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PRIMARY AND SECONDARY ATTRACTION IN *GNATHOTRICHUS SULCATUS* (LECONTE) (COLEOPTERA: SCOLYTIDAE) AND THEIR APPLICATION IN PEST MANAGEMENT

by

JOHN ALEXANDER McLEAN

B.Sc., University of Auckland, 1965
M.Sc., University of Auckland, 1968

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

in the Department

of

Biological Sciences

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ABSTRACT

Ethanol and the aggregation pheromone, sulcatol (6-methyl-5-hepten-2-ol), were deployed for the last week of the months April to October 1974, in traps at 10 locations in a commercial sawmill at Chemainus, British Columbia. Sulcatol was the only effective treatment for capturing the ambrosia beetle *Gnathotrichus sulcatus* (LeConte). Traps baited with it alone or in combination with ethanol caught over 98% of the 3,098 *G. sulcatus* captured. No significant interaction between ethanol and sulcatol was evident. Seasonal trend in numbers of beetles caught was distinctly bimodal. Locations with the greatest catches of beetles were those where unseasoned lumber was stored, suggesting that beetles either emerged from or were attracted to such lumber.

Eggs, larvae, pupae and a callow adult of *G. sulcatus* found in western hemlock boards 2 months after initial attack, indicated that *G. sulcatus* can survive and reproduce in sawn lumber and thus presents a threat of introduction to lumber-importing countries. In 1975, the first verified attacks on unseasoned lumber by *Trypodendron lineatum* and *G. retusus* were recorded.

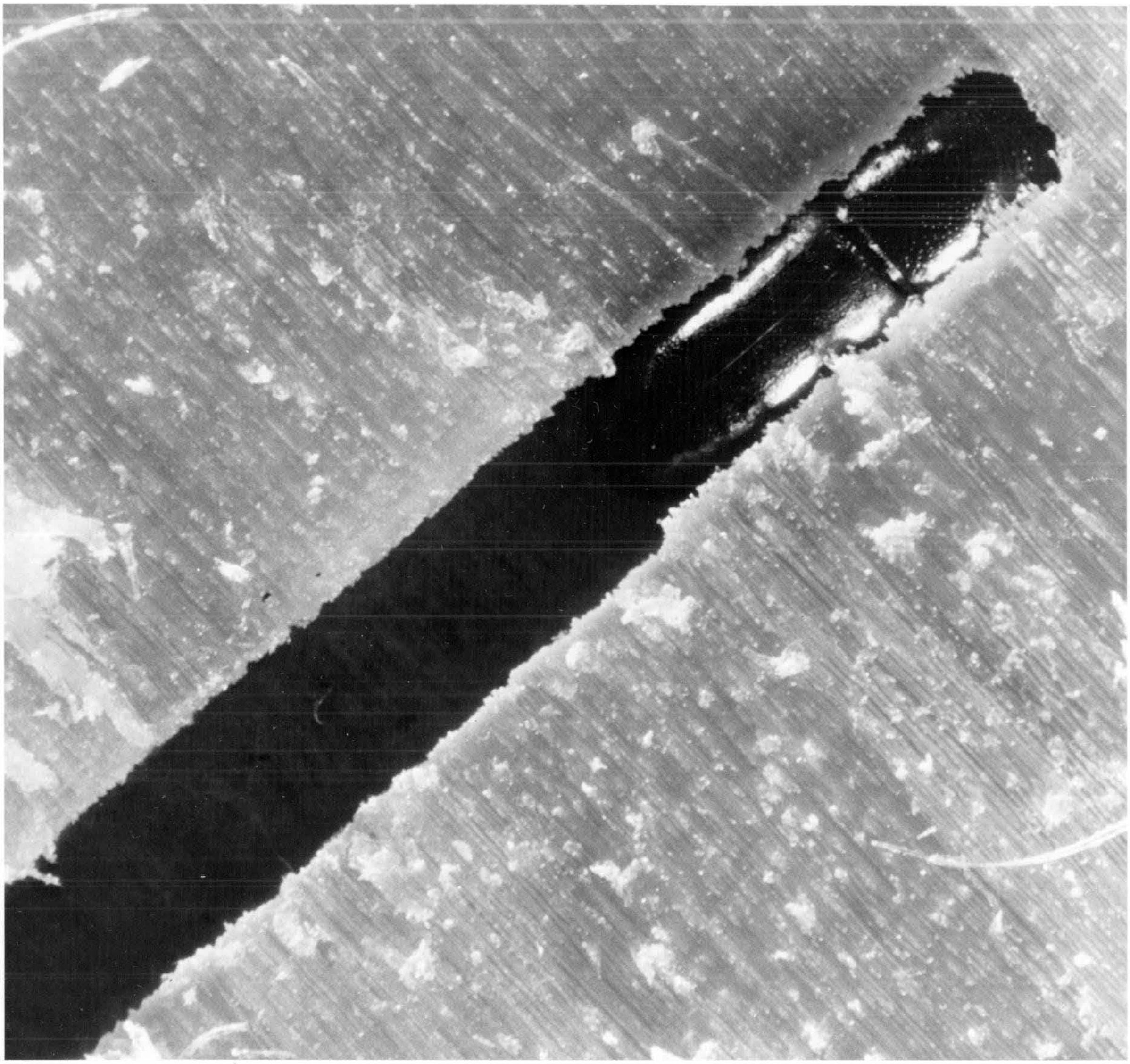
In 1975, traps were baited with sulcatol full-time in 1 location, for alternate biweekly periods in 2 locations, and left unbaited in a control location. Freshly-sawn test loads of lumber were set out at weekly intervals in each location. Suppression ratios [number of beetles caught on traps/(number of estimated beetles in lumber + number caught on traps)] were highest in the location where traps were continuously baited with sulcatol. In this location, suppression ratios of 0.70

and 0.87 were recorded for male and female beetles, respectively, indicating that sulcatol-baited traps have good potential for suppression of mill populations of *G. sulcatus*. Greatest attack was recorded on test loads 2 to 4 weeks after sawmilling, suggesting development of secondary attraction in the first week, and decline in host suitability due to drying after 4 weeks. Significantly greater attack on lumber piles near sulcatol-baited traps indicated an area response by male beetles. Future control of *G. sulcatus* in sawmills may utilize sulcatol-baited traps, placed next to "trap" piles of attractive fresh slabbing which could subsequently be disposed of.

In the University of British Columbia Research forest, Maple Ridge, B.C., 4 Douglas-fir trees were felled at each of 3 locations, and 4 western hemlock trees were felled at each of 3 other locations on 18 April 1974. Logs and their respective stumps were baited with ethanol and/or sulcatol on 26 April, 1 unbaited log and stump served as controls in each location. *G. sulcatus* attacks increased rapidly, reaching a maximum in June and July, followed by a steady decrease until October. Over half the attacks were on stumps, in which attack density reached 683.5/m^2. The majority of attacks were on stumps and logs baited with sulcatol or sulcatol plus ethanol. A significant interaction between sulcatol and ethanol occurred on Douglas-fir. Significantly more beetles attacked ethanol-baited western hemlock stumps and logs than unbaited controls. Stumps baited with sulcatol and then treated with ethanolic solutions of systemic insecticide may be used to trap and kill field populations.

In field experiments, the optimum release rates for sulcatol and ethanol were 100 mg/day and 10 g/day, respectively. Vertical cylindrical wiremesh sticky traps were more effective than horizontal wiremesh cylinders, a flat wiremesh trap, or a barrier trap. In the laboratory, both sexes of *G. sulcatus* were attracted to western hemlock sawdust and ethanol. The response of females to each substance alone was greater than that of the males, while the male response was greater to the combination. Isolation and identification of host-produced attractants in addition to ethanol will provide new materials to be used in applied control of *G. sulcatus*.

Frontispiece. A male *Gnathotrichus sulcatus* constructing a 1.2 mm diameter gallery in a board sawn from western hemlock sapwood. The female will deposit her eggs in niches made in the walls of the tunnel. Fungus introduced by the boring male will grow on the wood providing larvae and adults with food. The dark-staining fungus and pin hole tunnels degrade the lumber and so cause a considerable economic loss to the forest industries in British Columbia



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INTRODUCTION

The ambrosia beetle, *Gnathotrichus sulcatus* (LeConte), is one of the most common wood-boring insects which attacks recently-felled trees in the conifer forests of the Pacific Northwest (Mathers 1935, Prebble and Graham 1957). While never as abundant as the holarctic species *Trypodendron lineatum* (Olivier), during the early spring mass attack period, *G. sulcatus* continues to initiate attacks from May through November. Unlike *T. lineatum*, which requires logs that are several months "old" after felling (Prebble and Graham 1957, Dyer and Chapman 1965), *G. sulcatus* can attack logs within the first week after felling (Mathers 1935, Cade et al. 1970).

The attacking beetles bore directly through the bark into the sapwood, and construct gallery systems perpendicular to the grain, by following mainly the spring wood growth rings (Graham, Kinghorn and Webb 1950). As the beetles tunnel, fungal spores are released from their pre-coxal mycetangia (Farris 1963, Schneider and Rudinsky 1969). Three species of xylophagous fungi, *Ambrosiella sulcati* Funk, *Raffaelea sulcati* Funk, and *Graphium* sp have been isolated from *G. sulcatus* galleries in Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco (Funk 1970). The mycelia and fruiting bodies are considered to be the major food of *G. sulcatus* larvae and adults (Farris 1963).

Eggs are laid in niches cut in the sides of the gallery, and the larvae construct "cradles" in which they feed on the fungus growing on the surrounding wood. Pupation takes place in the cradles, and the resultant adults emerge to reattack the same or new host trees. Development from egg to adult may take about 2 months if conditions are favorable. There are usually 2 generations per year, the second or summer generation overwintering without diapause in the host, primarily as larvae or callow adults.

Emergence from the host and flight begin in the spring when daily temperatures exceed 15°C (Daterman, Rudinsky and Nagel 1965). The timing of maximal flight activity is regulated by light intensity (Rudinsky and Schneider 1969). In flight, the beetles are guided to host material by odor cues emanating from susceptible logs (Graham and Werner 1956, Chapman 1963). One such odor cue from attractive western hemlock, *Tsuga heterophylla* (Raf.) Sarg., has been identified as ethanol (Cade, Hrutifiord and Gara 1970). Ethanol is the most concentrated volatile component in the wood of attractive Douglas-fir and amabilis fir, *Abies amabilis* (Dougl.) Forb. (Moeck 1970). It is not present in fresh wood and is thought to be produced by anaerobic processes when translocative input of oxygen is prevented (Graham 1968).

Secondary attraction (Borden, VanderSar and Stokkink 1975) has been demonstrated under field conditions for *G. sulcatus* (Cade 1970) and in the laboratory (Borden and Stokkink 1973). An aggregation pheromone, present in the boring dust and hindgut of male beetles, was isolated, identified as 6-methyl-5-hepten-2-ol, synthesized, and given the trivial name sulcatol (Byrne et al. 1974). In field trials, traps baited with a racemic mixture of synthetic sulcatol attracted large numbers of both sexes of *G. sulcatus* despite competition from natural host and beetle odors (Byrne et al. 1974).

Together with other ambrosia beetles, especially *T. lineatum* and *G. retusus* (LeConte), *G. sulcatus* causes considerable economic loss by degrading wood products, especially sawlogs and peeler logs (McBride and Kinghorn 1960, Richmond and Radcliffe 1961). The presence of black-stained ambrosia beetle galleries (commonly referred to as pinholes) in the sapwood edges of larger dimension lumber, requires that it be resawn to produce clear lumber resulting in considerable economic loss (Richmond 1968). The presence of ambrosia beetles in exported lumber from the west coast of North America (Milligan 1970) has led to quarantine problems in importing countries that have extensive exotic forests (Graham and Boyes 1950). A recent interception in New Zealand of live *G. sulcatus* larvae in sawn Douglas-fir timber from the Pacific Northwest (Bain 1974) emphasizes the need for protection of freshly-sawn lumber.

My objectives were:

1) to evaluate ethanol and sulcatol, alone and together, as potential pest management agents in the forest and in a commercial sawmill;
2) to assess the effect of attractant release rates and trap design on the response of beetles in the field;
3) to elucidate the role of ethanol and other host odors in *G. sulcatus* attraction; and
4) to evaluate the capacity of *G. sulcatus* to infest and reproduce in freshly-sawn, unseasoned lumber.

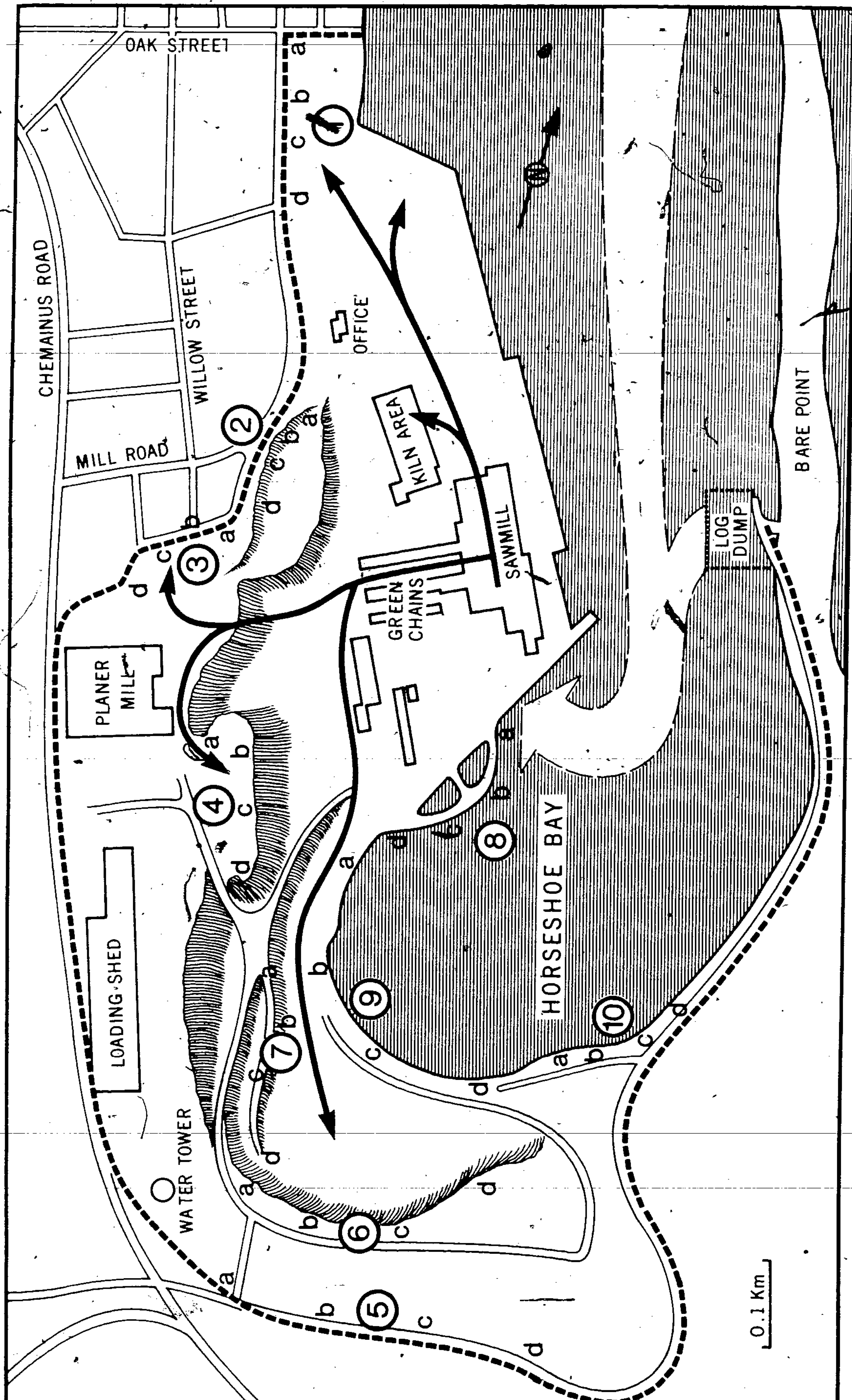
SURVEY FOR *GNATHOTRICHUS SULCATUS* IN A COMMERCIAL SAWMILL WITH THE PHEROMONE, SULCATOL

Infestation of freshly-sawn, unseasoned lumber by the ambrosia beetle *Gnathotrichus sulcatus* (LeConte) is of continuing concern to the forest industries of British Columbia (Richmond 1968). Such infestations have caused quarantine problems in export markets, e.g., in Australia (Graham and Boyes 1950) and New Zealand (Milligan 1970, Bain 1974). In this study at MacMillan Bloedel Ltd., Chemainus Division Sawmill, Vancouver Island, B.C., in 1974, the objectives were: to test sulcatol-baited traps as a detection, survey and potential population control tool; to test ethanol as an attractant alone, and as a possible synergist for sulcatol; to establish seasonal trends in beetle occurrence; and to determine the distribution of *G. sulcatus* throughout the mill area.

Methods

Groups of 4 traps were set out in 10 locations throughout the mill area and positioned so as not to interfere with mill operations (Fig. 1). The shortest distance between any 2 traps was 25 m. The traps, described by Byrne et al. (1974), were 0.3 m^2 cylinders of wire mesh coated with Stickem Special supported on poles approximately 1.5 m above the ground (see Fig. 23). Each group of 4 traps consisted of: an unbaited control with an empty vial, a trap baited with 2 ml of 95% ethanol, 1 with approximately 60 mg undiluted sulcatol, and 1 with 2 ml of 95% ethanol and 60 mg sulcatol in separate vials. The sulcatol was synthesized as described by Byrne et al. (1974).

Fig. 1. Map of MacMillan Bloedel Ltd., Chemainus Sawmill, Vancouver Island, B.C., showing trap locations 1 to 10 and trap sites a to d at each location. Dotted line delineates perimeter of work area of the mill. Clear arrow indicates direction of log movement in water. Log booms stored temporarily in Horseshoe Bay. Dark arrows indicate pathways of movement of freshly-sawn, unseasoned lumber


OAK STREET
CHEMAINUS ROAD
WILLOW STREET
MILL ROAD
OFFICE
KILN AREA
SAWMILL
GREEN CHAINS
LOG DUMP
BARE POINT
PLANER MILL
HORSESHOE BAY
LOADING SHED
WATER TOWER
0.1 Km

All volatiles were released from 4 ml vials with screw caps pierced by a 4 mm diameter hole. Vials were enclosed in an inverted 64 ml glass jar with a plastic snap-on cap pierced by 12 holes 4 mm in diameter. The glass jar assembly was taped to the top of the trap's supporting pole. From such a system, under constant laboratory conditions of 20°C and 68% R.H., the 24-hr evaporation rates of 95% ethanol and sulcatol were 180 mg and 2.5 mg, respectively.

While trap sites remained fixed, the allocation of the treatments at each location was by use of random numbers. The traps were operated for the last week in each month, from the first flight month, April (Daterman et al. 1965), through October 1974, the last month in which a major flight was expected (Byrne et al. 1974). All ambrosia beetles were removed from the traps at the end of the week and stored temporarily in Shell household cleaning solvent. When not in use, the traps were unbaited and covered with a plastic bag. In the laboratory the beetles were air dried, identified to species, sexed, and stored in 70% ethanol.

