FRONTISPIECE

Scanning electron micrograph of the head and thorax of a male _Trypodendron lineatum_. Photo: V. Bourne.

PHEROMONE-BASED MANAGEMENT OF AMBROSIA BEETLES IN TIMBER PROCESSING AREAS ON VANCOUVER ISLAND

by

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Title of Thesis/Project/Extended Essay

Pheromone-based management of Ambrosia beetles in timber processing areas on Vancouver Island

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ABSTRACT

Experiments assessed the use of the pheromones lineatin, (±)-sulcatol, and *S*-(+)-sulcatol in management of the ambrosia beetles *Trypodendron lineatum* (Olivier), *Gnathotrichus sulcatus* (LeConte), and *G. retusus* (LeConte), respectively.

In a 12-week experiment pheromone-baited and blank untreated trap logs were as efficient as pheromone-baited sticky traps for *T. lineatum* up to 4 weeks, whereafter they were inferior to sticky traps. Overall, pheromone-baited traps were more efficient than all logs for male *G. retusus*, or blank logs for *T. lineatum*, and equal to logs for male *G. sulcatus*.

Pheromone-baited sticky traps were superior to lindane-treated, pheromone-baited trap logs throughout another 12-week experiment for female *G. sulcatus*, after 4 weeks for *T. lineatum* and male *G. sulcatus*, but only for 4 weeks in mid-experiment for *G. retusus*. Overall, traps were superior to lindane-treated logs for *G. sulcatus*, whereas there was no difference for the other 2 species.

A newly designed multiple funnel trap compared favorably in performance to sticky traps and Scandinavian drainpipe traps. Sticky vane traps were more efficient than 3 other trap types for *T. lineatum* and *G. retusus*. For *G. sulcatus* the multiple funnel trap was more efficient than a sticky cylinder trap, but not better than vane or Scandinavian drainpipe traps. Placement of baits in the lower half of drainpipe traps increased their efficiency. T. lineatum demonstrated a silhouette response by responding equally to funnel and drainpipe traps releasing lineatin at 40 μg/24h and to traps releasing lineatin at 10 μg/24h, but with a nearby dispenser releasing the pheromone at 30 μg/24h. In late April traps placed 15 - 25 m inside the forest margin caught more T. lineatum than traps at the margin.

The populations of all 3 species were surveyed by trapping and/or overwintering samples in 4 dryland sorting areas. Mass trapping at Sooke, B.C., for 2 years did not appear to affect the populations of any species, despite catches of over 2.8 million beetles in 1981. Therefore pheromone-based management must be integrated with rigorous log management.

DEDICATION

To my parents, Eva and Rune Lindgren.

