO, D. (1961).—Studies on *Monilia sitophila* from Indonesia. *Bull. Torrey bot. Club*, **88:** 404-411.
ERSKINE, R. B. (1965).—Some factors influencing the susceptibility of timber to Bostrychid attack. *Aust For.* **29**(3): 192-198.
FRENCH, J. R. J. and KEIRLE, R. M. (1969).—Studies in fire-damaged Radiata Pine plantations. *Aust For.* **33**(3): 176-180.
FROGGATT, W. W. (1927).—"Forest insects and timber borers" (Govt. Print. Office: Sydney).
GRAY, B. (1973 a).—Observations on insect flight in a tropical forest plantation. I. Flight activity of *Hylurdrectonus araucariae* Schedl (Coleoptera: Scolytidae). *Z. angew. Ent.*, **74:** 113-119.
GRAY, B. (1973 b).—The immature stages of *Hylurdrectonus araucariae* Schedl and *H. piniarius* Schedl (Coleoptera: Scolytidae: Hylesininae). *J. Entomol., B.*, **42**(1): 49-58.
GRAY, B. (1974).—Observations on insect flight in a tropical forest plantation. III. Flight activity of Platypodidae (Coleoptera). *Z. angew. Ent.*, **75:** 72-78.
GRAY, B. and BUCHTER, J. (1969).—Termite eradication in *Araucaria* plantations in New Guinea. *Commonw. Forest. Rev.*, **48**(3): 201-207.
GRAY, B. and WYLIE, F. R. (1974).—Forest tree and timber insect pests in Papua New Guinea II. *Pacif. Insects* **16**(1): 67-115.
GREAVES, T., McINNES, R. S. and DOWSE, J. E. (1965).—Timber losses caused by termites, decay and fire in an alpine forest in New South Wales. *Aust. For.* **29**(3): 161-174.
GREAVES, T., ARMSTRONG, G. J., McINNES, R. S. and DOWSE, J. E. (1967).—Timber losses caused by termites, decay, and fire in two coastal forests in New South Wales. *CSIRO Aust. Div. Entomology Tech. Pap. No. 7*, pp. 4-18.
HILL, G. F. (1942).—"Termites (Isoptera) from the Australian Region" (CSIRO: Melbourne).
HOGAN, T. W. (1944).—Pin-hole borers of fire-killed Mountain Ash I. Survey and field observations. *J. Agric. Vict. Dept. Agric.* **42:** 513-524.
KALSHOVEN, L. G. E. (1963).—Notes on the biology of Indonesian Bostrychidae (101). *Ent. Ber., Amst.* **23:** 242-257.
LEVY, C. (1969).—Sapstain of stored wood products and its control. A review (Project RPE 6.2. Research Note held in the Library, Department of Forests, Papua New Guinea) 14 pp.
NEUMANN, F. G. and HARRIS, J. A. (1974).—Pinhole borers in green timber. *Aust. For.*, **37**(2): 132-141.
SCHEFFÉ, H. (1959).—"The analysis of variance" (Wiley: New York).
SHEAR, C. L. and DODGE, B. O. (1927).—Life histories and heterothallism of the red bread-mould fungi of the *Monilia sitophila* group. *J. agric. Res.*, **34:** 1019-1042.
WRIGHT, J. P. and GROSE, R. J. (1970).—Wood degrade due to fire. *Aust. For.*, **34**(3): 149-160.

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