All data were transformed to $x'=\log_{10}(x+1)$ before analysis of variance following the rationale of Williams (1951) and Moore and Tukey (1954).

Results and Discussion

Species Captured

Of the 3,158 ambrosia beetles captured, 3,098 were *G. sulcatus*, 17 were *G. retusus* (LeConte) and 43 were *Trypodendron lineatum* (Olivier). There was no indication that *G. retusus* or *T. lineatum* responded to any of the treatments. Very few other scolytids were captured, with no apparent response to any treatment. No effort was made to collect, count or identify these beetles.

Effectiveness of Treatments

The replicated factorial design of this experiment allowed an evaluation to be made of the effectiveness of ethanol and sulcatol when used alone and of their interaction when used together (Table I). Sulcatol was the only significant main effect ($P<0.01$). The mean 1-week catches in each month by treatment and sex are shown in Table II.

The male:female ratio of beetles trapped at sulcatol treatments was 1:1.69 (n=1,630). At no time did it approach the 1:2.65 level reported by Byrne et al. (1974) who trapped their beetles in a selectively logged forest area and caught 24.9 beetles/trap-day compared with the 3.1/trap-day in this study. The ratio of beetles trapped at the ethanol plus sulcatol treatment was 1:1.41 (n=1,420). Of the 38 beetles captured by the ethanol treatments, 25 were males, a possible indication of the reported role of ethanol as a primary attractant for *G. sulcatus* (Cade et al. 1970). The weekly evaporation rate in this experiment was low, seldom approaching the 2 ml deployed in the vials. The large response by *G. sulcatus* males reported by Moeck (1971) was to traps releasing approximately 10 gm ethanol/trap/day (H. A. Moeck,[1] personal communication).

---

[1] Pacific Forest Research Centre, 506 West Burnside Road, Victoria, B.C.

Table I. Analysis of Variance table for *Gnathotrichus sulcatus* caught in the Chemainus Sawmill, B.C., April-October 1974

Sources of Variation	df	MS	F[a]
Treatments			
Main Effect Ethanol	1	0.003	0.06
Main Effect Sulcatol	1	44.775	913.78**
Interaction Ethanol plus Sulcatol	1	0.069	1.41
Between:			
Sexes of Beetles	1	0.161	3.29
Months	6	1.681	34.31**
Locations	9	2.994	61.10**
First Order Interactions			
Sex x Treatment	3	0.179	3.65*[b]
Treatment x Month	18	0.472	9.63**[b]
Treatment x Location	27	0.711	14.51**[b]
Sex x Location	9	0.011	0.22
Sex x Month	6	0.062	1.27
Location x Month	54	0.137	2.80**[b]
Error	423	0.049	

[a] Significance levels indicated: *, P<0.05; **, P<0.01.

[b] These reported probabilities may vary slightly due to non-additivity effects as indicated by Tukey's test.

Table II. Mean catches per 1-week sampling period of *Gnathotrichus sulcatus*, by treatments, in the Chemainus Sawmill, April-October 1974 (n=7)

Treatment	$\bar{x}$ Catch (±1 S.E.)	
	Males	Females
Control	1.14 ± 0.34	0.29 ± 0.18
Ethanol	3.57 ± 1.96	1.86 ± 1.10
Sulcatol	86.71 ± 33.05	146.29 ± 69.23
Ethanol plus sulcatol	84.00 ± 19.90	118.71 ± 27.81

Seasonal Occurrence

A distinct seasonal variation occurred in the numbers of male and female *G. sulcatus* captured (Fig. 2). A small spring peak was followed by a much larger peak in late summer. These results are consistent with reports of "heavy flights" of beetles in the mill area during May and September, over a 4-year period, 1967 to 1970 (L. Cobb,[2] personal communication). Possible correlation between flight peaks and changes in log or fresh lumber inventory was not investigated. However, the data corroborate field studies which record moderate flight of *G. sulcatus* in May (Cade 1970) and in May to June (Daterman et al. 1965), and peak flights in late summer (Cade 1970, Byrne et al. 1974). The male:female ratio of the 3,098 beetles caught was 1:1.52. It varied from 1:1.08 in June (n=77) to 1:1.85 in August (n=1,098).

Variability Between Locations and Trap Sites

The number of *G. sulcatus* caught at each of the locations throughout the mill are recorded in Table III. Fifty-seven percent (n=1,766) of all beetles caught were trapped at location 4. This location was used to store freshly-sawn 50 mm x 100 mm western hemlock prior to its being processed through the planer mill. The next highest numbers of beetles were captured at locations 7, 1, and 3. All 4 locations have 1 feature in common; they are the first storage areas of newly-sawn lumber.

There is no conclusive evidence as to the origin of the captured beetles. Low catches at locations 2 and 5, near the inland perimeter

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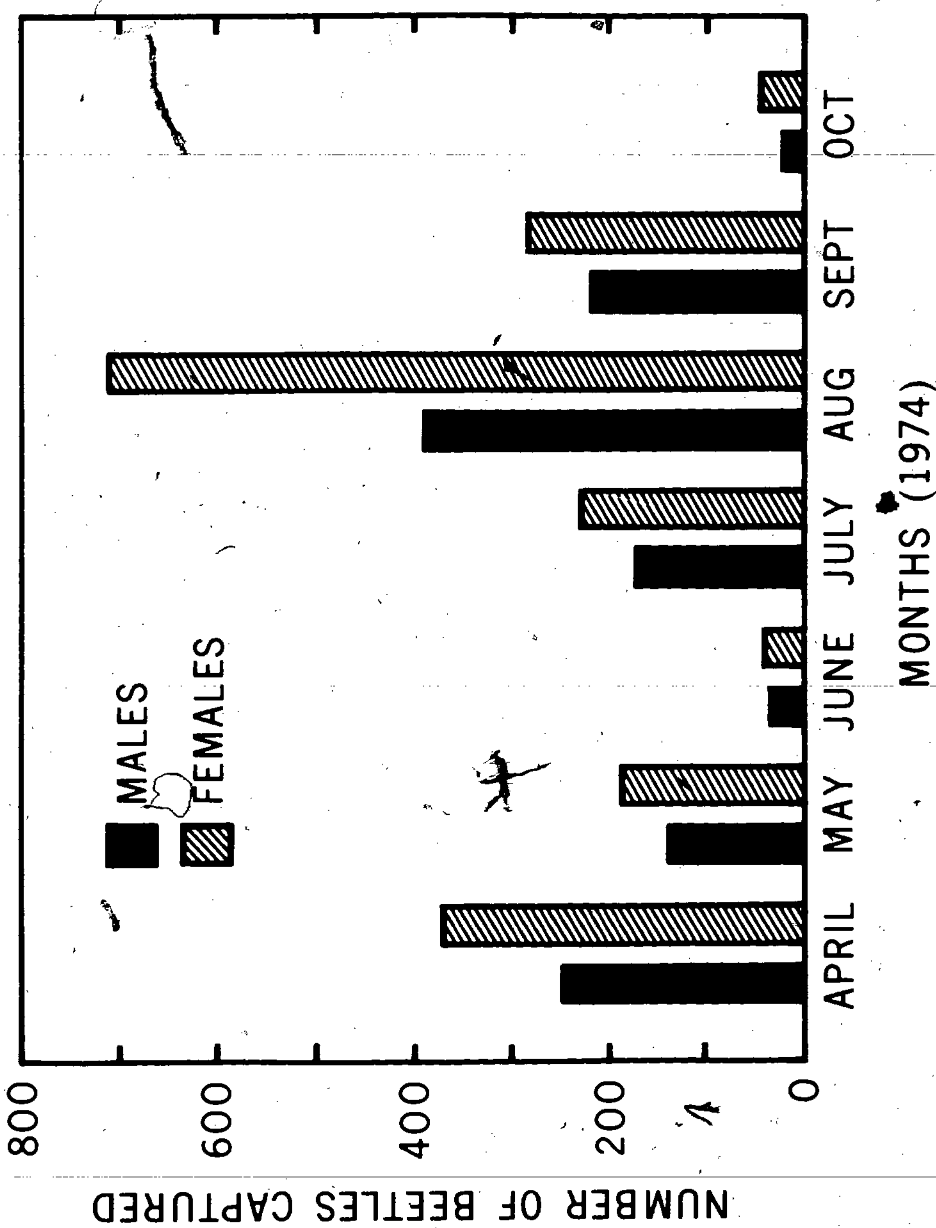
[2] Quality Control Officer, Chemainus Division Sawmill, MacMillan Bloedel Ltd., Vancouver Island, B.C.

Fig. 2. Variation in total catch of *Gnathotrichus sulcatus* in monthly sampling periods at the Chemainus Sawmill, April-October 1974



NUMBER OF BEETLES CAPTURED
0
200
400
600
800
MALES
FEMALES
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
MONTHS (1974)

Table III. Total catches of *Gnathotrichus sulcatus* at each location in the Chemainus Sawmill during 1974

Location	Total Number Beetles Caught	% of Total	Catch Significantly Greater Than Location(s)[a]
1. Assembly Yard, Western Boundary	316	10.2	2,5,8,9,10
2. Home Yard, Western Boundary	29	0.9	-
3. Planer Mill Yard, Northern Boundary	174	5.6	2,8,9
4. Planer Mill Yard, Eastern Boundary	1,766	57.0	1,2,3,5,6,7,8,9,10
5. Water Tower Yard, Southern Boundary	97	3.1	2,8
6. Water Tower Yard, Northern Boundary	130	4.2	2,8,9
7. Pit Lumber Yard, Western Boundary	402	13.0	1,2,3,5,6,8,9,10
8. Bark Settling Ponds, Seaward Boundary	18	0.6	-
9. Pit Lumber Yard, Seaward Boundary	58	1.9	8
10. South Shore of Horseshoe Bay	108	3.5	2,8

[a] Neuman-Keuls Test on ranked, transformed data ($P<.05$).

fences of the mill (Fig. 1), indicate that the beetles originate from within the mill area or from logs in the booming ground. Low numbers of beetles on traps at shoreline locations 8, 9, and 10 suggest that few are flying from the log booms into the mill and support the hypothesis that *G. sulcatus* emerges from drying lumber in the mill yards and re-attacks nearby, "attractive" stored lumber. However, if beetles were to gain sufficient altitude on leaving boomed logs, as has been proposed in the initial dispersal flights of other scolytids, e.g., *Conophthorous coniperda* (Schwarz) (Henson 1962), they might fly over locations 8, 9, and 10, and then orient preferentially towards locations 4, 7, 1, and 3 from which odors of both pheromones and freshly-sawn lumber emanate.

Within some locations, it appeared that more beetles were caught at certain trapsites. A comparison of mean catches to sulcatol-baited traps at each site in the 3 most active locations is recorded in Table IV. The number caught on a trap has been expressed as a percentage of the catch per sampling period at the location. While trap site 4a accounted for 35.5% (n=1,105) of all beetles caught in the mill, it was also baited 6 times with sulcatol. Therefore on a mean proportional catch basis it was bettered by trap sites 1d and 7b. Other trap sites, such as 1a, 4b, and 7a appeared to be clearly inferior. No indications of what constitutes a superior trap site appear from the analysis of the data or observation of the environment surrounding individual trap sites. For example, in location 4, all trap sites were equidistant (2-3 m) from piles of fresh lumber. Therefore, proximity to sources of attraction can be discounted as a cause of variability at this location. Until

Table IV. Mean percent *Gnathotrichus sulcatus* caught per sulcatol treatment at each trap site in 3 active locations, April-October 1974[a]

Trap	No. Times Baited With Sulcatol[b]	Mean Percent Beetles Caught When Trap Baited With Sulcatol[b]	Range
4a	6	62.5	31.2 - 79.0
4b	2	28.1	24.5 - 31.8
4c	2	44.0	20.4 - 67.5
4d	4	42.6	23.0 - 68.8
7a	5	24.0	0 - 60.0
7b	6	69.2	40.0 - 92.8
7c	1	40.5	nil
7d	2	46.8	22.0 - 71.5
1a	2	14.0	0 - 28.0
1b	3	54.8	10.3 - 92.1
1c	3	51.9	4.2 - 88.0
1d	2	72.0	48.0 - 100.0

[a] Data from June and October samples at location 1 not included as fewer than 15 beetles were caught.

[b] Includes all treatments with sulcatol alone or with sulcatol plus ethanol. Locations and trap positions are given in Fig. 1.

definitive criteria can be established, selection of optimal trap sites in applied pheromone control programs must be by trial and error.

First Order Interactions

The nonsignificance of Sex x Location and Sex x Month interactions (Table I) indicate that the overall sex ratio of beetles in the mill site throughout the season was relatively constant. The significant Sex x Treatment interaction (Table I) is a reflection of the differing responses of male and female beetles to the treatments. More male than female *G. sulcatus* were caught at ethanol-baited traps while more female than male *G. sulcatus* were caught at traps containing sulcatol, alone or in combination with ethanol (Table II).

Treatment x Month and Treatment x Location interactions are significant (Table I), indicating that the response to the treatments used varied throughout the season and within the mill site itself. With regard to the seasonal response, there was in particular a low June catch to ethanol plus sulcatol treatments (n=16) compared with sulcatol alone treatments (n=59) and an increase in ethanol catches in August and September (n=10 and 22 respectively). There was a greater response to sulcatol-baited traps at locations 1, 5, and 7 whereas at other locations the total response to ethanol plus sulcatol traps was greater. There are no obvious causes for these varying responses to treatments.

The significant Location x Month interaction (Table I) shows that the relative proportion of beetles captured at locations varied throughout the season. The overall ranking of locations is shown in Table III. While the catches at location 4 were the highest of all locations in all months, the catches at location 7 were bettered by locations 3 and 6 in July and location 1 in August. The interaction is a measure of such variation.

Assessment of Results, and Possible Future Applications of Sulcatol

As no reliable alternative methods of sampling *G. sulcatus* populations exist, it is not possible to determine what percentage of the total population was caught. However, several factors suggest that the sulcatol-baited traps may prove to be an effective method of gaining semiquantitative population estimates.

Populations of *G. sulcatus* were visually assessed as being light to moderate in 1974 when compared with populations in previous years (H. Hagg,[3] personal communication). The data reflect this trend, particularly when the relatively few beetles caught in the mill area are compared with the far greater numbers captured at the same times in a selectively logged forest containing much larger populations. The seasonal trend in beetles captured appears to be real, since it corresponds with the known bimodal seasonal flight patterns of *G. sulcatus*. Furthermore, greatest numbers of beetles were trapped at locations previously considered by visual assessment to be problem areas. Thus, the efficiency of the sulcatol-baited traps appears to be high.

These results indicate that sulcatol could be used as an inexpensive, reliable detection and survey tool that is considerably more accurate than currently-used visual methods. In operations processing export

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[3] Quality Control Officer, Chemainus Sawmill Division, MacMillan Bloedel Ltd., Vancouver Island, B.C.

lumber, sulcatol-baited traps could be used to indicate the onset of spring flights, seasonal fluctuations, and the beginning of "safe" winter periods, as well as to delineate major problem locations. In importing countries, sulcatol (and other scolytid pheromones) might be used as a sensitive detection tool at unloading and processing areas.

GNATHOTRICHUS SULCATUS ATTACK AND BREEDING IN FRESHLY-SAWN LUMBER

The attack by ambrosia beetles on freshly-sawn lumber in mill yards is of continuing concern to the forest industries in British Columbia (Richmond 1968). The objective of this 1974 study was to assess the extent of attack by and breeding of *Gnathotrichus sulcatus* (LeConte) in freshly-sawn lumber at the MacMillan Bloedel Ltd. Sawmill, Chemainus, B.C.

Methods and Materials

A load of 50 mm x 100 mm, western hemlock (ca 2,500 board feet) awaiting processing through the planer mill was observed to be under attack by *G. sulcatus* on 22 May. It was allowed to remain undisturbed until 29 July when half the load was turned and boards showing fresh boring dust were removed to the laboratory for dissection. On 21 August, during the late August peak flight of *G. sulcatus* (Fig. 2), a load of 50 mm x 150 mm, western hemlock (ca 2,500 board feet) near the planer mill was observed to be under attack. This load was left undisturbed until broken down 22 October. Boards containing initial attacks which had been marked in August, and all those under current attack, as evidenced by fresh boring dust, were removed to the laboratory.

Results

Early Summer Infestation

The entrance tunnels of 14 galleries dissected, penetrated at right angles to the freshly-sawn surface (indicating that attack was initiated after the sawmilling process), and then extended perpendicular to the grain of the board as in field-attacked logs (Prebble and Graham 1957). Each gallery had only 1 entrance/exit and did not intersect other galleries.

Eight galleries, all showing very little fungus growth, contained single, actively boring males. One female was found alone in a gallery, and in another instance, a long gallery contained 2 egg niches but no adults. Four galleries were dissected in which an adult of each sex was present.

The main tunnels extending from the radial entrance tunnel followed the annual rings, mainly in the spring wood. The best developed gallery system, in a board cut from the outer sapwood, had 4 such tunnels. Both parent beetles, as well as 5 egg niches, 2 larvae, 3 pupal chambers, 1 pupa and 1 callow adult were found. There was a good growth of ambrosia fungus. Although *G. sulcatus* larvae have been recorded in imported lumber from the Pacific Northwest (Bain 1974), this is the first time that a callow beetle, indicating completion of the life cycle, has been recorded in lumber attacked after sawmilling.

There was one *Xyleborus saxeseni* (Ratzeburg) gallery but no beetles, brood chamber or progeny were found in it.