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A. INTRODUCTION

BIOLOGY

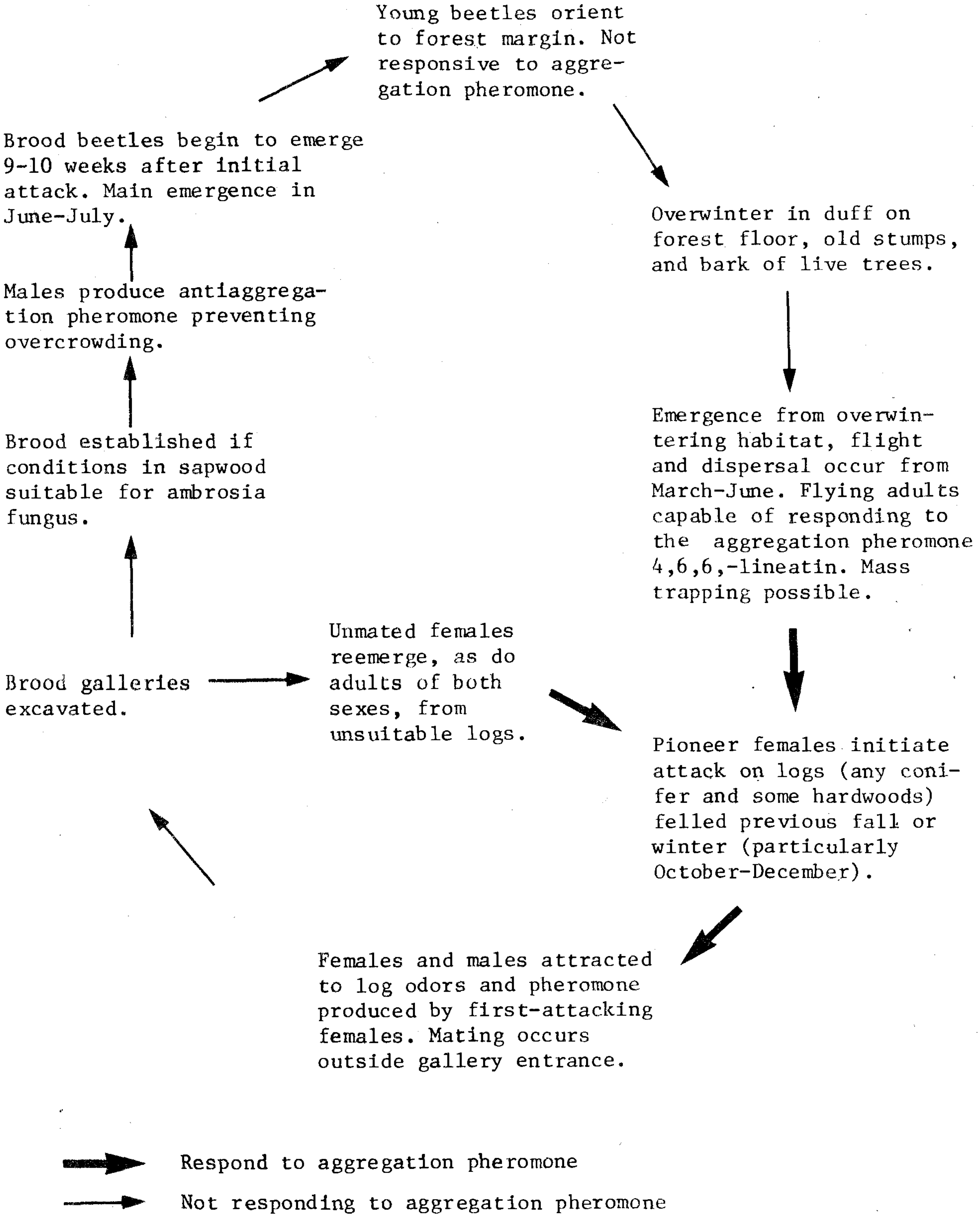
Ambrosia beetles are woodboring Coleoptera belonging to the families Platypodidae, Scolytidae, and Lymexilidae (Baker 1963). The name "ambrosia beetle" refers to their symbiotic association with certain fungi; the "ambrosia" upon which larvae and young adults feed (Baker 1963). These fungi may be relatively little specialized, e.g. *Ceratocystis* spp., which are similar to blue-stain fungi occurring with many bark beetles (Krebill 1975) but are ambrosial in the galleries of *Gnathotrichus sulcatus* (LeConte) (Doane and Gilliland 1929; Baker 1963), or highly specialized such as *Monilia ferruginea* Mathiesen-Kaarik, which occurs in galleries of *Trypodendron lineatum* (Olivier) (Mathiesen-Kaarik 1953, Baker 1963). Of the 10 species of ambrosia beetles found in Western Canada (Table I), only 3 are of economic significance in British Columbia.

T. lineatum, the striped ambrosia beetle, is holarctic in distribution (Lekander et al. 1977). It is by far the most abundant species in B.C., and has been the subject of extensive study (Nijholt 1979). Its lifecycle is outlined in Fig. 1. In coastal British Columbia *T. lineatum* overwinter in duff or bark in the forest margin near brood logs in which they were reared

TABLE I. Ambrosia beetles found in British Columbia. (Compiled from Bright 1976; Furniss and Carolin 1977).

FAMILY	SPECIES	HOST TREES
PLATYPODIDAE	*Platypus wilsoni* Swaine	*Abies* spp., western hemlock, Douglas-fir, occasionally other conifers
SCOLYTIDAE	*Gnathotrichus retusus* (LeConte)	*Alnus* spp., probably most conifers in its range
	G. sulcatus (LeConte)	Probably all conifers in its range
	Monarthrum scutellare (LeConte)	*Quercus* spp.
	Trypodendron betulae Swaine	*Betula* spp.
	T. lineatum (Olivier)	All conifers in its range, *Alnus* spp., *Betula* spp.
	T. retusum (LeConte)	*Populus* spp., *Picea* spp.
	T. rufitarsus (Kirby)	*Picea* spp., *Pinus* spp., probably other conifers
	Xyleborus dispar (Fabricius)	Probably all deciduous trees
	X. saxeseni (Ratzeburg)	Various deciduous species, *Pinus* spp., western hemlock, Douglas-fir

Fig. 1. Schematic lifecycle of _T. lineatum_ (Olivier) in coastal British Columbia.



Young beetles orient to forest margin. Not responsive to aggregation pheromone.

Overwinter in duff on forest floor, old stumps, and bark of live trees.

Emergence from overwintering habitat, flight and dispersal occur from March-June. Flying adults capable of responding to the aggregation pheromone 4,6,6,-lineatin. Mass trapping possible.

Pioneer females initiate attack on logs (any conifer and some hardwoods) felled previous fall or winter (particularly October-December).

Females and males attracted to log odors and pheromone produced by first-attacking females. Mating occurs outside gallery entrance.

Brood galleries excavated.

Unmated females reemerge, as do adults of both sexes, from unsuitable logs.

Brood established if conditions in sapwood suitable for ambrosia fungus.

Males produce antiaggregation pheromone preventing overcrowding.

Brood beetles begin to emerge 9-10 weeks after initial attack. Main emergence in June-July.

➡ Respond to aggregation pheromone

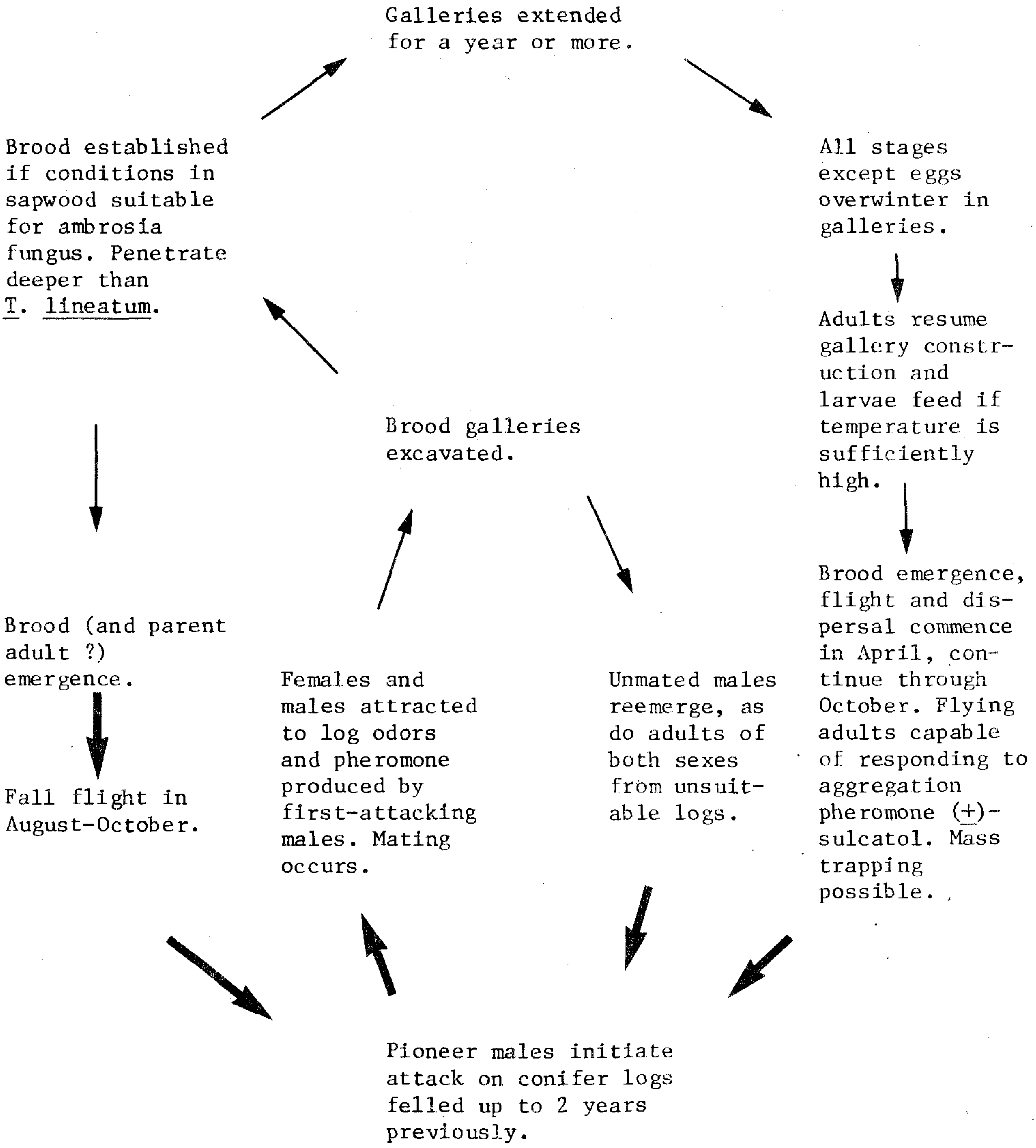
→ Not responding to aggregation pheromone