Late Summer Infestation

Seventeen marked entries, showing no evidence of boring dust, varied in length between 18 and 133 mm ($\bar{x}$=56 mm) and were no longer occupied. Galleries occupied by males alone (n=7) ranged in length from

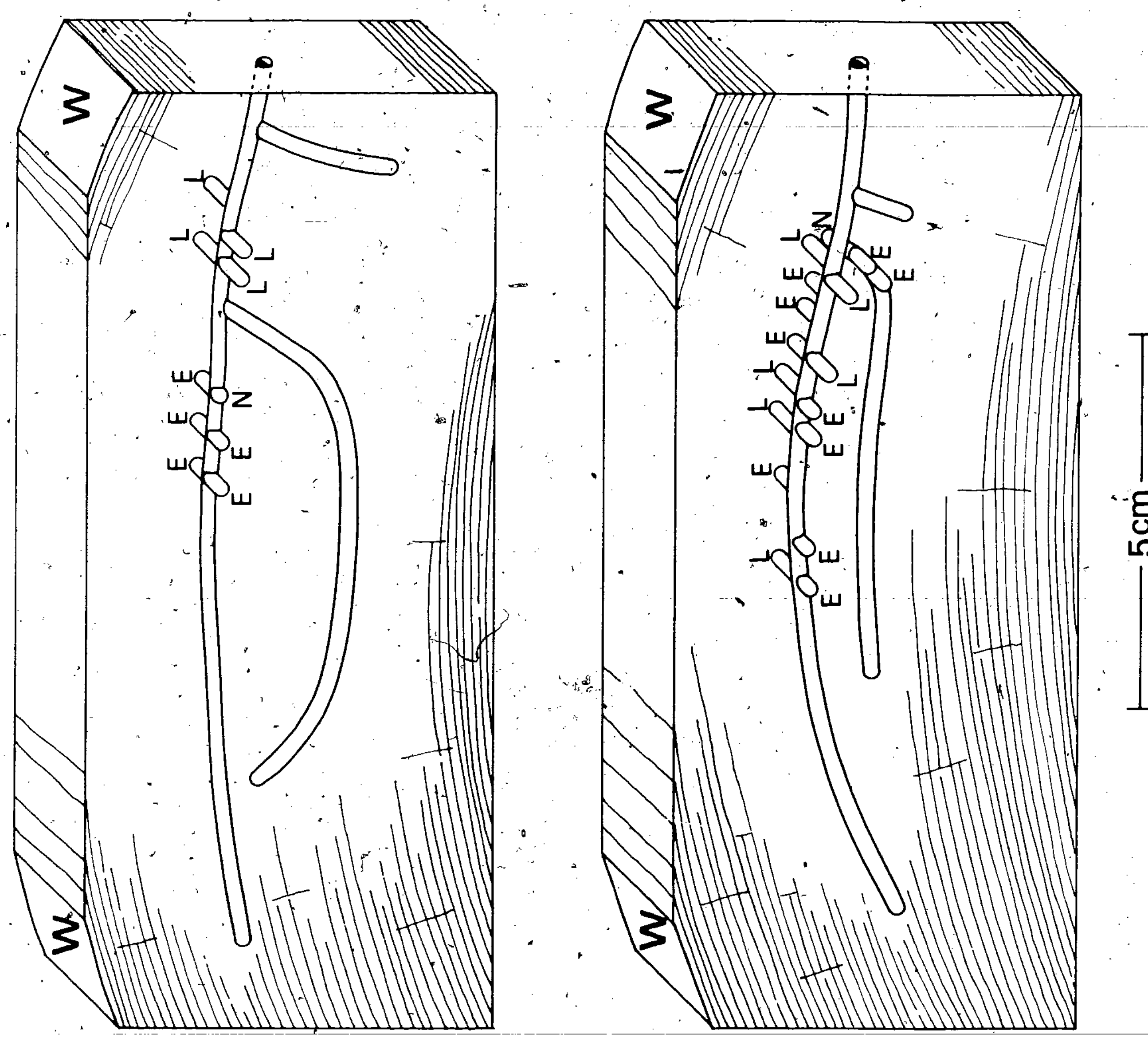
25 to 80 mm ($\bar{x}$=51.4 mm). In both cases, there was very little fungus development. One female was found alone in a 22 mm gallery. Twelve galleries containing both a male and a female beetle, varied in length from 64 to 167 mm ($\bar{x}$=105.1 mm), significantly longer (t-test, $P<0.01$), than empty galleries or those occupied by only 1 beetle. In all cases, there was good ambrosia fungus development. The 2 most extensively developed galleries, respectively, contained 5 and 10 egg niches, 5 and 8 eggs, and 4 and 6 occupied larval niches (Fig. 3), a total brood production of 9 and 14. No progeny had developed to the pupal stage at the time of dissection.

Seventeen *Trypodendron lineatum* (Olivier) galleries, most probably originating from attacks on logs, varied in length between 1 and 32 mm ($\bar{x}$=12.9 mm), but as expected in October, contained no beetles. Although *T. lineatum* has been intercepted in lumber at foreign ports (Milligan 1970, Bain 1974), there is no evidence that it attacks unseasoned lumber. A 21 mm gallery of *X. saxeseni* contained a single female which had not yet formed a brood chamber or laid eggs.

Discussion

The forest industries' concern that *G. sulcatus* may attack green lumber is well founded. Parent adults can survive in such lumber for at least 2 months, easily within the time taken for shipments from Canada to reach overseas importing countries that often have developing exotic conifer industries. The production of vigorous broods, including many larvae and pupae and 1 callow adult, within 2 months suggests that fairly

Fig. 3. *Gnathotrichus sulcatus* galleries in unseasoned western hemlock board 2 months after attack in late August, 1974. Note galleries penetrating at right angles from a freshly sawn face and the arrangement of egg niches (E), empty niches (N) and larval niches (L). Each gallery contained both parent adults. The presence of wane (W) indicates that the board was cut from the sapwood of the log


W
W
L
E
N
5cm

large numbers of progeny potentially could emerge from imported lumber.

Only 1 live *X. saxeseni* was found. However, its introduction into and establishment in New Zealand (Milligan 1969) indicates that it too should be of concern. *T. lineatum* is apparently no threat to lumber even though it causes the major damage to logs in the field in B.C. Although none was found in the infested lumber examined, *T. lineatum* might survive and be transported in lumber sawn in late spring or early summer from infested logs.

Insecticidal control of ambrosia beetles to protect export-bound lumber will continue to be justifiable in the absence of better control methods.

SUPPRESSION OF *GNATHOTRICHUS SULCATUS* (LECONTE) USING SULCATOL-BAITED TRAPS IN A COMMERCIAL SAWMILL

The results of a 1974 survey (Chapter II) suggested that sulcatol should be tested as a means of intercepting *Gnathotrichus sulcatus* (LeConte) before they are able to infest vulnerable lumber. Unlike programs directed at bark beetles in large tracts of forest (Cox 1972, Bedard and Wood 1974), a sawmill-based program would challenge a more limited and potentially manageable population. This situation is particularly true for the Chemainus Sawmill in which the only significant source of beetles appears to be infested logs transported to the mill site from distant logging operations. The objective of this subsequent study was to test whether sulcatol-baited traps could be used to trap out *G. sulcatus* in the sawmill area and thus reduce attack on lumber.

Methods

The 4 locations for study were those where the highest numbers of beetles were captured in a 1974 survey (Table III). The locations were (1) the North Planer Mill Yard, (2) the South Planer Mill Yard, (3) the Assembly Yard, and (4) the West Road to the Pit Yard (corresponding to locations 3, 4, 1, and 7 respectively in Fig. 1). Four trap sites (A, B, C and D) were set up at 25 m intervals around the perimeter of each location. Sulcatol was released from an open 4 ml vial within an inverted 64 ml glass jar with a perforated plastic lid. The jar was taped near the top of a pole supporting a 0.3 m^2 cylindrical wiremesh sticky trap (Byrne et al. 1974) (see Fig. 23). Traps were set out on

24 April; those in location 1 were left unbaited, those in location 2 were baited continuously with 0.5 ml sulcatol and those in locations 3 and 4 were alternately baited and unbaited for opposite 2-week periods. On 1 May, 2 baited traps were also set out on piles, 100 m offshore in the booming ground. All traps were cleared weekly. The beetles were stored temporarily in cleaning solvent, and identified and sexed on return to the laboratory.

Test loads of freshly-sawn 50 mm-thick Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, or western hemlock, *Tsuga heterophylla* (Raf.) Sarg. (estimated minimum volume of 3 m^3/load) were set out at weekly intervals in each location from 1 May to 3 July when labor problems precluded the availability of freshly-sawn lumber. They were removed at the end of the fourth week until 3 July, after which all loads were left in place. Every week the test loads were checked for fresh attacks which were marked and counted to assess the attack on lumber of known age.

A weekly survey was also made of 25 loads within each location. Those on the shaded periphery were checked first as they were usually the most frequently attacked in previous years (H. Hagg,[4] personal communication). Checks made within the storage areas confirmed the susceptibility of peripheral loads. Only accessible sides of yard loads were monitored whereas both sides of test loads were always checked. Very few attacks were observed in the end surface of boards. No attacks were found in interior boards within 4 attacked test loads broken down during the course of this investigation.

[4] Quality Control Officer, Chemainus Sawmill Division, Vancouver Island, B.C.

Attack by *Gnathotrichus* spp. was distinguished from that of *T. lineatum* by use of a tapered probe (Kinghorn 1957). It was not possible to distinguish between *G. sulcatus* and *G. retusus* attack by this technique. Measurement of gallery diameters with an ocular scale at a magnification of 50x disclosed that there is an overlap in the diameter of galleries constructed by these beetles, although those of *G. retusus* ($\bar{x}$=1.33 mm, SD=±0.04, n=92) were significantly larger (t-test, P<0.001) than those of *G. sulcatus* ($\bar{x}$=1.27 mm, SD=±0.04, n=100). Heavily attacked boards were taken from test loads before their removal from the yards and dissected in the laboratory to confirm the identity of attacking beetles. Offcuts, showing ambrosia beetle galleries, were collected from the chipper chain each week and dissected to ascertain which species of beetles were being transported into the mill.

Core samples, approximately 2 cm long and 4 mm in diameter were taken from 29 freshly attacked boards in lumber piles, as well as from boards directly above and below. The cores were transported in sealed 4 ml vials to the laboratory, where percentage moisture was determined by weight loss following oven drying at 70°C for 48 hrs. On 11 September, core samples were taken from 12 boards in yard loads which had been attacked, but in which the galleries were no longer showing accumulations of boring dust.

Data were transformed to $x'=\log_{10}(x+1)$ before analyses of variance.

Results

Of the 6,428 ambrosia beetles captured on the sticky traps, 80.5% were from location 2 (Table V) which was baited continuously. This location, south of the Planer Mill, was the site of greatest *G. sulcatus* captures in 1974. The significant, but as yet unexplained, superiority of certain trapsites (Table V) also corroborates results obtained in 1974 (Table IV). There were large numbers of *T. lineatum* caught in locations 1 and 2 as well as some on the boom traps. Although most of the *G. retusus* were captured in location 2, 23.1% of the total captured were on the 2 boom traps.

There was a steady increase of attacks by *G. sulcatus* on lumber in location 1, the unbaited control, during May, reaching a peak in the first week of June (Fig. 4). Small numbers of attacks were recorded in July. In location 2, a similar pattern of lumber attack was seen even though large numbers of beetles were being captured on baited traps (Fig. 5). Both these yards were cleared of lumber in mid-June and gradually refilled with freshly-sawn lumber during late June and early July.

Baiting traps for alternating bi-weekly periods in locations 3 and 4 (Figs. 6, 7), produced similar results as in location 2, but with fewer beetles being caught when the traps were unbaited. The attack on lumber in location 4 was high during late May to early June, primarily on large dimension timbers (30 cm square and larger) with much vulnerable sapwood. This location was cleared of lumber around 18 June and subsequently very little attack on lumber was recorded while traps caught numerous beetles when baited (Fig. 7).

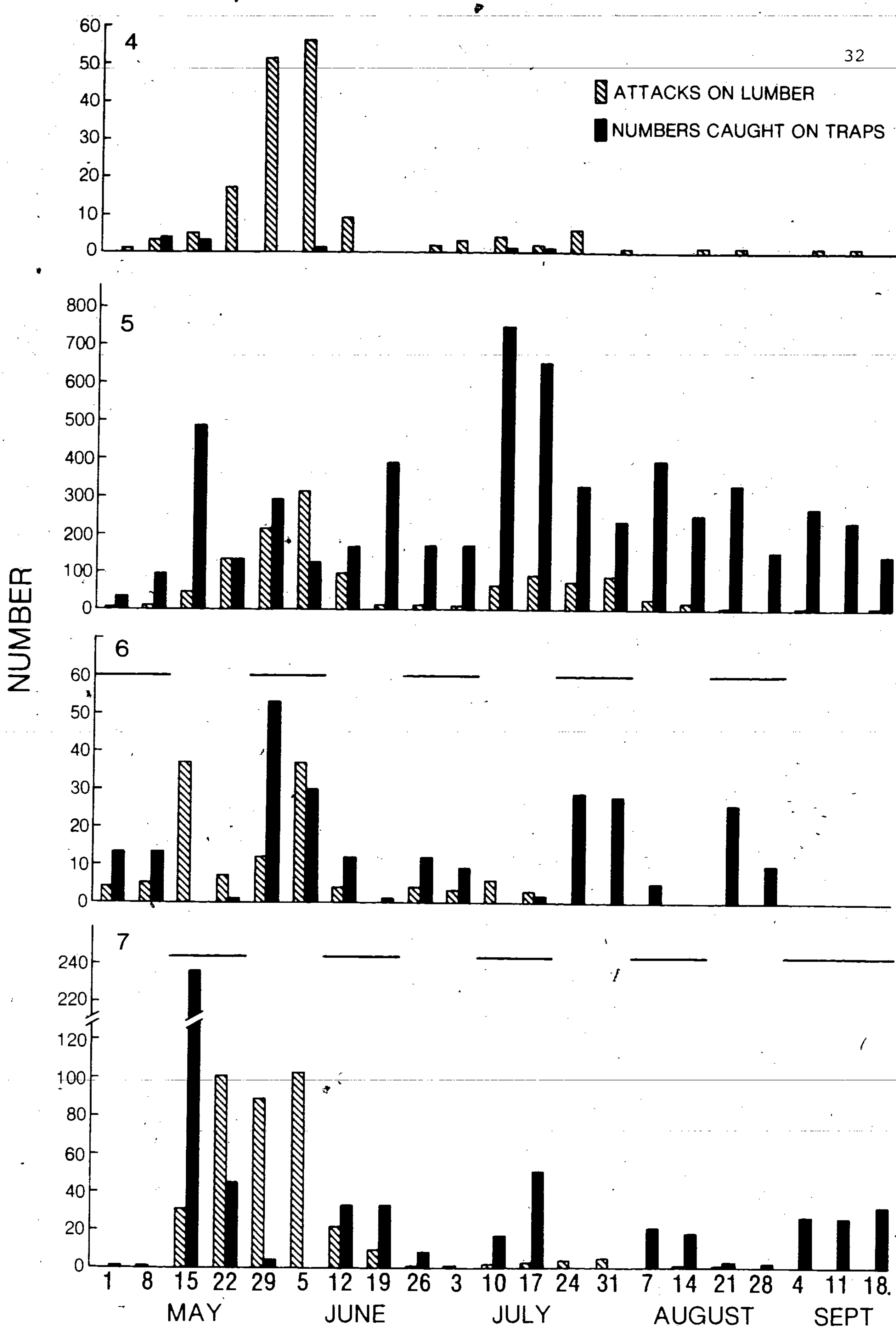
Table V. Numbers of ambrosia beetles captured on wire-screen sticky traps in the Chemainus Sawmill, MacMillan Bloedel Ltd., Vancouver Island, B.C., during 1975

Location	Trapsite	*Gnathotrichus sulcatus*	*Gnathotrichus retusus*	*Trypodendron lineatum*	Total Catch
1. North Planer Mill Yard	A	6	3	35	187
	B	1	4	97	
	C	2	2	9	
	D	9	11	8	
2. South Planer Mill Yard	A	2,475[a]	24	43	5,290
	B	699	33	59	
	C	1,083	27	101	
	D	703	8	35	
3. Assembly Yard	A	38	7	2	279
	B	17	2	4	
	C	77[b]	6	5	
	D	112[b]	7	2	
4. West Road to Pit Yard	A	81	4	3	590
	B	122	2	6	
	C	269	4	6	
	D	85	1	7	
Booms (2 traps)		17	46	19	
Totals		5,796	191	441	6,428
Sex Ratio (M:F)		1:2.07	1:1.52	1:1	

[a] Catch at trapsite A significantly greater than at trapsites B, C and D (Newman-Keuls Test, $P<0.05$).

[b] Catches at trapsites C and D significantly greater than at trapsites A and B (Newman-Keuls Test, $P<0.05$).

Figs. 4-7. Numbers of *Gnathotrichus sulcatus* captured on sulcatol-baited traps and attacks on lumber in 4 locations in the Chemainus Sawmill, MacMillan Bloedel Ltd., Vancouver Island, B.C., during 1975. Fig. 4: Location 1, the North Planer Mill Yard. Fig. 5: Location 2, the South Planer Mill Yard. Fig. 6: Location 3, the Assembly Yard. Fig. 7: Location 4, the west road to the Pit Lumber Yard. Horizontal bars in Figs. 6 and 7 indicate periods when traps were baited with sulcatol



4
5
6
7
ATTACKS ON LUMBER
NUMBERS CAUGHT ON TRAPS
NUMBER
1 8 15 22 29 5 12 19 26 3 10 17 24 31 7 14 21 28 4 11 18
MAY
JUNE
JULY
AUGUST
SEPT

No estimation could be made of the numbers of reattacking *G. sulcatus* on lumber, and it was not possible to determine if a beetle had attacked and left lumber before it was caught on a trap. The expected increase in numbers of *G. sulcatus* in late August/early September (Fig. 2) did not occur as in previous years. The mill was closed down from 17 July until 16 October, and no field-infested logs were transported to the millsite during this period, suggesting that the number of beetles in the mill is directly related to amount of wood processed.

Attack on Test Loads

As new test loads were set out each week it was possible to monitor attacks on lumber aged for known periods of time (Table VI). The greatest numbers of attacks were recorded on loads aged for 2, 3 or 4 weeks. Test loads left out more than the planned 4 weeks were significantly less attacked in weeks 6, 7 and 8 (Table VI). There was a significant variation (ANOVA, $P<0.01$) in the dates of greatest attack frequencies between locations.

Attacks on Yard Lumber

A total of 596 attacks was recorded on yard lumber in the 4 locations. There was significantly more attack on loads in location 4 than in all other locations and more attack in location 2 than in locations 3 and 1 (Newman-Keuls test, $P<0.05$). Maximum attack occurred in the weeks ending 22, 29 May and 5 June; 80% (285/319) of these attacks were in location 4 (Fig. 7). A second major group of high attack levels was in weeks ending 17, 24 and 31 July; 88% (136/155) of these attacks were in location 2 (Fig. 5).

Table VI. Total attack by *Gnathotrichus sulcatus* on test loads set out in 4 locations in the Chemainus Sawmill, MacMillan Bloedel Ltd., Vancouver Island, B.C., during 1975

Age of load (in weeks)	Number Monitored	Attack by Location[a] 1	2	3	4	Total Attack	Mean attack /load/week[b]
1	40	4	32	11	1	48	1.2
2	40	37	84	23	13	157	3.9
3	40	38	156	26	4	224	5.6
4	40	52	154	22	12	240	6.0
5	27	1	59	3	2	65	2.4
6	20	0	8	1	2	11	0.6
7	17	0	4	0	0	4	0.2
8	13	0	1	0	0	1	0.1

[a] Attacks in location 2>location 3, 1>location 4 (Newman-Keuls Test, $P<0.05$).

[b] Analysis of variance of attack data from first 4 weeks showed attack in weeks 2, 3, and 4 significantly greater than in week 1 (Newman-Keuls Test, $P<0.05$). Attack of 6-, 7-, and 8-week-old loads significantly less than on 4-week-old test loads (t-test, $P<0.05$).

A survey of attacks on perimeter loads adjacent to baited traps showed significantly greater *G. sulcatus* attack on loads near to sulcatol baited traps (Table VII). Fifty-five percent of the 590 *G. sulcatus* attacks in locations 2, 3, and 4 were on loads beside baited traps or on the first 3 loads in either direction. On 3 occasions, this trend was maintained when the traps in locations 3 and 4 were unbaited, apparently due to the effect of secondary attraction emanating from previously attacked piles. The predominance of attack in piles north of the trap-site (Table VII) may reflect the occurrence of prevailing southerly winds during fair weather when the beetles were flying.