(Kinghorn and Chapman 1959). In late March through June they emerge and embark on a brief dispersal flight (Graham 1959; Chapman and Nijholt 1980). Recently dead trees or logs felled the previous winter are attacked by pioneer females (Chapman 1961; Christiansen and Saether 1968; Annila et al. 1972). These females produce an aggregation pheromone, racemic 4,6,6,lineatin (3,3,7-trimethyl-2,9-dioxatricyclo $[3.3.1.0^{4,7}]$ nonane) (Borden et al. 1968, 1979). This pheromone, referred to as lineatin, attracts both sexes to the brood log. Mating occurs outside the gallery entrance (Nijholt 1978), and gallery construction is usually completed in about 3 weeks (Prebble and Graham 1957). In B.C. oviposition commences in the first 2 weeks of gallery construction, eggs hatch after about 10 days, and brood emergence begins about 9-10 weeks after initial attack (Hadorn 1933; Prebble and Graham 1957). The main brood emergence continues through July (Shore et al., 1981) whereafter very few beetles emerge. Brood beetles do not respond to the aggregation pheromone (W.W. Nijholt[1], unpubl. data), but fly to overwintering sites (Prebble and Graham 1957; Chapman and Kinghorn 1958). Parent beetles in unsuitable logs may reemerge and attack new logs (Chapman and Kinghorn 1958). Some parent beetles survive to overwinter a second year (Dyer 1961).

G. sulcatus is less abundant than *T. lineatum*, but may constitute a more severe problem due to its habits. (Fig. 2) All life stages overwinter in the logs, (Chamberlin 1939; Prebble and Graham 1957) and parent beetles resume gallery construction whenever ambient temperatures are suitable. In the southern coastal area of B.C., flight begins approximately 2 weeks later than that of *T. lineatum* (Prebble and Graham 1957). Pioneer males attack logs 2 weeks to 2 years after felling (Mathers 1935), and produce the aggregation pheromone (±)-sulcatol (6-methyl-5-hepten-2-ol) (Byrne et al. 1974) which attracts males and females to the log. After mating, females take over construction of the gallery (Doane and Gilliland 1929; Prebble and Graham 1957), and egg laying commences. Brood from eggs laid in midsummer do not emerge until the following spring (Prebble and Graham 1957). Brood beetles emerging in late summer and fall, when a second major flight occurs, respond to the aggregation pheromone, attack new logs, and establish brood. A gallery may be extended for a year or more if the conditions for ambrosia fungi are suitable (Prebble and Graham 1957).

The life history of *Gnathotrichus retusus* (LeConte) is similar to that of *G. sulcatus* (Prebble and Graham 1957; Rudinsky and Schneider 1969). In British Columbia *G. retusus* flies in late spring, with minimal activity in August through September. *G. retusus* appears to prefer a drier habitat than *G. sulcatus* (J.H. Borden[2],pers comm.).

Fig. 2. Schematic lifecycle of *G. sulcatus* (LeConte) in Coastal British Columbia.



Galleries extended for a year or more.

Brood established if conditions in sapwood suitable for ambrosia fungus. Penetrate deeper than *T. lineatum*.

All stages except eggs overwinter in galleries.

Adults resume gallery construction and larvae feed if temperature is sufficiently high.

Brood galleries excavated.

Brood emergence, flight and dispersal commence in April, continue through October. Flying adults capable of responding to aggregation pheromone (±)-sulcatol. Mass trapping possible.

Brood (and parent adult ?) emergence.

Fall flight in August-October.

Females and males attracted to log odors and pheromone produced by first-attacking males. Mating occurs.

Unmated males reemerge, as do adults of both sexes from unsuitable logs.

Pioneer males initiate attack on conifer logs felled up to 2 years previously.