Moisture of Attacked Lumber

Mean percentage moisture of 29 freshly attacked boards was 62.3% (SE=±3.1), significantly higher than in boards immediately above ($\bar{x}$=46.6%, SE=±5.2) (t-test, $P<0.02$), or below ($\bar{x}$=46.6%, SE=±5.0) (t-test, $P<0.01$). Fourteen of the 58 adjacent boards had a higher moisture content. Their mean percentage moisture was 85.7%, significantly higher than the attacked boards (t-test, $P<0.01$). It appears that *G. sulcatus* attacks neither very moist nor very dry boards. Samples taken on 11 September from 12 boards attacked early in the season, and no longer producing frass, showed a mean percentage moisture of 26.0% (SE=±3.9), significantly less than all previous measurements (t-test, $P<0.05$). No living beetles were found when one of these boards was dissected. These observations support an hypothesis developed for *T. lineatum* that beetles emerge from lumber which has dried to the point at which it is no longer suitable for gallery formation and brood production (Kinghorn 1956).

Table VII. Attacks by *Gnathotrichus sulcutus* on loads of yard lumber adjacent to traps baited with sulcatol in the Chemainus Sawmill, MacMillan Bloedel Ltd., Vancouver Island, B.C., during 1975

Location	Number of Observations	Position of Lumber Piles[a]						
		N3	N2	N1	TS	S1	S2	S3
2	3	0	0	0	8	0	0	0
3	15	1	17	20	48	34	7	1
4	6	1	26	61	59	35	6	1
Totals[b]		2b	43a	81a	115a	69a	13b	2b

[a] N = North, TS = Trap site, S = South.

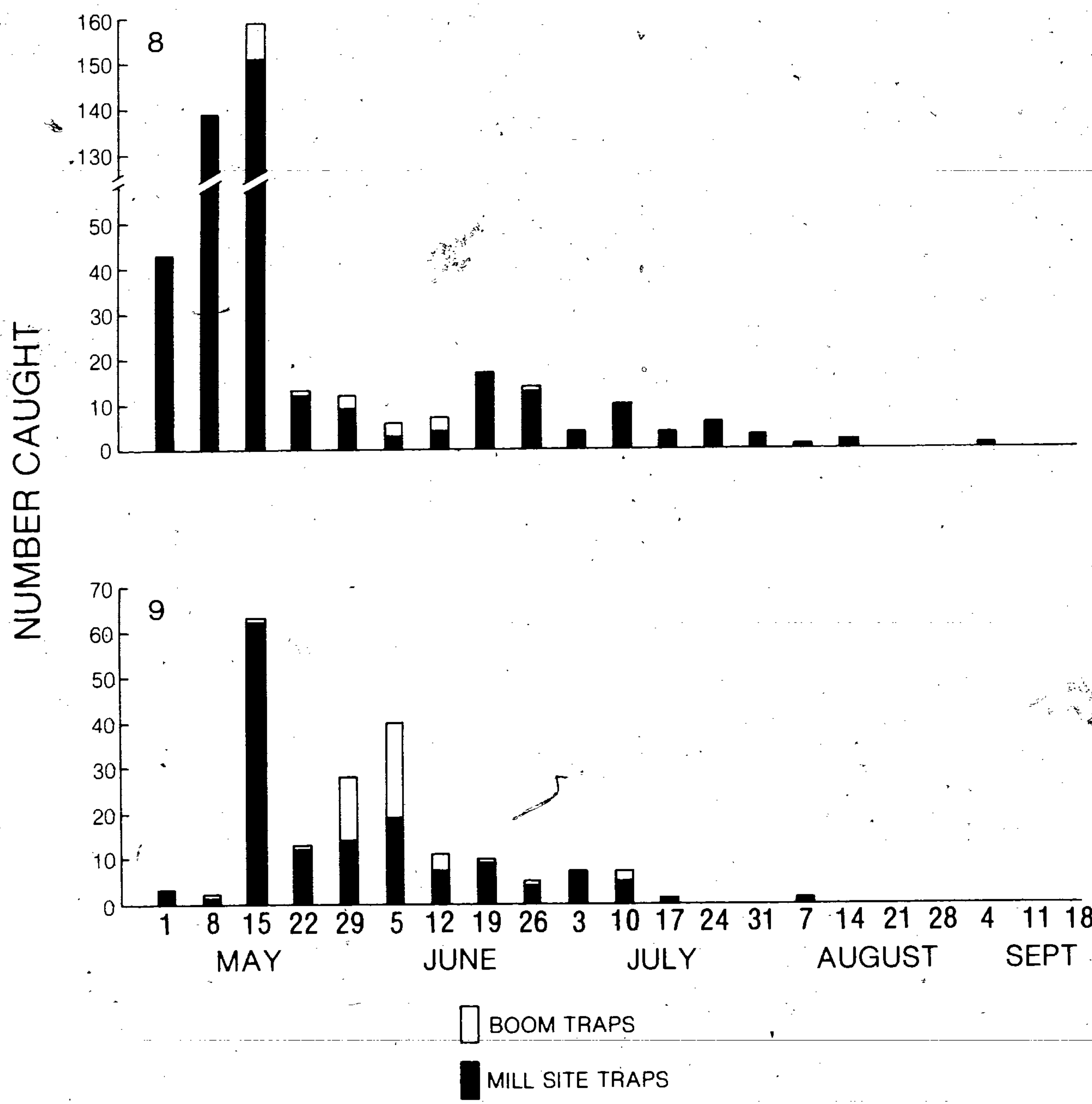
[b] Totals followed by same letter not significantly different, Newman-Keuls Test, $P<0.05$.

Capture of and Attack by Other Species of Ambrosia Beetles

Greatest catches of *T. lineatum* were on 8 and 15 May (Fig. 8). As the traps were not baited with any known attractant for *T. lineatum*, these records are of random interceptions of beetles flying in the millsite. Most beetles of this species were caught on traps adjacent to freshly-sawn lumber in locations 1 and 2 (Table V). Ninety-two *G. retusus* were captured in location 2, and the species was also the one most frequently captured on the 2 boom traps (Table V). Peak numbers of *G. retusus* were caught in the millsite on 15 May and on the boom traps on 5 June (Fig. 9). During the 1975 season, only 1 major flight period was observed for each of these species, probably reflecting the lack of infested logs from which brood beetles could emerge to fly to overwintering sites *(T. lineatum)* or to establish a second summer generation *(G. retusus)*.

Several (123) *T. lineatum* attacks on freshly-sawn lumber were noted, the first record of this species attacking lumber. Half-a-board dissected on 5 May showed 5 pairs of active adults in galleries with a mean length of 40.3 mm. When the other half of the board was dissected on 17 June, only 1 pair of beetles was found and the 4 galleries dissected had a mean length of 69.8 mm. Although 15 egg niches had been formed, no eggs were found. On 3 July, an attacked section of a 50 mm by 200 mm western hemlock board showing 1 full surface of wane, was collected from location 3. On dissection, 4 adult males, 3 females, 5 callow adults and 3 *T. lineatum* pupae were found. This attack could have been initiated on a log while it was in the booming ground or in the

Figs. 8, 9. Numbers of two species of ambrosia beetles captured on traps in the mill site and in the booming ground, Chemainus Sawmill, MacMillan Bloedel Ltd., Vancouver Island, B.C., during 1975. Fig. 8: *Trypodendron lineatum*. Fig. 9: *Gnathotrichus retusus*


NUMBER CAUGHT
8
160
150
140
130
50
40
30
20
10
0
9
70
60
50
40
30
20
10
0
1 8 15 22 29 5 12 19 26 3 10 17 24 31 7 14 21 28 4 11 18
MAY
JUNE
JULY
AUGUST
SEPT
BOOM TRAPS
MILL SITE TRAPS

forest and exemplifies the possibility that *T. lineatum* could be introduced to other countries in imported lumber.

Two *Xyleborous saxeseni* (Ratz.) attacks were found in a test load in location 2 at the end of July. No *X. saxeseni* were caught on the traps.

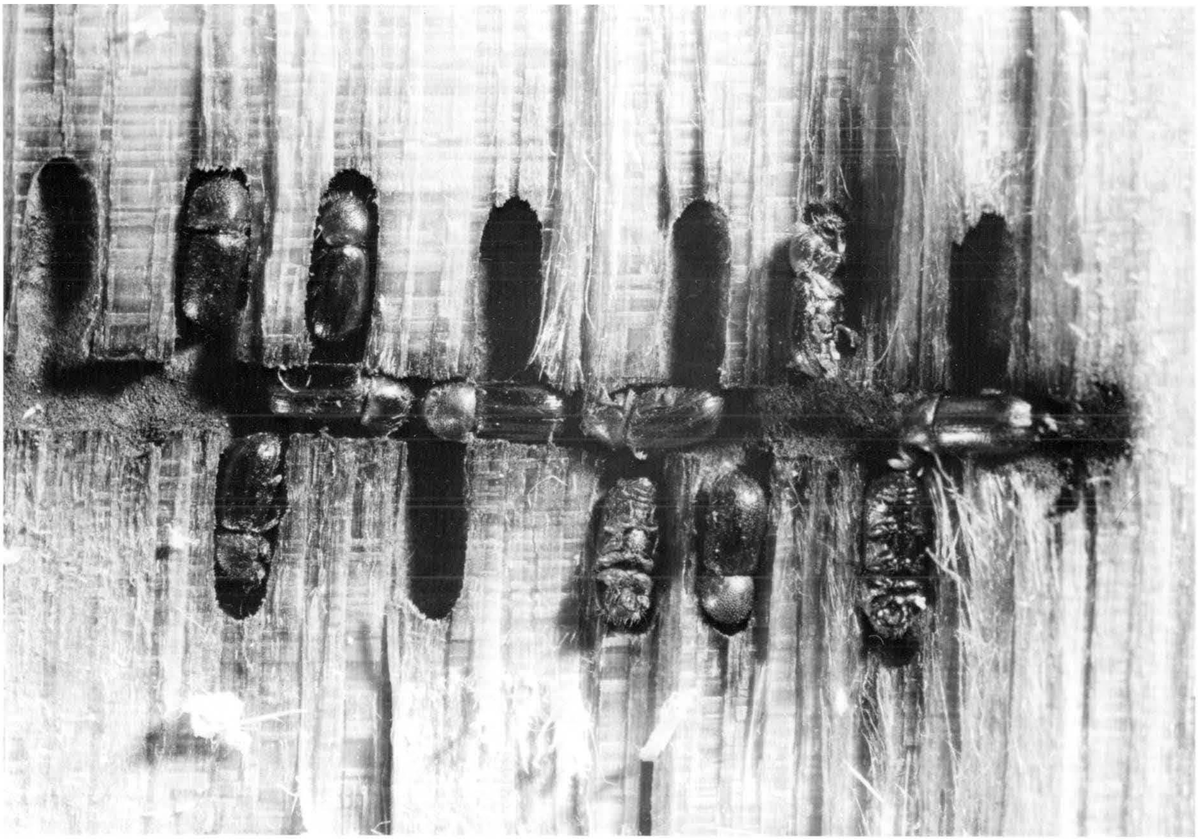
Dissection of Lumber and Offcuts

Dissections of chipper chain material on 1 and 8 May produced 8 live prepupae and 8 live female *T. lineatum* respectively. Numbers of dead *T. lineatum* found in this material were 421 adults, 50 prepupae, 17 larvae, and 9 eggs. Many of the dead adults were found in pupal niches and in some cases pupal niches had been extended. Large groups found at the ends of galleries (Fig. 10) suggest that after retreating as far as possible, the beetles may have been drowned by waters seeping into the boomed logs or died from asphixiation after their gallery entrances were blocked by water.

The densities of *T. lineatum* pupal niches in offcuts (Fig. 10) suggests that attack and development was initiated in the forest. Previous studies have shown that while *T. lineatum* will attack boomed logs at densities comparable to those in the forest, there will be little or no brood production (Dyer and Chapman 1962). These studies indicate that less than 2% (8/429) of field-produced beetles survive booming and sawmilling. Nine dead adults and 1 live larva of *G. retusus* were found in the chipper chain samples. Only 1 dead *G. sulcatus* adult was found.

Heavily attacked boards collected from test loads throughout the season were dissected in the laboratory, yielding totals of 160 male and

Fig. 10. Dead *Trypodendron lineatum* in an offcut taken from the chipper chain at the Chemainus Sawmill, MacMillan Bloedel Ltd., Vancouver Island, B.C., on 1 May 1975. Note that all beetles in pupal niches are head-in, as opposed to the normal head-out position of pupae and callow adults



121 female *G. sulcatus*. When a pair of beetles was present in an unbranched gallery, the male was at the head in 22 out of 23 cases. This pattern was consistent throughout the season, there being no evidence of changeover from male to female predominance in gallery construction as was suggested by Prebble and Graham (1957). Two pairs of *G. retusus* were found in these boards as well. The boards attacked by *T. lineatum* contained no other ambrosia beetle species.

An inspection of boomed logs in Horseshoe Bay, adjacent to the millsite, on 24 July showed active attack by ambrosia beetles on less than 5% of the logs. Most of the attack was by *T. lineatum*. Samples taken from *Gnathotrichus*-infested boom logs revealed 4 male and 6 female *G. retusus* and 1 female *G. sulcatus*.

Discussion

The most important modifying effect, in this assessment of the suppression of *G. sulcatus* with sulcatol-baited traps, was the natural secondary attraction (Borden et al. 1975) set up by male beetles that attacked lumber piles. This attraction is significant within 12 hrs for females and 24 hrs for males in the laboratory (Borden and Stokkink 1973). This natural secondary attraction in attacked lumber apparently competed favorably with the baited traps [see 5 June catch records in locations 2 and 3 (Figs. 5, 6)]. It was probably the most important factor leading to the continued build up of attacks in locations 3 and 4 when they were unbaited [see 15 May location 3 (Fig. 6) and 29 May and 5 June in location 4 (Fig. 7)]. Identification of additional natural primary attractants for *G. sulcatus* may lead to their use as baits in traps with ethanol (Cade et al. 1970) and sulcatol. With such an attractive bouquet, the traps might outcompete lumber that has low to moderate levels of secondary attraction, thus resulting in a greater reduction in attacks on lumber.

Lumber is most readily attacked when it has been set out for 2, 3, or 4 weeks, suggesting development of and subsequent decrease in primary attraction. The buildup in attack levels in locations 1, 2, and 4 during late May and early June (Figs. 4, 5, 7) corresponds to periods when lumber of this age was present in the yards in large quantities. A smaller peak of activity was noted in locations 1 and 2 in July (Figs. 4, 5) when the yards were restocked with freshly-sawn lumber after previously stored loads had been processed through the planer mill. The majority of attacks were judged to be on lumber sawn from the outer sapwood of logs.

The number of attacks on test loads and yard lumber gives a measure of male *G. sulcatus* activity only. In samples taken from 3 freshly attacked boards, 70% of the males (23/33, 7/10, 5/7 for a total of 35/50) were paired. Thus, the number of females in lumber can be estimated as the number of males x 0.7, and an estimate of the total *G. sulcatus* in observed lumber attacks can be made. The effectiveness of different trapping regimes can be assessed by calculating a suppression ratio, i.e., the number caught on traps/(number of estimated beetles in lumber+number caught on traps). A summary of these data, by locations, is given in Table VIII.

From calculations of the suppression ratio by sex and location in each weekly period, comparisons between locations were made. A

Table VIII. Assessment of sulcatol-baited traps in suppressing *G. sulcatus* populations in 4 locations in the Chemainus Sawmill, MacMillan Bloedel Ltd., Vancouver Island, B.C. during 1975

Location	Baiting Schedule	# of Attacks Observed			Assumed # Males in Lumber[a]	Estimated # Females in Lumber[a]	Beetles on Traps		Suppression Ratio[b]	
		Test Loads	Yard Lumber	Total			Males	Females	Males[c]	Females[c]
1. North Planer Mill Yard	unbaited	132	33	165	165	116	11	7	0.06b	0.06c
2. South Planer Mill Yard	full-time	498	195	693	693	485	1,635	3,324	0.70a	0.87a
3. Assembly Yard	1/2-time	86	19	105	105	74	67	176	0.39b	0.70b
4. Pit Yard	1/2-time	34	349	383	383	268	157	399	0.29b	0.60b

[a] Number of males assumed to equal the number of attacks. Number of females estimated by multiplying number of attacks by 0.7 (see text).

[b] Suppression Ratio = Number caught on traps/(Number caught on traps + number attacking lumber).

[c] Ratio of beetles suppressed in each column followed by the same letter, not significantly different (t-tests, $P<0.05$).

significantly higher suppression of the females occurred in location 2 (baited fulltime) than in locations 3 and 4 (baited 1/2 time) where in turn, significantly higher suppression was recorded than in location 1 (no baiting). There was a significantly higher suppression of male *G. sulcatus* in location 2 than in locations 3, 4, and 1, which did not differ among themselves (Table VIII). Significantly higher proportions of male and female *G. sulcatus* were suppressed when locations 3 and 4 were baited as compared with when they were unbaited (t-test, $P<0.05$). Estimates of the suppression ratio are conservative for 2 main reasons. Firstly, there is no measure of the number of beetles which attack a board, subsequently emerge and attack the same or another board in the same or subsequent week. Such activities could result in the same beetle being counted more than once. Secondly, if a re-emerged beetle is subsequently caught on a trap, it is counted again. It is clear that the most effective suppression of *G. sulcatus* (0.87 of females, 0.70 of males) occurred in location 2 where traps were baited continuously (Table VIII).

Although the number of *G. sulcatus* attacks on lumber decreased from July to September, a large number of beetles continued to be caught on baited traps in locations 2, 3, and 4 (Figs. 5-7). The termination of operations on 3 July, and the closure of the mill of 17 July, was undoubtedly a major reason for the subsequent low attack rate on lumber that would have become unattractive within 4 weeks (Table VI). Many beetles probably emerged from drying lumber and were attracted by the sulcatol in the traps rather than to other lumber. The relatively warm temperatures at this time would cause lumber to dry out faster, and more sulcatol would evaporate from the traps. Thus, decreasing lumber attractiveness and optimal pheromone release conditions during this period would have made baited traps the most attractive source in the mill for flying beetles.