➡ Respond to aggregation pheromone

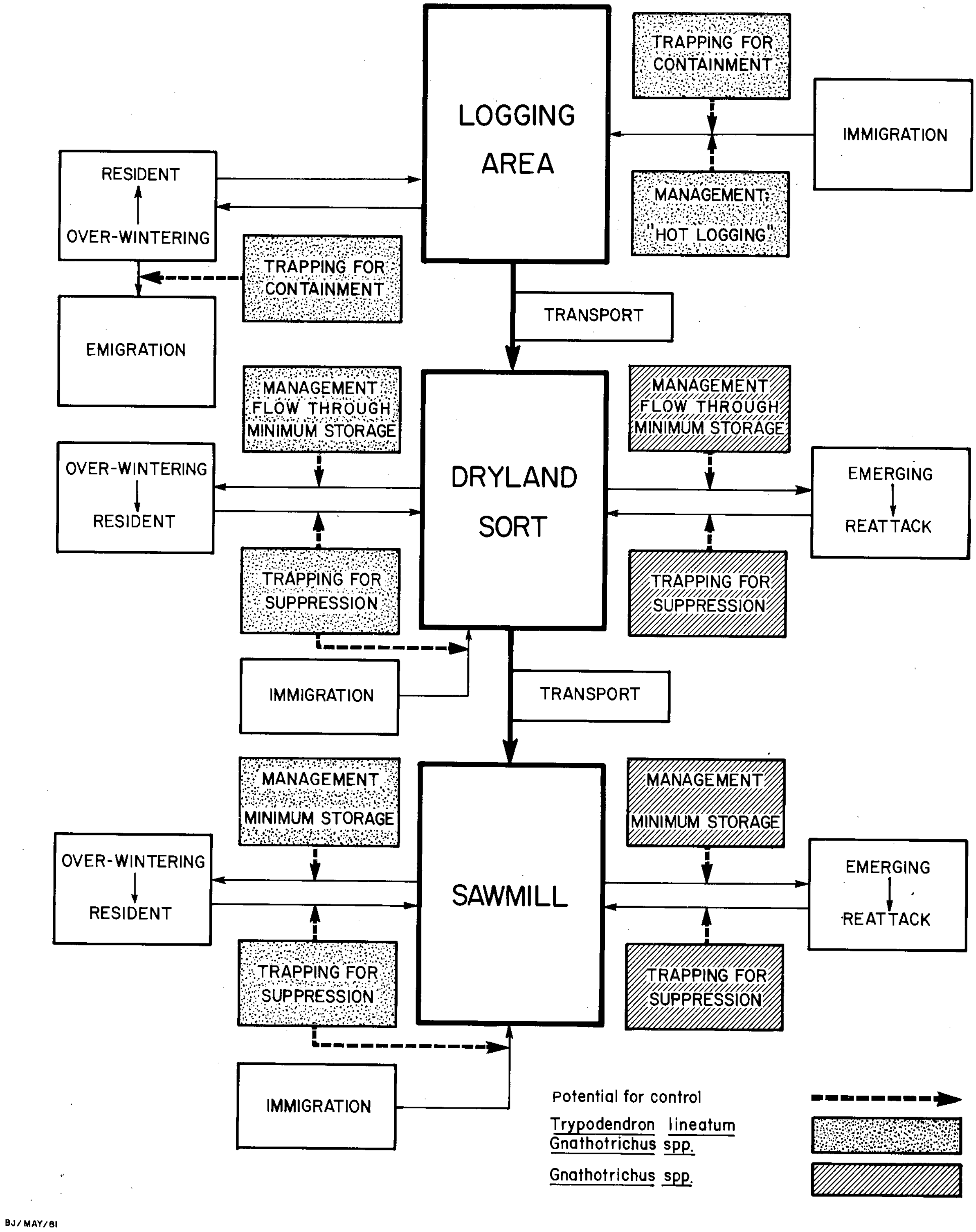
→ Not responding to aggregation pheromone

DAMAGE AND MANAGEMENT

All 3 species attack timber and lumber in the Pacific Northwest (Nijholt 1978). Consequent economic losses are due to degrade of lumber and plywood veneer and export restrictions (McBride and Kinghorn 1960; Dobie 1978). The trend from water to dryland sorting and storing has accentuated the problem (Nijholt 1978). Damage may occur at 3 distinct levels as logs are moved from logging sites, through sorting areas to sawmills (Fig. 3).

Borden and McLean (1981) outlined 3 principal strategies of ambrosia beetle management: 1) habitat management (e.g. rapid inventory turnover before the product is attacked), 2) protection of the product, and 3) suppression of beetle populations. The possible management options as outlined in Fig. 3 are only utilized to a limited extent. Rapid movement of vulnerable logs and lumber is practiced to the extent that logging operations, weather, mill capacity, market conditions, and labor disputes will allow. The practice of protecting log booms and decks by application of lindane (Graham and Webb 1952; Graham 1953; Richmond 1961) was discontinued due to environmental considerations (Finegan 1967; Richmond and Nijholt 1972). The only current protection measure in dryland sorting areas is water misting of valuable log decks (Richmond and Nijholt 1972), and the use of trap bundles, i.e. pulp logs placed so as to absorb maximum attack, whereafter they can be

Fig. 3. Flow chart outlining ambrosia beetle activity and their potential management.