This study has shown that sulcatol-baited traps can capture the majority of a *G. sulcatus* population (Table VIII), that lumber sawn from sapwood, and aged for 2 to 4 weeks, is the most attractive to flying beetles in sawmills (Table VI), and that highest attack densities can be expected on loads adjacent to sulcatol-baited traps (Table VII). These data suggest that *G. sulcatus* could be effectively suppressed in sawmills through a modification of the trap tree method (see p. 72). I suggest placing piles of freshly-sawn sapwood slabs (destined for the chipper chain) in strategic positions around the mill site. Ethanol, which is hypothesized to be a boring stimulant for *G. sulcatus* (see p. 71), might be incorporated as a slab pile treatment. Sulcatol-baited trap(s) placed next to each slab pile would attract and capture the majority of beetles, and those not caught could attack the slabbing. At the end of the attractive period (i.e., 4 weeks) the slabs could be removed, and chipped to kill any residual beetles. Fresh slab piles should be set out at each location during the third week so that they will have reached optimal attractiveness by the time the old piles are removed. This technique would have special application in yards where fresh lumber is stored. It could be modified for use around the perimeter of dryland sorting areas where sulcatol-baited traps could be set out next to piles of cull logs that could be removed and chipped at the end of 2 months to destroy the beetles in them. This procedure would supplement protection of logs within the dryland sorting area by water-misting (Richmond and Nijholt 1972). Control measures against *G. sulcatus* would need to be maintained over the entire summer as some *G. sulcatus* are always flying during warmer weather (Byrne et al. 1974) (Fig. 5). Operation of sulcatol-baited traps in this way would prevent build-up of large populations of *G. sulcatus* around commercial operations.

ATTACK BY *GNATHOTRICHUS SULCATUS* ON STUMPS AND FELLED TREES BAITED WITH SULCATOL AND ETHANOL

Gnathotrichus sulcatus (LeConte) attacks trees soon after felling in the conifer forests of the Pacific Northwest (Mathers 1935, Prebble and Graham 1957). Hopkins suggested, as early as 1907, that trees of poor form may be used as trap logs (Fisher et al. 1953, 1954). Later it was proposed that attractants be used to lure ambrosia beetles to trap billets (Browne 1952). The objective of this study was to determine if ethanol and sulcatol, alone or in combination, could attract field populations of *G. sulcatus* to baited stumps and logs of freshly cut western hemlock and Douglas-fir.

Methods

The experiment was conducted in 1974 at the University of British Columbia Research Forest, Maple Ridge, B.C. In each of 6 locations, 4 trees were felled, topped and limbed on 18 April. Western hemlocks were felled in 3 locations, and Douglas-firs in the remainder. The mean (±SD) diameter at breast height and length of the western hemlock logs were 29.2(±3.2) cm and 18.4(±3.4) m while those of the Douglas-fir logs were 29.8(±2.5) cm and 21.3 (±3.4) m. Trees were no closer than 25 m and locations were at least 1 Km apart.

The research forest is located in the coastal western hemlock biogeoclimatic zone (Anonymous 1975). Locations 1 and 2, at altitudes of 200 m and 312 m, respectively, were situated in a second growth subhygric moss/swordfern/western red cedar/western hemlock ecosystem on northwest facing slopes. The remaining locations were in the moss/oregon grape/ Douglas-fir/western hemlock ecosystem. Locations 3 to 6, on south facing slopes, were at altitudes of 122 m, 305 m, 122 m, and 122 m respectively. Location 3 was in second growth forest surrounding a 10-year-old clear cut. Locations 4 and 6 were also in second growth forest, while location 5 had been selectively logged in 1970.

Four treatments were randomly assigned to each of the stump/log combinations in each location. The treatments were an unbaited control, ethanol, sulcatol, and ethanol plus sulcatol. The volatiles were released individually from 4 ml vials with a 4 mm diameter hole in the cap. Vials were contained in inverted 65 ml glass jars with plastic caps pierced with 12, 4 mm diameter holes. Each jar was supported in a wire holder driven into the top of a stump or into the top of the tenth meter of a log (Fig. 11). Under laboratory conditions of 20°C and 68% R.H., the evaporation rates of the 95% ethanol and undiluted sulcatol from this type of release system, were 180 mg and 2.5 mg/day, respectively.

Stumps and logs were first baited on 26 April and volatiles were replenished during the weekly checks for new attacks (Fig. 12). All fresh scolytid attacks were marked with pins (Figs. 13, 14). As attack densities increased, especially on stumps (Fig. 13), frass was blown away to expose all new entry holes. The number of attacks for the stumps and each meter of a log were recorded separately. Sample beetles were excised to confirm their identification until attack characteristics were reliably determined.

A 10 cm thick disk was cut from 10 to 20 cm below the top of each

Figs. 11-14. Aspects of the study of *Gnathotrichus sulcatus* response to baited stumps and felled logs in the U.B.C. Research Forest, Maple Ridge, B.C., 1974. Fig. 11: Vials containing volatile substances in release jar in wireholder on Douglas-fir log. Fig. 12: Weekly field search for fresh scolytid attacks. Fig. 13: Heavily attacked Douglas-fir stump in mid-summer. Note marking pins and accumulation of frass around the base. Fig. 14: Pinned *G. sulcatus* entry hole in Douglas-fir log with accumulation of frass below


11
12
13
14

stump and the second meter of each log during the 1974/75 winter. The number of pinned attacks was compared with the number seen after peeling off the bark. The disks were dissected to determine the length of gallery produced per attack and the number of egg, larval, and pupal niches produced. The second meter of every log, or the first completely free of the ground, was stripped of its bark, the number of attacks in the top, bottom, and lateral quadrants recorded, and its surface area measured.

Data on the response of *G. sulcatus* to the various treatments were analyzed separately for each host category, i.e., for Douglas-fir stumps, Douglas-fir logs, western hemlock stumps, and western hemlock logs. Bark beetle attacks were analyzed for response to treatments. For analyses, attacks over entire logs were summed biweekly. All data were transformed to $x' = \log_{10}(x+1)$ before analyses of variance.

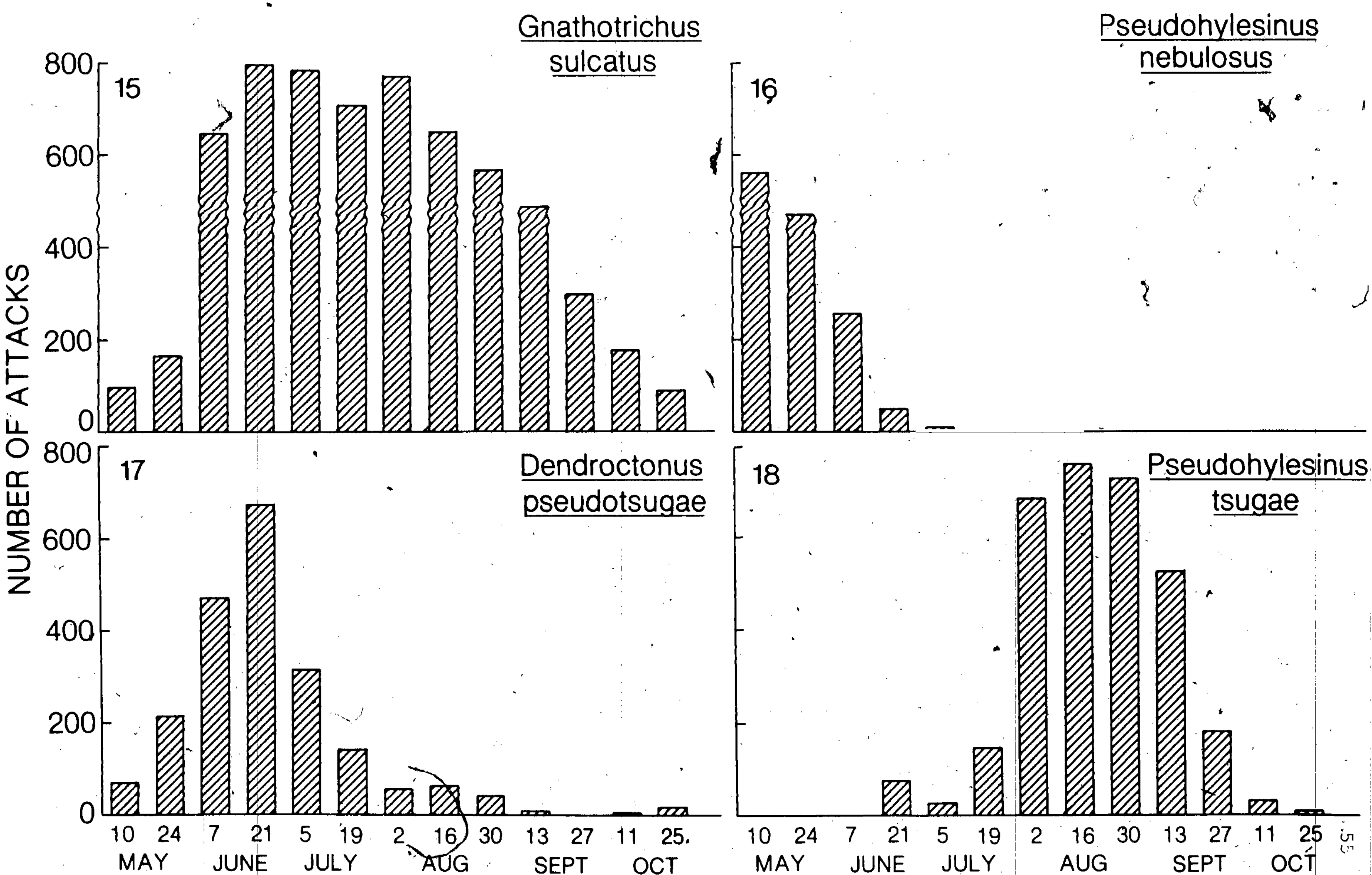
Results

Seasonal Attack Patterns

Four scolytid species, each with a distinct seasonal attack pattern, attacked the test logs and stumps (Figs. 15-18). There was considerable variation by location in the number of attacks by each species (Table IX), possibly in relation to temperature regimes, aspects of site and proximity of beetle source. *Dendroctonus pseudotsugae* Hopkins and *Pseudohylesinus nebulosus* (LeConte) were restricted to Douglas-fir, and *P. tsugae* Swaine to western hemlock (Table IX).

Although total *G. sulcatus* attacks reached a maximum in June and remained high in July (Fig. 15), the attack pattern on stumps and logs

Figs. 15-18. Seasonal attack of 4 scolytid species on stumps and logs of spring-felled Douglas-fir and western hemlock in the U.B.C. Research Forest, Maple Ridge, B.C., 1974. Fig. 15: *Gnathotrichus sulcatus*. Fig. 16: *Pseudohylesinus nebulosus*. Fig. 17: *Dendroctonus pseudotsugae*. Fig. 18: *Pseudohylesinus tsugae*



NUMBER OF ATTACKS
800
600
400
200
0
15
Gnathotrichus sulcatus
16
Pseudohylesinus nebulosus
17
Dendroctonus pseudotsugae
18
Pseudohylesinus tsugae
10 24 7 21 5 19 2 16 30 13 27 11 25
MAY JUNE JULY AUG SEPT OCT

55

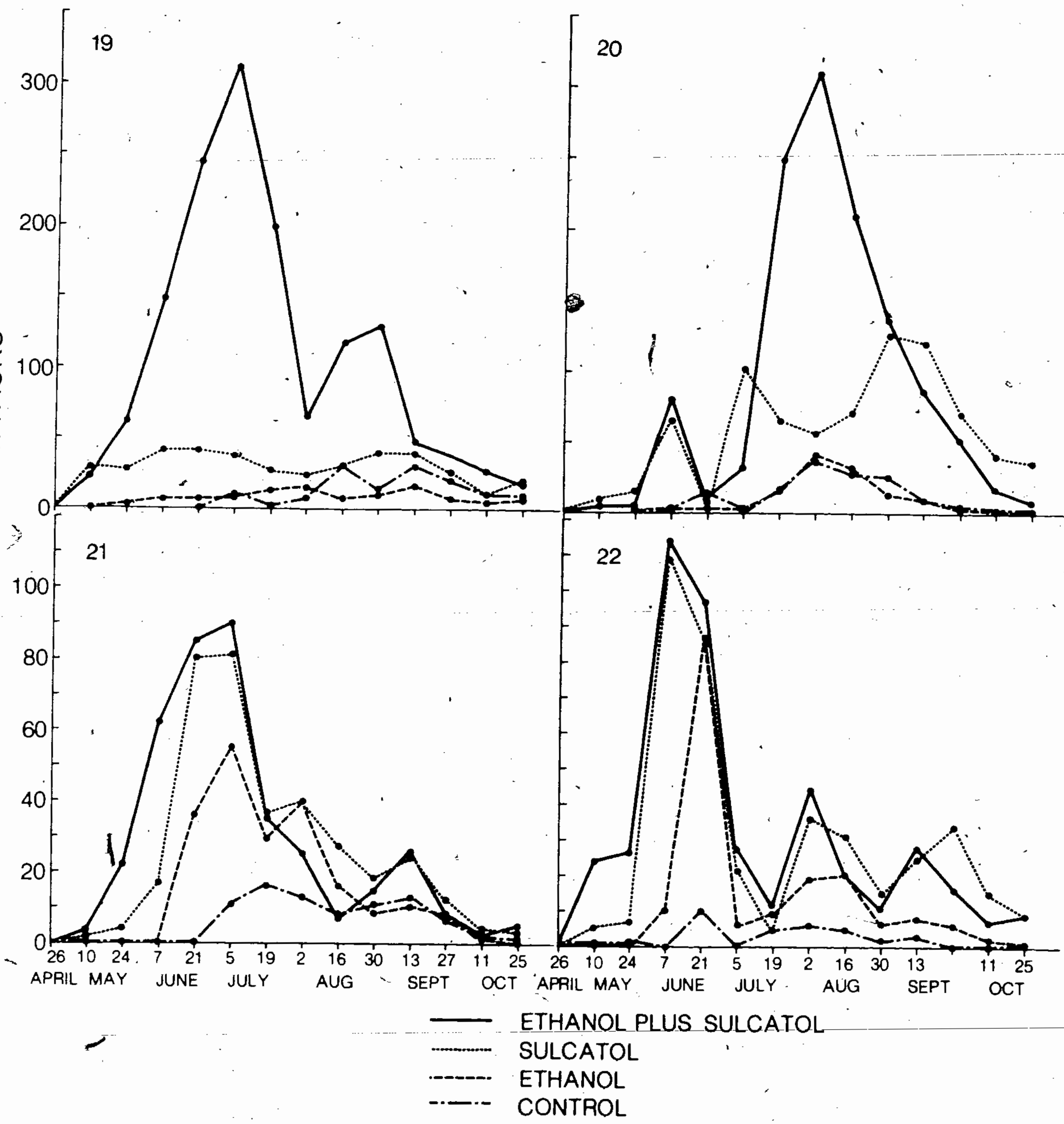
Table IX. Numbers of scolytid attacks on spring-felled western hemlock and Douglas-fir at 6 locations in the U.B.C. Research Forest, Maple Ridge, B.C., April-October, 1974

Host Species	Location	*Gnathotrichus sulcatus*	*Dendroctonus pseudotsugae*	*Pseudohylesinus nebulosus*	*Pseudohylesinus tsugae*
Western Hemlock	1	491	0	0	1,761
	2	81	0	0	1,184
	3	1,481	0	0	439
Douglas-fir	4	908	384	640	0
	5	2,070	1,160	538	0
	6	1,198	475	139	0
Total Attacks		6,229	2,029	1,314	3,384

of the 2 host tree species differed. The peak attack on stumps of both host species was in late June to early July (Figs. 19, 21) with a smaller peak in attack frequency in August, only on Douglas-fir stumps (Fig. 19). On all logs, the *G. sulcatus* attack increased in late May to early June (Figs. 20, 22), and reached a maximum on western hemlock in June (Fig. 22). The early attack on Douglas-fir logs collapsed, but increased again in early July to reach a maximum in late July to early August (Fig. 20). A minor increase in attack on western hemlock occurred at this time also (Fig. 22). A steady rate of decrease in attack occurred on all host material during September and October (Figs. 15, 19-22).

The 1974 dispersal flight of *P. nebulosus* was apparently underway by the time attacks were first monitored on 3 May, and numbers of attacks gradually decreased through May and June (Fig. 16). Attack was confined to the smooth-barked tops of trees, with attack densities reaching $200/m^2$ in log sections 15 to 16 cm in diameter. *D. pseudotsugae* attack increased through May to peak in June, and continued at lower levels through July and August. Late season attacks persisted at low levels through October (Fig. 17). All *D. pseudotsugae* activity was confined to the larger diameter sections of logs with fissured bark. Mean attack density was $19(SE\pm0.9)/m^2$ in regions of the logs greater than 14 cm in diameter. Attack of western hemlock logs by *P. tsugae* commenced in late June, and gradually declined through September and October (Fig. 18). *P. tsugae* did not show a preference for any particular log diameter; attacks were initiated beneath bark scales, were found over the entire log surface, and reached a maximum density of $37/m^2$.

Figs. 19-22. Biweekly attack, by treatments, of *Gnathotrichus sulcatus* on stumps and logs of 2 host species in the U.B.C. Research Forest, Maple Ridge, B.C., 1974. Fig. 19: Douglas-fir stumps. Fig. 20: Douglas-fir logs. Fig. 21: Western hemlock stumps. Fig. 22: Western hemlock logs. Note the difference in scale between Figs. 19, 20 and 21, 22



19
20
21
22
NUMBER OF ATTACKS
300
200
100
0
100
80
60
40
20
0
26 10 24 7 21 5 19 2 16 30 13 27 11 25
APRIL MAY JUNE JULY AUG SEPT OCT
26 10 24 7 21 5 19 2 16 30 13 11 25
APRIL MAY JUNE JULY AUG SEPT OCT
ETHANOL PLUS SULCATOL
SULCATOL
ETHANOL
CONTROL

Response to Treatments

G. sulcatus attack on stumps and logs of each host species varied between treatments. In the first 6 weeks of the experiment (Figs, 19-22), 97.3% (869/893) of the attacks were on stumps and logs baited with sulcatol or sulcatol plus ethanol. The mean numbers of weekly attacks and attack densities were greatest on stumps and logs baited with ethanol plus sulcatol, and were far greater on stumps than on logs (Table X). Analysis for the effect of the individual treatments disclosed that sulcatol was a significant treatment for each host category, and that ethanol was a significant treatment on all but Douglas-fir logs (Table XI). There was a strikingly high attack rate on Douglas-fir stumps baited with ethanol plus sulcatol, especially in late June to early July and late August (Fig, 19). While the interaction between ethanol and sulcatol on Douglas-fir logs was not significant over the whole experiment, as it was on Douglas-fir stumps (Table XI), separate analyses of data for each month showed it to be so during August ($P<0.01$), when attack on logs baited with ethanol plus sulcatol was much greater than that on any other (Fig. 20).

The variation in numbers of *G. sulcatus* attacks between locations for each host (Table IX) was significant except for Douglas-fir stumps (Table XI), indicating that only the total attack on Douglas-fir stumps was similar from location to location. There was considerable variation in the proportion of attacks as related to treatments within each location causing significant treatment by location interaction (Table XI). In location 4, for example, the numbers of attacks on stumps baited with

Table X. Mean weekly attack and mean attack density of *Gnathotrichus sulcatus*, by treatments, on stumps and logs of spring-felled western hemlock and Douglas-fir in the U.B.C. Research Forest, Maple Ridge, B.C., April-October 1974

Host Species	Treatment	Mean Weekly Attack[ab]		Density of Attack/0.1m²[c]	
		Stumps	Logs	Stumps	Logs
Western hemlock	Control	3.12c	1.27d	4.06	0.09
	Ethanol	7.73b	6.69c	8.63	0.43
	Sulcatol	13.38a	15.31b	17.06	1.20
	Ethanol plus Sulcatol	14.73a	16.73a	20.93	1.24
Douglas-fir	Control	4.77c	5.23c	5.93	0.39
	Ethanol	3.65c	4.42c	5.22	0.33
	Sulcatol	14.85b	29.31b	13.79	1.52
	Ethanol plus Sulcatol	54.15a	44.23a	68.35	2.52

[a] Means followed by the same letter, within each host category, not significantly different, Neuman-Keuls Test, $P<0.05$.