LOGGING AREA
TRAPPING FOR CONTAINMENT
IMMIGRATION
MANAGEMENT: "HOT LOGGING"
RESIDENT
OVER-WINTERING
TRAPPING FOR CONTAINMENT
EMIGRATION
TRANSPORT
MANAGEMENT FLOW THROUGH MINIMUM STORAGE
MANAGEMENT FLOW THROUGH MINIMUM STORAGE
OVER-WINTERING
RESIDENT
DRYLAND SORT
EMERGING
REATTACK
TRAPPING FOR SUPPRESSION
TRAPPING FOR SUPPRESSION
IMMIGRATION
TRANSPORT
MANAGEMENT MINIMUM STORAGE
MANAGEMENT MINIMUM STORAGE
OVER-WINTERING
RESIDENT
SAWMILL
EMERGING
REATTACK
TRAPPING FOR SUPPRESSION
TRAPPING FOR SUPPRESSION
IMMIGRATION
Potential for control
Trypodendron lineatum Gnathotrichus spp.
Gnathotrichus spp.
BJ/MAY/81

transported to a pulp mill and destroyed in a chipper. Repellents, such as turpentine (Nijholt 1973a) and pine oil (Nijholt 1980b) have been tested, but are not used operationally, whereas pheromone-baited traps have been utilized against *G. sulcatus* in a commercial sawmill (McLean and Borden 1979).

Utilization of pheromones to contain bark beetles in already infested areas to prevent new attacks has been successful for the southern pine beetle, *Dendroctonus frontalis* Zimmermann (Richerson et al. 1980). Similar techniques utilizing pheromone-baited traps or stumps (McLean and Borden 1975) should be tried in logging areas to minimize the spread of ambrosia beetles to new sites (Fig. 3).

OBJECTIVES

My objectives were: 1) to develop new trapping techniques utilizing synthetic aggregation pheromones against all 3 species, 2) evaluate these techniques in comparison with those already existing, and 3) to design an optimal scheme for mass trapping all 3 species of ambrosia beetle in dryland sorting areas (dryland sorts) in British Columbia.

B. EVALUATION OF TWO TRAP LOG TECHNIQUES FOR AMBROSIA BEETLES IN TIMBER PROCESSING AREAS ON VANCOUVER ISLAND

Control of ambrosia beetles has been attempted by utilizing trap bundles. These are pulp or cull log bundles placed around the periphery of the sort to intercept T. lineatum as they emerge from overwintering sites in the surrounding forest margin. An experimental evaluation of the efficacy of trap bundles has not been made.

Scolytid beetles orient to their host in response to visual stimuli, to host specific chemicals (primary attraction), and to species specific aggregation pheromones alone or in combination with primary attractants (secondary attraction) (Borden 1977, 1982).

The successful isolation, identification, synthesis and field testing of (±)-sulcatol, the G. sulcatus aggregation pheromone (Byrne et al. 1974), led to the operational suppression of this species at a commercial sawmill, using pheromone-baited sticky traps (McLean and Borden 1977a, 1979). Logs and stumps, baited with pheromone, were evaluated as potential suppression tools for field populations of G. sulcatus (McLean and Borden 1977b). A comparative study of pheromone-baited trap logs and traps was never undertaken, however. The recent availability of lineatin and S-(+)-sulcatol, the aggregation pheromones, respectively, of *T. lineatum* (Borden et al. 1979), and *G. retusus* (Borden et al. 1980a), and the demonstrated potential of pheromone-baited trap logs for controlling some scolytid beetles (Heath 1981), have made such a study for all 3 species of ambrosia beetles possible.

My objective was to evaluate the relative efficacy of lindane-treated or untreated trap logs (logs), against that of sticky traps (traps) for managing ambrosia beetle populations in dryland sorts.

MATERIALS AND METHODS

The experiments were carried out at a dryland sort of MacMillan-Bloedel Ltd., Shawnigan Woodlands Division, near Duncan, on the east coast of Vancouver Island, B.C. The area perimeter is ca. 1 km and it is mainly surrounded by 2nd growth coniferous forest about 45 years old. Over 272,000 m^3 of timber are processed annually through the sort.

Experiment 1

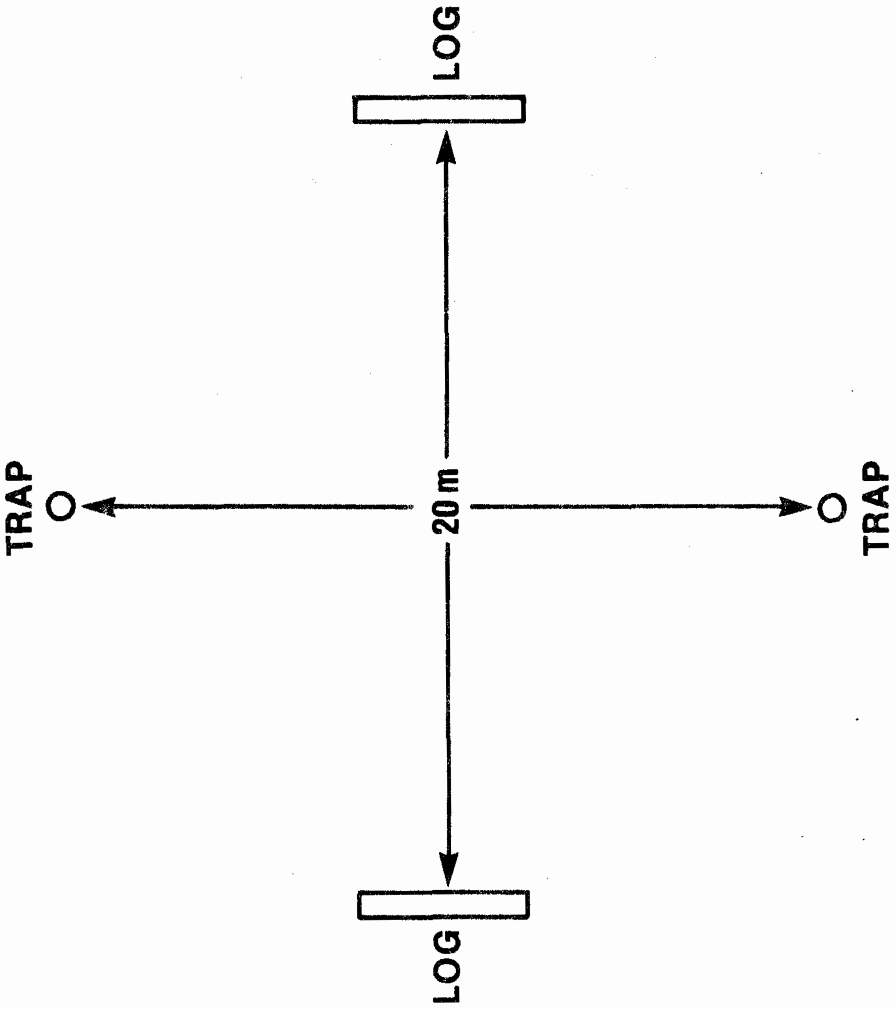
This experiment compared untreated logs to sticky traps, and was conducted between March 15 and June 7, 1979. Forty-eight Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, logs ($\bar{x}$

length = 469 cm, range = 360 - 540 cm; $\bar{x}$ diam = 27.9 cm, range = 19.8 - 39.9 cm) were obtained from a November 1978 cutting in a 2nd growth stand infested by the root rot, *Phellinus* (=*Poria*) *weirii* (Murr.) Gilbertson. This cutting date ensured that the logs were properly aged, and therefore, suitable for infestation by *T. lineatum* in the spring (Dyer and Chapman 1965). The logs were placed around the periphery of the sort on Feb. 8 and 9, 1979.

Cylindrical hardware cloth traps (Byrne et al. 1974), coated with Stikem Special (Michel and Pelton, Ltd., Emeryville, Calif.), were set up on Mar. 15. In a randomized block design, each of 24 plots around the forest margin was randomly assigned pheromone for 1 species of ambrosia beetle. Three plots, 1 for each species of beetle, made up a block, for a total of 8 replicates/species. Each plot had 2 logs and 2 traps placed as in Fig. 4. One trap and 1 log were randomly chosen for pheromone baiting, the other trap and log left unbaited as blank controls. Blank traps were used to record background flight. The minimum distance between plots was 35 m.

Lineatin was released from 4 Conrel fibers (Albany International Co., Needham, Mass.) (aperture diam. = 0.2 mm) at a rate of 8-10 μg/fiber/24h[3] (H.D. Pierce, Jr.[4], unpublished data). (±)-Sulcatol and S-(+)-sulcatol were released from open glass vials (aperture diam. = 8 mm) at a release rate of 4.9 mg/day (McLean 1976). These were complemented by the synergistic

Fig. 4. Diagram of plot layout for Experiment 1.


LOG
TRAP
20 m
TRAP
LOG

primary attractants (Borden et al. 1980c) (±)-α-pinene (Aldrich Chemical Co., Inc., Milwaukee, Wis.) which was released from an open glass vial (aperture diam. = 8 mm) at 40 mg/day, and 95% ethanol released from a plastic bottle with 1 hole (diam. = 3 mm) drilled in the cap, giving a release rate of 200 mg/day. The baits were taped to the central support pole ca. 20 cm from the top of the 46 cm high wire mesh cylinder of the traps, or were affixed to a large spike, with a 100 cm^2 plastic rain cover, at the midpoint of the logs (Fig. 5).

Captured beetles were removed from sticky traps in hot Shell Household Solvent (Shell Chemical Co., Ltd.). This procedure was done biweekly until the onset of major flight on Apr. 26, and thereafter weekly until termination of the experiment on June 7. Beetles were kept in solvent until counted and their sex determined.