[b] Attacks on the 3 replicates of each host category-treatment combination summed for this calculation.

[c] $0.1 m^2 = 1.076 ft^2$.

Table XI. Analyses of variance for *Gnathotrichus sulcatus* attack on Douglas-fir and western hemlock stumps and logs in the U.B.C. Research Forest, Maple Ridge, B.C., April-October 1974

Sources of Variation	Douglas-fir stumps			Douglas-fir logs		Western hemlock stumps		Western hemlock logs	
	df	MS	F	MS	F	MS	F	MS	F
Between									
Treatments									
Main effect Ethanol	1	2.65	18.51**[a]	0.01	0.04	0.31	4.26*	1.04	17.74**
Main effect Sulcatol	1	17.48	120.09**	15.01	104.56**	5.79	79.09**	7.19	123.19**
Ethanol plus Sulcatol	1	3.65	25.51**	0.29	2.07	0.16	2.12	0.14	2.45
Time[b]	10	0.30	2.10*	1.43	9.97**	0.63	8.53**	0.77	13.15**
Locations	2	0.32	2.22	3.98	27.73**	8.69	118.59**	5.58	95.69**
First Order Interactions									
Treatments by Time	30	0.21	1.46	0.16	1.12	0.09	1.25	0.08	1.45
Treatments by Locations	6	1.28	8.94**	0.56	3.87**	0.41	5.53**	0.56	9.63**
Time by Locations	20	0.25	1.77*	0.22	1.55	0.16	2.24**	0.08	1.29
Error	60	0.14		0.14		0.07		0.06	

[a] Significance levels indicated: *, P<0.05; **, P<0.01.

[b] Time is defined as biweekly totals of attack.

ethanol plus sulcatol, or sulcatol alone, were near equal but in locations 5 and 6, the number of attacks on sulcatol-baited stumps was less than half that on stumps baited with ethanol plus sulcatol. There were also significant time by location interactions for both Douglas-fir and western hemlock stumps (Table XI). The attack levels in location 5, for instance, were relatively high throughout the year, whereas there was a build-up at location 6 to peak attack in June, and the highest attack levels in location 4 were not reached until August.

There was no significant response of any of the 3 bark beetles monitored to the ethanol, sulcatol or ethanol plus sulcatol baited Douglas-fir and western hemlock.

Distribution of Attack on Logs

The numbers of attacks recorded on the basal 5 meters of the logs and on the 3 meters to each side of the bait (on meter 10), show the effect of the treatments on final *G. sulcatus* distribution (Table XII). The greatest attack was on the baited tenth meter with numbers decreasing on either side. The number of attacks on the first 3 meters of the logs, next to the baited stumps, was significantly greater than those on meters 4 and 5. Significantly more attacks occurred on Douglas-fir than on western hemlock ($P<0.01$).

The 12 debarked, second meter Douglas-fir log sections had sustained a total of 413 verified *G. sulcatus* attacks. Significantly fewer attacks occurred in the top quadrant than the other 3, which were not different from each other (t-test, $P<0.05$) (Table XIII). Analysis of

Table XII. Total field-marked *Gnathotrichus sulcatus* attacks, by treatments, in individual meter sections of spring-felled western hemlock and Douglas-fir logs in the U.B.C. Research Forest, Maple Ridge, B.C., 1974

Host Species and Treatment	Attack on Basal 5 m of log[a]					Attack in Meter in Which Bait was Placed (B) and in 1 m Sections toward the Stump (B-1 etc.) and Crown (B+1 etc.)[a]						
	1	2	3	4	5	B-3	B-2	B-1	B	B+1	B+2	B+3
Western Hemlock												
Control	1	4	4	1	0	0	2	1	1	4	1	3
Ethanol	8	6	5	8	2	9	22	21	42	11	8	2
Sulcatol	38	48	37	24	17	34	29	33	57	27	14	4
Ethanol+Sulcatol	40	42	43	24	20	29	29	36	73	44	28	15
Total Attacks	88	100	89	57	39	63	82	91	173	86	51	24
Douglas-fir												
Control	21	27	23	7	11	13	5	5	2	0	1	0
Ethanol	14	11	9	11	7	13	4	11	6	6	0	1
Sulcatol	54	72	63	34	28	38	33	53	65	43	36	27
Ethanol+Sulcatol	92	135	122	91	80	80	84	102	107	78	46	33
Total Attacks[b]	181	245	217	143	132	144	136	171	180	127	83	61
Grand Totals[c]	269	345	306	200	171	207	218	262	353	213	134	85
Percent of Grand Total (n=2,763)	9.7	12.5	11.1	7.2	6.2	7.5	7.9	9.5	12.8	7.7	4.8	3.1

[a] Each cell represents the total attack on 3 replicates for each treatment and host.

[b] Significantly more attack on Douglas-fir than on Western hemlock.

[c] Meters 1, 2 and 3 > 4 and 5; Meter B > B-2, B-3, B+1, B+2 and B+3; Meter B-1 > B+2 and B+3; Meters B-2, B-3 and B+1 > B+3, Neuman-Keuls test, $P<0.05$.

Table XIII. Distribution of *Gnathotrichus sulcatus* attack on the second meter of 12 Douglas-fir logs in the U.B.C. Research Forest, Maple Ridge, B.C., April-October 1974 (n=413)

Quadrant	% attack[a]	Attacks/0.1m²	
		mean[a]	range
Top	12.6a	1.9a	0- 8.4
Left	27.8b	4.8b	0-16.6
Right	29.8b	5.0b	0-17.1
Bottom	29.8b	5.4b	0-12.6

[a] Values within a column followed by the same letter not significantly different (t-test, P<0.01 for $\bar{x}$ attacks/m^2).

987 attacks on the basal 16 m of the debarked Douglas-fir log baited with ethanol plus sulcatol in location 5 showed a similar distribution and significance pattern.

Gallery and Niche Development

In both host species, galleries formed in stumps were longer than those in logs, and productivity, as measured by the total number of egg, larval and pupal niches, per gallery was also greater in stumps than logs. Gallery length and number of niches per attack were significantly greater in western hemlock than in Douglas-fir stumps (Table XIV). Productivity, on a niche/cm of gallery basis, was approximately equal between different tree species, and the productivity in stumps was 6 to 11 times that in logs.

Verification of Attacks

Comparisons of pinned attacks with numbers of verified attacks showed that 64.9% (333/513) of attacks on the debarked second meters of logs and 44.4% (271/610) of attacks on debarked stump discs had been pinned. The majority of unpinned log attacks were in the lower quadrant where the tell-tale piles of frass (Fig. 14) did not accumulate but fell to the ground. On stumps, extensive accumulation of frass in the bark fissures apparently prevented observation of every fresh attack.

Discussion

Attack Distribution and Success

The attack frequency of *G. sulcatus* gives an indication of male

Table XIV. Mean gallery length and number of niches per *Gnathotrichus sulcatus* attack on 10 cm discs taken from Douglas-fir and western hemlock stumps and logs in the U.B.C. Research Forest, 1974

Host Species and Sample Site	Number Attacks in Sample	Mean Gallery Length (cm)[a]	Mean Number Niches per Gallery[ab]	Productivity Niches/cm Gallery
Western hemlock				
Stumps	71	20.55a	5.00a	0.22
Logs	20	7.67c	0.15c	0.02
Douglas-fir				
Stumps	192	14.43b	3.38b	0.23
Logs	44	6.71c	0.28c	0.04

[a] Means followed by the same letter, within columns, not significantly different, t-test, $P<0.05$.

[b] Includes egg, larval and pupal niches.

beetle activity, as males are the first sex to attack (Prebble and Graham 1957). An estimated total attack on test material of approximately 11,800; 6,800 on stumps and 5,000 on logs was derived by extrapolating from comparisons of pinned with verified attacks after debarking sections of stumps and logs.

The 9- to 45-fold preference of *G. sulcatus* for stumps over logs (see densities of attack in Table X) contrasts with the preference of *T. lineatum* for logs over chunks, tops or stumps (Dyer 1963a). A less favorable environment in logs, as evidenced by shorter galleries and reduced brood production (Table XIV), may have caused males to re-emerge and go elsewhere. I have no measure of such activity, or of reattack on the same "favorable" host, e.g., stumps. The longer galleries in western hemlock may reflect the larger proportion of available sapwood (Prebble and Graham 1957, McBride and Kinghorn 1960). Although there were twice as many attacks on Douglas-fir as on western hemlock, in mill situations *G. sulcatus* attacks and breeds more readily in boards sawn from western hemlock because of the greater sapwood volume (Fig. 3).

The greater attack frequency by *G. sulcatus* in the lateral and lower quadrants of logs (Table XIII), may indicate rejection of the upper quadrant because of dryness, higher temperatures and/or higher light intensities. Shaded Douglas-fir logs are attacked evenly by *T. lineatum*, while logs in exposed sites, such as slash fields, are attacked more on lower and shaded quadrants (Dyer 1963b). Development of galleries and brood by *T. lineatum* in logs showed a similar pattern (Gibson et al. 1958). Both trends are corroborated by subjective observations on *G. sulcatus* attacks.

Seasonal Attack by G. sulcatus
and Associated Scolytids

Although the freshness of the stumps and logs may have delayed mass attack, some attacks were observed from the first week after baiting, confirming earlier reports (Mathers 1935, Cade et al. 1970), that *G. sulcatus* can attack within the first week after felling. The overall *G. sulcatus* attack sequence (Fig. 15) suggests a single generation, with attack by pioneer and responding beetles (Borden 1974) building to a maximum in June and July. However, more detailed analyses indicate some bimodality (Figs. 19-22) as in other areas (Chapman and Kinghorn 1958). It is hypothesized that by the time a summer generation of beetles emerged in August to September, the heavily attacked, spring-felled hosts were greatly lessened in attraction and/or suitability. Therefore, a bimodal generation development and flight pattern which is noted in trapping experiments (Byrne et al. 1974) (Fig. 2), would not be noted in attack on the same hosts.

The peak attack on Douglas-fir logs occurred 4 weeks after peak attack on stumps (Figs. 19, 20). Subsequent stump attack in late August was mostly at the base and on lateral roots. This pattern further supports the hypothesis that *G. sulcatus* avoids host material which is already attacked (Prebble and Graham 1957). In laboratory studies on *G. sulcatus*, a switch off or masking mechanism was suggested to explain the decreased attraction to frass produced by beetles after pairing (Borden and Stokkink 1973). On western hemlock, a reverse sequence occurred. Log attack reached a peak before the attack on stumps (Figs. 21, 22), possibly because the fresh stumps were too moist to sustain a successful attack.

No correlation could be established between the attacks of *G. sulcatus* and *P. tsugae* on western hemlock, nor between *G. sulcatus* and *P. nebulosus* or *D. pseudotsugae* on Douglas-fir. When the Douglas-fir logs were checked 3 May, they were already under heavy attack by *P. nebulosus* (Fig. 17), characteristic of the early spring attack habit in this species (Walters and McMullen 1956). The midsummer attack by *P. tsugae* reflected its habits of overwintering in any larval stage, pupating in April and emerging in July (Bright and Stark 1973). *D. pseudotsugae* overwinters primarily in the adult stage and emerges in spring to attack new hosts. The attacks were notably evenly distributed, possibly a consequence of the paired beetles producing 3-methyl-2-cyclohexen-1-one which prevents attack in the vicinity of an established gallery (Rudinsky et al. 1972). The sustained attack throughout the summer and into October was probably by beetles which had overwintered as larvae (Walters 1956), developed near or below ground level in stumps or in other cool habitats, or had reemerged after establishing their first brood.

Response to Treatments

The results suggest that the role of ethanol is not that of a major attractant. While hosts baited with sulcatol were consistently attacked at high levels (Figs. 19-22), those baited with ethanol were not. Moreover, the combination of ethanol plus sulcatol produced only a transitory increase in attack on Douglas-fir. Few *G. sulcatus* are attracted to ethanol alone (Cade et al. 1970, Moeck 1971) (see also Table XX). When ethanol and sulcatol were deployed alone or in combination in a sawmill, sulcatol was the only significant attractant (Table I).

Significant interaction may occur with other host odors. *G. sulcatus* have been captured on traps baited with ethanolic solutions of α-pinene (1%), β-pinene (1%), camphene (1%), or Douglas-fir resin (2.5%), but not on control traps baited with ethanol alone (Rudinsky 1966).

The circumstantial evidence implicating ethanol in primary attraction of scolytids was reviewed by Moeck (1970). In addition, window flight traps, deployed in an Oak-Hickory forest, were ineffective in catching scolytids until ethanol was added to the collecting vessels (Roling and Kearby 1975). It is hypothesized that the major role of ethanol is that of an arrestant/stimulant. It acts as a tunneling stimulant for *Xyleborus ferrugineus* F. (Norris and Baker 1969). Spraying ethanol on the bark of healthy beech trees stimulated landing, copulation and boring by *Xyloterus (=Trypodendron) domesticus* L. (Kerck 1972). Presoaking logs in 10% ethanol increased frass production by female *T. lineatum* 5-fold (J. H. Borden, unpublished). Ethanol was found to be the most concentrated volatile present in logs attractive to *T. lineatum* and was absent in unattractive logs (Moeck 1970).

The significant sulcatol plus ethanol interaction of Douglas-fir (Table XI) may have been due to ethanol stimulating boring, which in turn would have led to the production of more secondary attraction. A similar phenomenon could have occurred in the tenth meter of ethanol-baited western hemlock logs which sustained more attacks than adjacent sections which were to either side of the ethanol bait (Table XII). I have no explanation for the lack of interaction between ethanol, sulcatol and the odor of hemlock (Figs. 21, 22), or of the attack rate on ethanol-baited Douglas-fir not differing from that on controls (Table XI).

Practical Implications of Results

Unlike *T. lineatum* which requires logs aged for several months (Dyer and Chapman 1965, Chapman and Dyer 1969), *G. sulcatus* can attack logs within 5 days (Cade 1970) to a month (Mathers 1935) after felling. Thus, it can easily infest felled timber before it is transported out of the forest, and cannot be controlled by "hot" logging, i.e., rapid removal of cut logs from the forest (Richmond 1968). In addition, adoption of proposed alternatives to slash burning (Dell and Green 1968) could result in the build-up of large *G. sulcatus* populations, particularly in unburned stumps. A practice of baiting selected stumps with sulcatol, at least 50 m distant from decked logs, and then treating them basally with ethanolic solutions of systemic insecticide could be used to trap and kill field populations, thus reducing the numbers of *G. sulcatus* transported to log booming grounds, dryland sorting areas and sawmills. In log processing or milling areas, baited trap logs or piles of inferior grade lumber might be used to divert beetles from high value material, particularly plywood peeler logs or export-bound, unseasoned lumber.

RESPONSE OF *GNATHOTRICHUS SULCATUS* TO SULCATOL-BAITED TRAPS OF VARIOUS DESIGNS

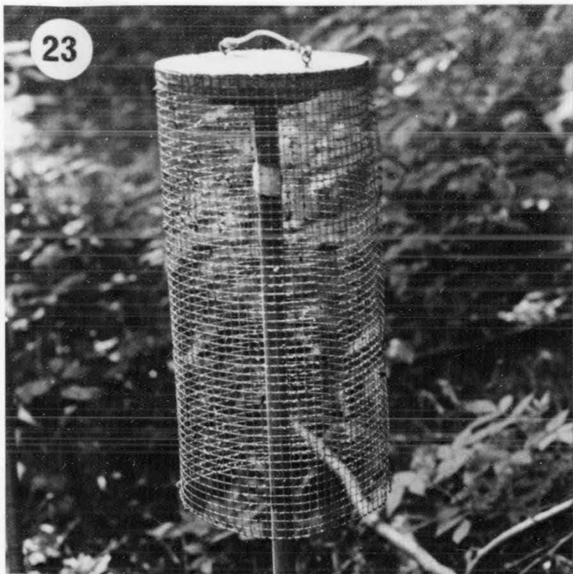
In earlier studies of field populations of ambrosia beetles, including *Gnathotrichus sulcatus* (LeConte), samples of the flying population have been made with window flight traps (Chapman and Kinghorn 1958, Cade et al. 1970, Moeck 1971), rotary insect nets (Daterman et al. 1965), polyethylene or wire gauze covered with Stickem Special[R] (Moeck 1971, Furniss and Schmitz 1971, Byrne et al. 1974). The objective of this experiment was to compare the effectiveness of variously modified cylindrical wiremesh traps, a flat wiremesh trap, and a plexiglass barrier trap.

Methods

The standard trap used in this study was a 21 cm diameter cylinder of 6 mm wiremesh closed at 1 end by a plywood disc. The trap was supported vertically by a 1.5 m length of 2.5 cm diameter dowling (Fig. 23). The 6 designs tested were a vertical and horizontal standard trap (Figs. 23, 24), a vertical and horizontal standard trap with an inner cylinder of 1.6 mm mesh black gauze to increase the visibility of the trap silhouette (Figs. 25, 26), a flat wiremesh trap of the same mesh and surface area as a standard trap (Fig. 27), and a plexiglass cross-vaned barrier trap (Fig. 28). All wiremesh traps were coated with Stickem Special[R].

All traps were baited with an open vial containing 0.5 ml of undiluted sulcatol. The vial was taped near the top of the supporting pole of the vertical wiremesh traps, suspended inside the horizontal wiremesh traps, and secured in the center of the cross-vaned trap.

Figs. 23-28. Trap designs tested in a selectively logged forest, Point Roberts, Washington, 14 July to 1 August 1975. Fig. 23: The standard cylindrical wiremesh sticky trap. Fig. 24: A horizontal standard trap. Fig. 25: The vertical standard trap with a black gauze insert. Fig. 26: The horizontal standard trap with black gauze insert. Fig. 27: The flat wire mesh sticky trap. Fig. 28: The plexiglass barrier trap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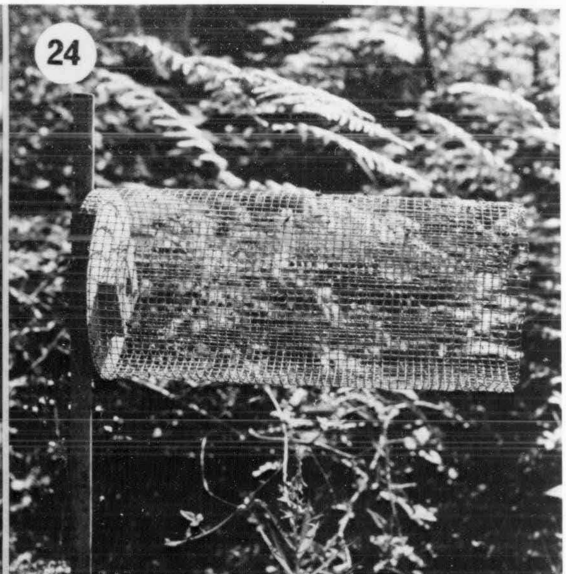
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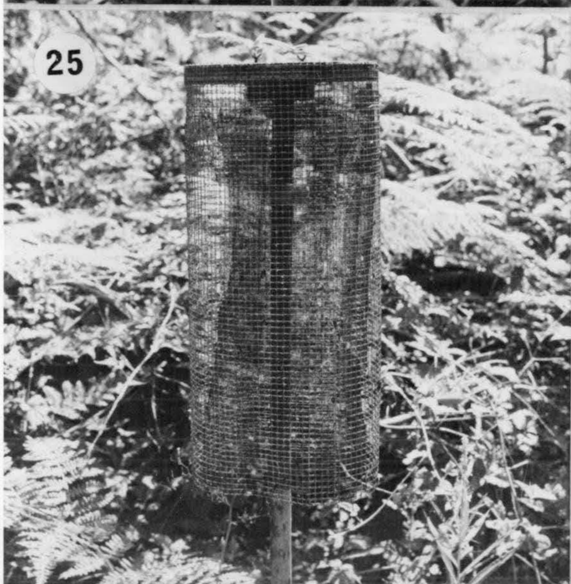
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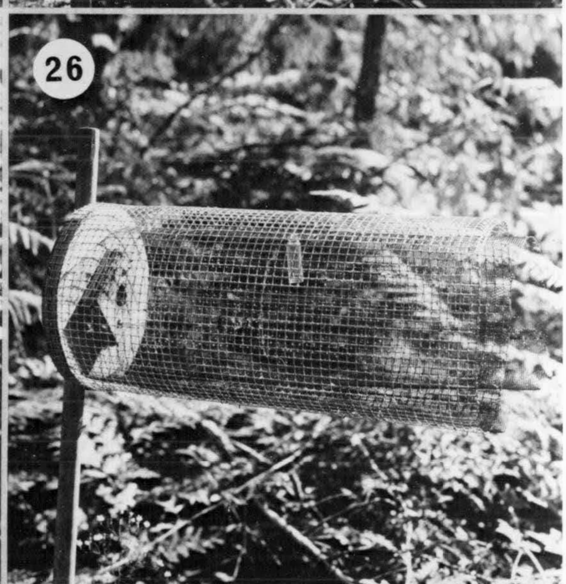
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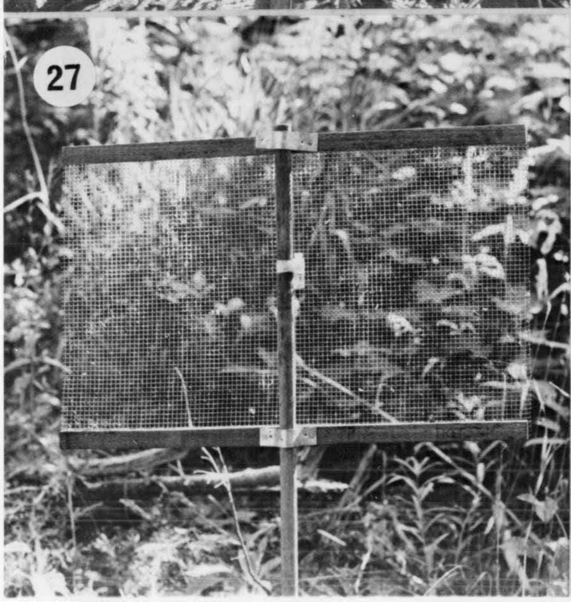
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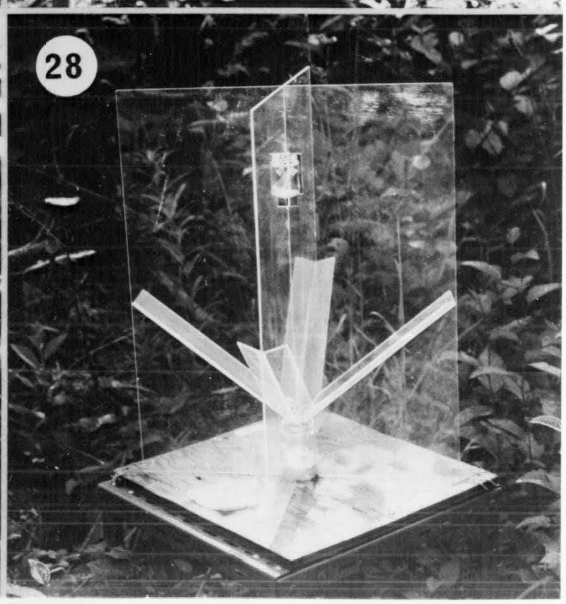
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A set of traps were deployed at each of 2 locations (A and B) in a selectively logged forest at Point Roberts, Washington, on 14 July 1975. Latin square designs were used to ensure that each design of trap was exposed once at each trapsite within a location. Traps were cleared of beetles every third day, the sulcatol baits replenished, and the traps moved to their next trapsite. Beetles were identified and sexed in the laboratory. Data were transformed to $x'=\log_{10}(x+1)$ before analysis of variance.

Results and Discussion

Vertical cylindrical traps captured significantly more *G. sulcatus* than other wiremesh traps which in turn captured significantly more than the barrier traps (Table XV). The preference for vertical cylinder traps is somewhat surprising, as *G. sulcatus* is a pest of felled logs and piled lumber. However, the preference for stumps over logs (Table X) and the greater brood production in stumps than logs (Table XIV) indicates that in nature a response to vertical traps would predominate. The 9- to 14-fold superiority of wiremesh over barrier traps corroborates earlier results (Moeck 1971). Greatest catch in Location A was on trap design No. 2 while in Location B it was trap design No. 1. This variation contributed to the significant Location by Trap Design interaction in the ANOVA. These results indicate that use of the unmodified standard trap in experimental and applied detection, survey and control programs is justified.

For the six, 3-day sampling periods from 17 July to 1 August, there was an increase in the number of beetles caught during the second

Table XV. Numbers of *Gnathotrichus sulcatus* captured at traps of 6 designs in a selectively logged Forest, Point Roberts, Washington, 14 July to 1 August 1975

Trap Design	Number Males per Trapday	Number Females per Trapday	Sex Ratio Male:Female	Total Beetles per Trapday[a]
1. Vertical cylinder	10.14	32.50	1:3.31	42.64a
2. Vertical cylinder with black gauze insert	9.75	38.33	1:3.92	47.97a
3. Horizontal cylinder	8.56	26.06	1:3.04	34.62b
4. Horizontal cylinder with black gauze insert	7.14	23.97	1:3.36	31.11b
5. Flat wiremesh trap	9.64	26.58	1:2.76	36.22b
6. Barrier trap	0.89	2.53	1:2.84	3.42c

[a] Totals followed by the same letter, not significantly different, Newman-Keuls Test, $P<0.05$.

sampling period and a steady decline thereafter as follows: 1,399, 1,699, 1,189, 1,037, 954 and 771. The 20 July catch was significantly greater than on all other days except 17 July (Newman-Keuls Test, $P<0.05$). The seasonal response of *G. sulcatus* at this period in 1973 (Byrne et al. 1974) suggests that increasing numbers of beetles should have been caught. The decline in numbers caught could reflect many phenomena, such as a gradual decrease in the number of beetles available for capture, disrupted orientation due to sensory adaptation, inability to orient in a sulcatol-saturated atmosphere, or changes in the weather. Although results in the Chemainus sawmill (Table VIII), suggest that *G. sulcatus* can be trapped out using sulcatol-baited traps, further investigation is necessary before such a conclusion can be drawn in the forest.

The relative magnitude of catches at trapsites was not consistent between Locations, leading to a significant Trapsite by Location interaction in the ANOVA. This variability may have been due to proximity of sources of beetles, or to microclimatic differences caused by varying light and temperature regimes, important regulators of *G. sulcatus* flight behavior (Daterman et al. 1965, Rudinsky and Schneider 1969).

There were significantly more *G. sulcatus* captured at Trapsites 1 (1,634), 5 (1,617), and 6 (1,306) at the ends of the traplines, than at trapsites 2 (876), 3 (745), and 4 (886) (Newman-Keuls Test, $P<0.05$). The opening in the forest made by the logging spur road, along which the trapsites were laid out, may have acted as a partial wind tunnel. This would create downwind plumes which may have drawn *G. sulcatus* to terminal traps preferentially. Alternatively an end effect may simply reflect the larger area that a terminal trap may draw beetles from and suggests that because of overlapping effective radii, the traps at a 30 m spacing are too close together. For all traps to be equal, their effective radius should not exceed half the distance between adjacent traps. My calculation, based on the 2:1 ratio of the catches at the terminal trap and the next one indicates that the effective radius of each trap is approximately 57 m. A minimum between-trap distance of 100 m is recommended for future experiments.

RESPONSES OF *GNATHOTRICHUS SULCATUS* (LECONTE) TO SULCATOL AT VARIOUS CONCENTRATIONS IN THE LABORATORY AND FOREST

Efficient use of pheromones in pest management requires that the insect response to the synthetic pheromone be fully characterized. The objectives of these experiments were to determine the most effective sulcatol release rates by testing the responses of *G. sulcatus* to pheromone at various concentrations in the laboratory and in the forest.

Methods

Laboratory Bioassay

An open-stage olfactometer (Borden and Stokkink 1973) was used to measure *G. sulcatus* response to airborne stimuli. Air was passed at a rate of 4 l/min. through a 1 mm aperture, and then through a 7.5 cm length of 10 mm diameter glass tubing lined with filter paper. Beetles were pretested to ensure that they could walk satisfactorily and were kept in groups of about 20, in 6 cm diameter petri dishes with moist paper towelling at 4°C until required for bioassays. They were warmed at room temperature (20-23°C) for 5 min before use. At the beginning of each trial 0.05 ml of stimulus was placed on the filter paper, the tube placed in the front of the air aperture and 20 beetles released 10 to 20 cm downwind. Beetles which approached within 1 cm of the glass tubing outlet were scored as positive responders. All others, including immobile ones throughout the 2.5 to 3 min test, were classed as nonresponders. Fresh filter paper, glass tubes, and beetles were used for each trial within a stimulus test series, and the brownpaper runway was changed between stimuli. Accumulation of pheromone in the air in the olfactometer room was avoided by the continuous operation of an open fume hood. Concentrations ranging from 0 (benzene control) to 5 mg of synthetic sulcatol/ trial were tested.

Field Test

A series of release systems, vials and glass jars with lids perforated by varying numbers of 4 mm diameter holes, were tested under laboratory conditions, of 22°C and 70% R.H., to assess daily evaporation rates of undiluted sulcatol. Six of the release systems were deployed on 10 June 1975, in each of 2 locations (A and B) in a randomized block design experiment in a Point Roberts, Washington forest, which had been selectively logged for the last 4 years. Linear arrays of standard vertical sticky traps (Fig. 23) were set out at 30 m intervals in each location. Insects were cleared from traps, sulcatol baits replenished, and release systems reassigned to trap positions by use of random numbers, every 3 days until completion of the experiment on 25 June. Beetles were identified to species and sexed on return to the laboratory. Data were transformed to $x'=\log_{10}(x+1)$ before analysis of variance.

Results and Discussion

Laboratory Bioassays

Highest female *G. sulcatus* responses were obtained to stimuli containing 50 ng to 50 ug of sulcatol. No significant male response was recorded (Table XVI), similar to results in other comparative tests between the sexes (Byrne et al. 1974). Stimuli at concentrations below 50 ng

Table XVI. Responses of *Gnathotrichus sulcatus* to sulcatol at various concentrations in an open-arena laboratory olfactometer, 20 December 1974

Wgt. sulcatol per 0.05 ml benzene stimulus	Order of Presentation	Male Response		Female Response		χ^2 Test[c] Males vs Females
		Number Tested	Percent Positive[a]	Number Tested	Percent Positive[b]	
0 (benzene control)	8	20	0	19	5.3d	NS
.5 ng	7	43	0	41	2.4d	NS
5 ng	6	42	4.8	42	4.8d	NS
50 ng	5	44	0	40	42.5b	**
500 ng	4	41	2.4	43	53.5a	**
5 ug	3	14	2.4	41	51.2a	**
50 ug	2	43	7.0	41	48.8b	**
500 ug	1	42	0	42	35.7c	**
5 mg	0	38	0	39	7.7d	NS

[a] No male response significantly greater than any other, χ^2 test.

[b] Percent positive responses followed by the same letter, not significantly different, χ^2 test, $P<0.05$.

[c] Probability levels indicated; **, $P<0.01$; NS, not significant.

apparently did not contain enough pheromone to elicit a directional response by female beetles and stimuli at 500 ug and 5 mg apparently contained so much sulcatol that directional response was disrupted in the test area.

Field Test

Greatest numbers of *G. sulcatus* were captured on traps baited with release systems 4 and 5 which had mean sulcatol evaporation rates of 54.7 and 128.7 mg/24 hr respectively (Table XVII). These data indicate that release systems used to date (Byrne et al. 1974, Borden et al. 1976) (Tables IV, V) may have yielded less than the optimum pheromone concentration of approximately 100 mg/day.

The relative catches to the release systems were not consistent between locations. Release system No. 2 attracted the least beetles in location A but the most in location B, contributing to a significant release system by location interaction in the ANOVA. There was also a significant release system by time interaction.

A significant decrease occurred in numbers of beetles captured over time, with catches in week 1 (1,342) > weeks 2 (718), 3 (681) > weeks 4 (398) and 5 (323) (Newman-Keuls test, $P<0.05$). This result suggests that, as in the trap design experiment (see p. 78), the population was reduced by trapping, or that high sulcatol concentrations may have caused disruption of directional response by *G. sulcatus*. Also as in the trap design experiment (see p. 78) there was evidence of an end effect in location A where about twice as many beetles were captured at trapsites 1 and 6 as at inner trapsites.

Table XVII. Numbers of *Gnathotrichus sulcatus* captured on sticky traps baited with systems releasing different amounts of sulcatol in a randomized block experiment conducted in a selectively logged forest, Point Roberts, Washington, 13 to 25 June 1975

	Release System	mg sulcatol per 24 hr[a]	No. males per trapday	No. females per trapday	Sex Ratio male:female	Total beetles per trapday[b]
1.	4 ml Vial 1 hole in cap	2.2	5.30	8.33	1.57	14.10b
2.	4 ml Vial No cap	4.9	8.40	12.10	1.44	20.47b
3.	64 ml glass jar 2 holes in cap	71.4	5.37	10.57	1.97	16.81b
4.	64 ml glass jar 4 holes in cap	57.7	6.57	14.23	2.17	22.99a
5.	64 ml glass jar 8 holes in cap	128.7	7.40	15.97	2.16	25.37a
6.	64 ml glass jar 12 holes in cap	168.6	7.77	13.40	1.73	18.22b

[a] Average of 3 runs in the laboratory at 22°C, 70% R.H.

[b] Geometric means followed by the same letter not significantly different, Newman-Keuls test, $P<0.05$.

The significant decrease in numbers of beetles captured over time, the release system by time interaction, and the variation between trapsites indicate that randomization of release systems among trapsites, as was done in this experiment, did not obtain the random sampling intended. To overcome this a Latin Square design is recommended for subsequent experiments.

RESPONSE OF *GNATHOTRICHUS SULCATUS* TO HOST ODORS

The response of *Gnathotrichus sulcatus* to host odors (Cade et al. 1970, Borden and Stokkink 1973), and specifically to ethanol (Cade et al. 1970, Moeck 1971), clearly demonstrates primary attraction in this species. Moreover, the response to freshly-sawn lumber in the Chemainus Sawmill (Tables VI, VII) is concluded to be due to attractive odors and/or boring stimulants.

The objectives of these experiments were to investigate in the laboratory, *G. sulcatus* responses to ethanol, host sawdust of increasing age after exposure of wood to ambient air, and to ethanol and host odor combined, and in the field, to ethanol released at various rates.

Methods

G. sulcatus response to aqueous solutions of ethanol were tested in the open-stage laboratory olfactometer. Stimuli were first delivered by placing 0.05 ml of test solution on a filter paper in a glass tube in front of an air aperture delivering 4 l/min. The same concentrations of ethanol were also tested by placing 50 ml of solution in a 100 ml Erlenmeyer flask and passing air over it at 2 l/min. The vapor was led through a glass delivery tube which opened directly over the air aperture which supplied air at 2 l/min.

The effect of airflow rate on ethanol release was investigated by passing air over an ethanol solution in a 100 ml Erlenmeyer flask, and trapping vapors in a dry ice condensation trap. The experiment was repeated for 1-hour periods at airflow rates of 500, 1,000, 1,500, and

2,000 ml/min. Ethanol concentrations in the flask and condensate were measured with an Abbey Refractometer. Refractive indexes were converted to percentage ethanol by weight using standard tables (Weast 1974).

An unattacked 1 m-long western hemlock log, from a tree felled on 18 April 1974, and collected from the U.B.C. Research forest in April 1975, was sawn in half longitudinally on 10 June 1975. The cut surfaces were marked into 14 transverse bands each 7 cm wide. Every 2 to 4 days, samples of sapwood and heartwood sawdust were prepared from 1 randomly selected band, with an electric drill. Male and female *G. sulcatus* responses to the fresh sawdust were determined by passing air, at 4 l/min, over 250 mg of sawdust in a 5 cm diameter petri dish insert in the olfactometer runway directly in front of the air aperture. Beetles were released 12 cm downwind and those reaching the edge of the petri dish were judged as positive responders.

Ethanol and sawdust stimuli were tested together by delivering ethanol vapor at 2 l/min from a flask containing 50 mls of 50% ethanol directly into the airstream passing at 2 l/min over attractive western hemlock sawdust.

For field bioassays, a series of release systems, 4 ml vials and 120 ml glass jars with caps perforated by varying numbers of 4 mm diameter holes, were tested under laboratory conditions at 22°C and 70% R.H., to assess daily evaporation rates of undiluted ethanol. Four of the release systems and an unbaited control, were deployed on 7 August 1975, using Latin Square designs, in each of 2 locations (A and B) in a selectively logged forest in Point Roberts, Washington. Linear arrays of 5 vertical sticky traps (Fig. 23) were set out at 30 m intervals in each location. Insects were cleared from the traps, ethanol baits replenished, and the treatments reassigned to new trapsites every 3 days until 22 August. Beetles were identified and sexed on return to the laboratory. Data were transformed to $x'=\log_{10}(x+1)$ before analysis of variance.

Results and Discussion

Laboratory Response to Ethanol

The only significant responses to 0.05 ml of ethanol solutions in glass tubes were by female *G. sulcatus* to 1% and 95% ethanol, the response of the latter being the only response significantly greater than the male response (Table XVIII). However, when air was passed over the test solutions in a flask, all responses, except the female response to 10% ethanol, were significantly greater than to water controls. The male response was greater than the female response to 0.1% and 10% solutions and the female response was greater to the 0.05% solution (Table XVIII).

When air was passed at various flow rates over a test solution, the amount of ethanol in the solution decreased over time indicating that proportionally more ethanol than water was evaporating (Table XIX). The concentration of ethanol in the condensed vapor was much higher than that in the test solution. It remained almost constant, even though the concentration in the test solution decreased (Table XIX). The 3 higher airflow rates yielded ethanol at 24, 22, and 26 mg/min, respectively, suggesting that the mean rate of 24 mg/min might approximate the upper limit of supply from this type of delivery system at 21°C.

Table XVIII. Comparison of *Gnathotrichus sulcatus* responses to ethanol in 2 delivery systems in laboratory bioassays

Concentration of ethanol (% by volume)	0.05 ml stimulus on filter paper					Flask Delivery System				
	Males		Females		χ^2	Males		Females		χ^2
	Number Tested	Percent Positive[b]	Number Tested	Percent Positive[ab]	Males vs Females[ac]	Number Tested	Percent Positive[ab]	Number Tested	Percent Positive[ab]	Males vs Females[ac]
Water Control	39	7.7	39	7.7	NS	64	4.7	62	6.5	NS
0.05	-	-	-	-		72	25.0**	67	37.3**	*f
0.1	79	5.1NS	77	10.4NS	NS	80	42.5**	80	25.0**	**m
0.5	79	3.8NS	81	4.9NS	NS	73	27.4**	79	21.5**	NS
1.0	82	11.0NS	79	16.5**	NS	83	28.9**	79	30.4**	NS
10.0	80	6.3NS	80	7.5NS	NS	78	28.2**	79	7.6NS	**m
95.0	83	8.4NS	81	17.3**	*f	42	23.8**	42	21.4**	NS

[a] χ^2 probability levels: **, P<0.01; *, P<0.05; NS, Not Significant.

[b] All responses tested by χ^2 test against response to water controls.

[c] Greater response by females or males indicated by f or m, respectively.

Table XIX. Laboratory determination of the concentrations of ethanol in a test flask and condensed vapors at 4 air-flow rates in consecutive 1 hr periods, at 21°C

Percent ethanol (by weight)[a] in flask at start of each 1 hr period	Air Flow ml/min	Percent ethanol (by weight) in condensate	mg ethanol/min
47.5	500	62.0	18
45.5	1,000	62.0	24
45.0	1,500	62.0	22
43.0[b]	2,000	60.0	26

[a] Determined from refractive index measured at the beginning of each trial.

[b] Ethanol concentration at end of experiment was 39.5%.

When these results are related to the response by *G. sulcatus* (Table XVIII) it appears that the amount of ethanol in a 0.05 ml stimulus is so small that total evaporation would occur in 20 to 30 seconds. Minimal response levels would be expected in this type of bioassay. Alternatively, the consistent results to all solutions tested by the flask delivery system were obviously due to the relatively constant vapor concentrations in the airstream, regardless of the concentration of the solutions. Clearly, this type of delivery system is desirable for testing ethanol and other highly volatile compounds in laboratory bioassays.

Field Response to Ethanol

There was a significant response by *G. sulcatus* to ethanol at all release rates, and significantly greater catches to the 2 higher concentrations of ethanol (Table XX). Significantly more males were trapped than females at all release rates ($P<0.01$). Even the highest catch rate (4.86 beetles/trapday) however, was much less than to sulcatol-baited traps (Tables XV, XVII).

Treatment 4 caught the most beetles in location B whereas treatment 5 captured the most in location A, contributing to a significant treatment by location interaction. Greatest numbers of females were captured to treatment 4 while greatest numbers of males were caught to treatment 5 (Table XX) causing a significant treatment by sex interaction. There is no obvious reason for the comparatively low catch of males to treatment 4. As in the trap design and sulcatol release rate experiments (pp. 78 and 83), there were marked end effects with significantly more *G. sulcatus* being caught on terminal traps (170) than on inner traps (43).

Table XX. Numbers of *Gnathotrichus sulcatus* captured on traps baited with systems releasing varying amounts of ethanol in a selectively logged forest at Point Roberts, Washington, 7 to 22 August 1975

Treatments	Ethanol release rate, b/24 hr[a]	Number males per trapday	Number females per trapday	Sex Ratio males:females	Mean total beetles[b] per trapday
Unbaited Control	0	0.13	0.00	-	0.13c
4 ml vial 1 hole in cap	0.25	0.87	0.33	2.64:1	1.20b
120 ml glass jar 1 hole in cap	1.10	2.80	0.40	7.00:1	3.20b
120 ml glass jar 8 holes in cap	10.00	2.60	2.20	1.18:1	4.80a
120 ml glass jar No cap	35.10	3.93	0.93	4.23:1	4.86a

[a] As determined in the laboratory at 22°C and 70% R.H.

[b] Means followed by the same letter not significantly different, Newman-Keuls test, $P<0.05$.

Both the laboratory results (Table XVIII) and field results (Table XX) confirm other studies (Cade et al. 1970, Moeck 1971) which indicated that ethanol is an attractant for *G. sulcatus*. However, when compared to sulcatol, ethanol is a relatively weak attractant.

Laboratory Responses to Sawdust, and Sawdust with Ethanol

A measure of attractiveness of a freshly sawn log, over time, was obtained by bioassays of freshly prepared sawdust at 2- to 4-day intervals for 31 days (Table XXI). In nearly all cases, both male and female *G. sulcatus* response to sawdust from sapwood and heartwood was significantly greater than to air controls. The highest responses were by females to heartwood and sapwood (66.3% and 61.3% respectively) on day 24. The highest male response to sapwood (51.3%) was also recorded on this day. Female response to sapwood was significantly greater than male response on days 0, 4, 8, 13, and 31 while male response was greater on days 17, 20, and 27. Female response to heartwood was significantly greater than male response on days 0, 10, 24, and 31 (Table XXI). Clearly, sawdust odor is attractive to both sexes, and the more frequently higher female response suggests that females may be the more responsive sex. This result was not as expected, as the male is the pioneer sex in this species (Prebble and Graham 1957). The significant responses to heartwood were not expected, because few if any galleries are ever initiated in or extended into heartwood (Prebble and Graham 1957, McBride and Kinghorn 1960). However, when the response to sapwood and heartwood by each sex are compared, the significantly different responses all favor

Table XXI. *Gnathotrichus sulcatus* response over time to sawdust prepared from an unattacked western hemlock log felled 18 April 1974, field collected April 1975 and bisected longitudinally on 10 June 1975

Days after wood exposed to air	Sapwood				χ^2	Heartwood				χ^2	χ^2	
	Males		Females		Males vs Females[ac]	Males		Females		Males vs Females	Sapwood vs Heartwood	
	number tested	percent positive[ab]	number tested	percent positive[ab]		number tested	percent positive[ab]	number tested	percent positive[ab]		Males[ad]	Females[ad]
0	80	31.2**	80	43.7**	*f	79	15.2	79	24.1**	*f	**s	**s
2	79	35.4**	78	38.5**	NS	79	16.5**	80	22.5**	NS	**s	**s
4	78	39.6**	75	48.0**	*f	79	16.5	77	32.4*	NS	**s	**s
6	83	25.2**	82	19.5**	NS	77	13.0*	82	15.8**	NS	**s	NS
8	81	23.5**	80	38.8**	**f	82	9.8*	83	16.9*	NS	**s	**s
10	78	23.3**	82	19.5**	NS	80	12.5**	77	22.0**	*f	**s	NS
13	83	12.0NS	73	26.0**	**f	80	12.5NS	79	11.4**	NS	NS	**s
17	80	47.5**	80	13.8*	**m	83	24.1**	81	23.5**	NS	**s	*h
20	83	37.3**	79	19.0NS	**m	81	11.1*	78	10.3NS	NS	**s	*s
24	80	51.3**	80	61.3**	NS	80	25.0**	80	66.3**	**f	**s	NS
27	72	36.1**	75	22.7**	**m	76	22.4NS	75	20.0*	NS	**s	NS
31	80	16.2NS	80	33.8**	**f	80	25.0**	80	36.3**	*f	NS	NS

[a] χ^2 probability levels: **, $P<0.01$; *, $P<0.05$; NS, not significant.

[b] All responses tested by χ^2 test against response to air controls.

[c] Greater response by females or males indicated by f or m, respectively.

[d] Greater response to sapwood or heartwood indicated by s or h, respectively.

sapwood, except for females on day 17 (Table XXI). Thus, the attractive component(s) are to be found in greater concentration in the sapwood.

Persistently high attraction of host material does not compare with results obtained in the Chemainus Sawmill where loads of fresh lumber were most heavily attacked in weeks 2, 3, and 4 after sawmilling (Table VI). This difference could be explained by the hypothesis that in the mill site, secondary attraction would have made the lumber more attractive after male beetles had attacked the boards in the first week. As freshly-sawn lumber is attractive to both sexes of *G. sulcatus*, processing units (such as the Planer Mill in the Chemainus Sawmill) which release odor in milling and have large quantities of fresh lumber stored around them, would be expected to attract large numbers of beetles.

When ethanol and sawdust were tested together, there was a significantly greater response by both sexes than to either stimulus alone (Table XXII). The greater male than female response to the combined ethanol and sawdust stimulus supports the results of the field tests (Table XX) in which more males than females were captured to ethanol-baited traps. The ability of males to respond more readily to the combined ethanol plus sawdust odor is of adaptive significance in that it would enable them to pioneer attack on the most suitable hosts in nature. Isolation and identification of the active host-produced components in addition to ethanol is recommended. The total complex of naturally-occurring attractants (sulcatol, ethanol, and the yet unknown other host compounds) could then be used in applied control of *G. sulcatus*.

Table XXII. *Gnathotrichus sulcatus* responses to ethanol and western hemlock sapwood sawdust, tested alone or together in laboratory bioassays, on 10 October 1975

Stimulus	Males		Females		χ^2
	Number Tested	percent[a] response	Number Tested	percent[a] response	males vs females[c]
Air control	87	4.6a	82	9.8a	NS
Sawdust	88	27.3b	83	33.7b	NS
Ethanol[b]	90	28.9b	83	24.1b	NS
Sawdust plus ethanol	88	60.2c	83	48.2c	*

[a] Percents within a column followed by the same letter not significantly different, χ^2 test, $P<0.01$.

[b] Flask delivery system with 50% solution of ethanol.

[c] χ^2 probability levels: *, $P<0.05$; NS, not significant.

CONCLUSIONS

Various phenomena related to host selection, host suitability and pheromone response have been elucidated by these studies. Stumps are concluded to be a more favorable habitat for *G. sulcatus* than logs, because of superior attack rates (Table X) and brood productivity (Table XIV). The preference for vertical cylinder traps over other designs (Table XV) may reflect this preference for stumps over logs. A preference for unseasoned lumber in weeks 2, 3, and 4 after sawmilling (Table VI) is related to favorable moisture content, an increase in secondary attraction in the first week, and finally to decreasing moisture content. The demonstration that *G. sulcatus* can develop and reproduce in unseasoned lumber (Fig. 3) emphasizes the threat of *G. sulcatus* introduction into lumber-importing countries.

In all experiments, sulcatol was always superior to ethanol as an attractant. While ethanol was marginally attractive alone in the field (Table XX) it appears to modulate attraction to host material in the field. Thus, its major role may be more that of an arrestant/boring stimulant than an attractant. High responses by both male and female *G. sulcatus* to sawdust and ethanol when tested together in the laboratory (Table XXII) suggest that there are other as yet unidentified, attractive components in host volatiles. The increased vulnerability to attack of lumber adjacent to sulcatol-baited traps (Table VII) is concluded to reflect an area response by males to sulcatol and their diversion to a host-positive response before being intercepted by a trap. This response could be exploited by combining attractive slab lumber with sulcatol-baited traps in trap out programs in commercial sawmills.

My studies have shown that sulcatol is ideally suited for species-specific insect pest management (Glass 1975). It is a markedly species-specific aggregation pheromone that is active at very low concentrations in the laboratory (Table XVI) and in the field (Table XVII), and attracts *G. sulcatus* in a ratio of approximately 2♀♀:1♂ (Tables II, XV, XVII). Sulcatol-baited traps deployed in a commercial sawmill demonstrated their ability in pest detection and survey. They indicated areas of high pest populations (Table III), and disclosed seasonal patterns of *G. sulcatus* flight activity (Figs. 2, 4-7). In lumber-importing countries, sulcatol-baited traps could be used in surveillance surveys.

Sulcatol is also concluded to be a promising tool for *G. sulcatus* control. In a sawmill site, continuously-baited traps suppressed an estimated 0.70 of males and 0.87 of females in the most heavily infested problem area (Table VIII). In the forest, sulcatol--or sulcatol plus ethanol-baited stumps and logs sustained much higher densities of attack than did ethanol-baited or unbaited host material in the same areas (Figs. 19-22). Therefore, the trap tree (or stump) method of beetle control could be employed in the forest by utilizing sulcatol and ethanol baits.

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CURRICULUM VITAE

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Born 31 March 1943, Auckland, New Zealand; 5'11"; 175 lbs.; married; health excellent; Canadian Landed Immigrant, eligible for citizenship December 1978.

ADDRESSES

Work: Pestology Centre,
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RESEARCH INTEREST AND EXPERIENCE

Extensive experience and publications in basic insect ecology and taxonomy, pheromone biology, and use of naturally-occuring chemical attractants in insect pest management. Familiar with tropical and temperate zone entomology and fresh water biology, and methods of mass rearing insects. Additional competence in biometrics and computer programming (APL). Interest in research on basic biology and management of agricultural and forest insect pests, applied chemical ecology, and development of reliable detection and survey methods for insect pest management programs.

EDUCATION

Ph.D. Graduate Student, Simon Fraser University, 1974 to present.
Expected completion date, May 1976.
Awarded NRC Postgraduate Scholarship, 1975.

Research on the role of natural attractants of the ambrosia beetle, *Gnathotrichus sulcatus* has been undertaken with emphasis on use of the population aggregation pheromone, sulcatol, in management of pest populations in forests and commercial sawmills. Graduate coursework in Statistics and Experimental Design, Entomology and Pest Management.

M.Sc.(Hons.) in Zoology, 1968, University of Auckland, New Zealand.
Awarded Post-Primary Teachers' Studentship 1961-66.

Research on the taxonomy, morphology and ecology of the mayfly *Oniscigaster wakefieldi* (Ephemeroptera: Siphlonuridae). Graduate coursework in General Entomology, Evolution and Natural Selection.

B.Sc. in Zoology, 1965, University of Auckland, New Zealand.

Secondary and primary school training in Auckland, New Zealand, 1948-60.

PROFESSIONAL TRAINING

Diploma in Teaching, 1968, New Zealand Education Department.

Secondary Teachers College Diploma (with distinction), 1967, Auckland Secondary Teachers' College, New Zealand.

TEACHING EXPERIENCE

Teaching Assistant, Simon Fraser University, 1974-76.
BISC 306 Invertebrate Zoology 1974(1), 1974(3)
BISC 101 Introductory Biology 1975(1)
BISC 417 Entomology 1976(1)

Guest Instructor, Simon Fraser University,
BISC 601 Urban and Industrial Pest Management 1975(2)

Lecturer in Biology, School of Natural Resources, University of the South Pacific, Suva, Fiji, 1970-73 (Equivalent to Assistant Professor rank). Special responsibilities included:

a) Development of courses in Introductory Biology for students of varying backgrounds in preparation for advanced degree studies in Science, Medicine and Agriculture.

b) Development of a two-year program of Basic Science for Home Economics, as part of the Diploma in Education curriculum.

Biology Master, Lytton High School, Gisborne, New Zealand, 1968-69. Acting Head of Biology in 1969. Duties included:

a) Coordination of Biology syllabi at all levels with special responsibilities for a pilot program in Form 6 (Grade 12) Biology.

b) Setting and approving of Biology examinations at all levels.

c) Organisation of the Biology Laboratory.

Demonstrator in first year Zoology Laboratories, University of Auckland, New Zealand, 1964-66.

OTHER PROFESSIONAL EXPERIENCE

Consultant to Concord Engineering Ltd., Vancouver, on control of fly problem in a fish factory, 1974.

Research Collaborator on a Coconut Rhinoceros Beetle Research Project, University of the South Pacific, Fiji, 1972-73. Established a mass-rearing facility to provide beetles of known history for host selection and basic biological research.

Consultant Biologist to the Basic Science Group, UNDP/UNESCO Regional Curriculum Development Workshop, Suva, Fiji, January 1973.

Editor and Co-author of a series of 3, 6th Form Ecology Field Guides on "Streams and Ponds," University of the South Pacific, 1972-73.

Housing Committee Member, University of the South Pacific, 1972-73.

Member of Advisory Committee for 6th Form Ecology Field Guide Series on Islands Grasslands and School Compounds, Mangrove Swamps, and Intertidal Mudflats, 1971.

MEMBERSHIP IN PROFESSIONAL SOCIETIES

Entomological Society of Canada

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Entomological Society of British Columbia

Entomological Society of New Zealand

New Zealand Limnological Society

PAPERS PUBLISHED

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McLean, J. A. Comparative study of three stream fauna in Auckland Area. Tane. *12:*97-102. 1966.

PAPERS PRESENTED AT SCIENTIFIC MEETINGS

"Practicality and limitations of the use of bark and ambrosia beetle pheromones as a control tactic, with special reference to studies in British Columbia." Annual Western Forest Insect Work Conference. Mount Hood, Oregon. 1976.

"Survey of a sawmill population of *Gnathotrichus sulcatus* with the synthetic pheromone, sulcatol." Annual meeting of the Entomological Society of British Columbia. 1975.

"Survey of a sawmill population of *Gnathotrichus sulcatus* Coleoptera: Scolytidae) using the pheromone sulcatol." Annual meeting of the Entomological Society of America. Portland, Oregon. 1975.

"Entomology in Fiji with special reference to Biological Control." Annual meeting of the Entomological Society of British Columbia. 1974.

"Studies on the Ecology of *Oniscigaster wakefieldi* (Ephemeroptera: Siphlonuridae)." Annual meeting of the New Zealand Limnological Society. Auckland, New Zealand. 1968.

SEMINARS

"In pursuit of pheromones and the insects that produce them." With J. H. Borden, Biological Sciences Seminar, Simon Fraser University, 1975.

"Status of Freshwater Biology Research in Fiji and the Streams and Ponds Field Guides." School of Natural Resources Seminar, University of the South Pacific, 1973.

EXTRACURRICULAR ACTIVITIES

Current interests in Ballroom Dancing, Skiing and Photography.

Boat Club Committee Member, University of the South Pacific, Fiji, 1971-73.

Coached Soccer Teams at Lytton High School, 1968-69, and at the University of the South Pacific, 1971-72.

Judo Champion, Auckland University, 1966. Club President 1964, 1965, represented Auckland University at the New Zealand Universities Tournament, 1963, '64, '66, and '67. Selected for New Zealand Universities' Team on three occasions.

Active member of the Auckland University Field Club, 1963-66.

Participant in Field Club Scientific Camps, reports of which published in Field Club's Journal, *Tane*.

Territorial Army Service in the Royal New Zealand Engineers, 1963-67.

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