Fresh attacks in ten, 20 X 20 cm squares (Fig. 5) in 5 positions (1 m apart) on both sides of each log (Fig. 6) were counted biweekly and marked with pins. Total attack was extrapolated from the sample squares to the total surface of the log. At the termination of the experiment, 2 discs, ca. 10 cm thick, were cut from each of the 5 positions on each log. The bark on the discs was removed and attacks were recorded in top, side, and bottom quadrants, respectively, to obtain a more accurate estimate. Total attack was again extrapolated. The estimates from pinning of attacks were corrected by dividing by the ratio between the total estimated from pinning attacks over the total estimated from counting attacks on log discs.

Attack density and brood production of *T. lineatum* are higher in logs from fast growing than slow growing trees (Dyer and Chapman 1964; Chapman and Dyer 1969). Therefore, log diam. and sapwood depth were measured to determine if these parameters would be useful in identifying susceptible logs for use in trap bundles.

Species differentiation of galleries was achieved by use of 2 probes (diam. = 1.48 mm and 1.29 mm). Based on earlier data (Kinghorn 1957; McLean and Borden 1977a), holes 1.48 mm and larger were recorded as being made by *T. lineatum*, holes smaller than 1.29 mm by *G. sulcatus*, and holes between 1.29 and 1.47 mm by *G. retusus* . Accuracy was determined by dissection of 8, 8, and 15 galleries recorded as made by *T. lineatum*, *G. sulcatus*, and *G. retusus*, respectively.

The data on catch and estimated number of attacks were transformed as $[x' = \log10(x + 1)]$ before factorial analysis of variance (factors attractant, trapping device, and block) and the Newman-Keuls Test ($P<0.05$). The relation between attack density, and log diam. and sapwood depth was analyzed by multiple regression. The criterion for selecting the best equation was the value of the coefficient of correlation.

Fig. 5-7. Experimental setup and assessment for trap log experiments. Mid-section of log in Experiment 1 showing 20 X 20 cm sample square, and sulcatol and synergist dispenser (Fig. 5). Counting ambrosia beetle attacks in sample squares (Fig. 6). Lindane-treated trap log in collecting trough in Experiment 2 (Fig. 7).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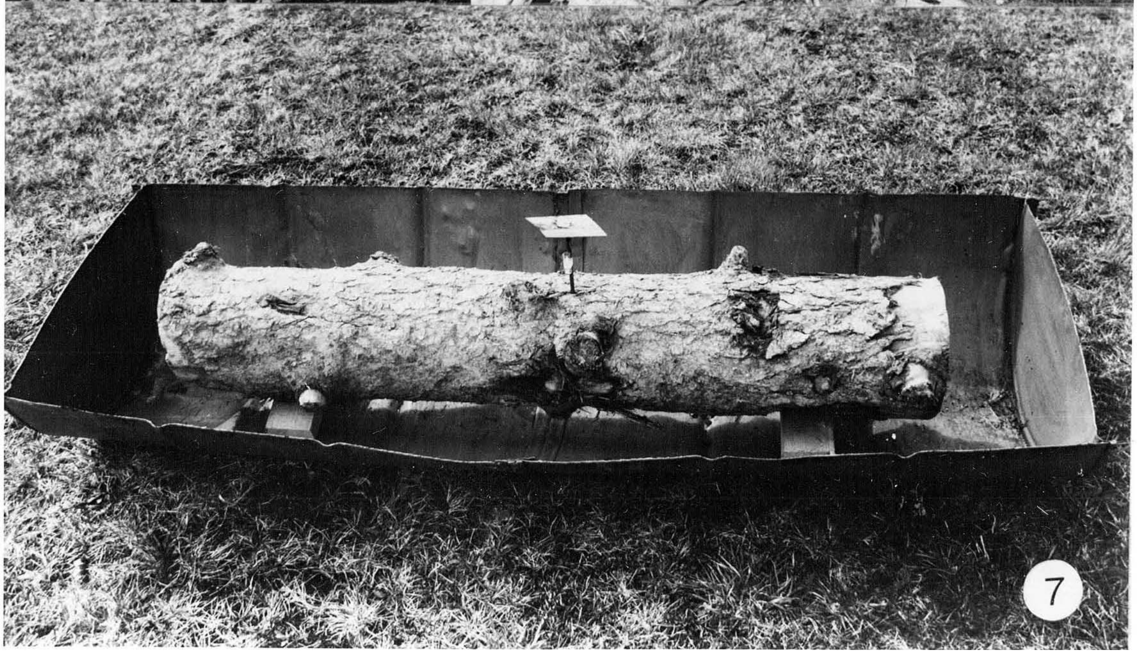
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Experiment 2

This experiment compared lindane-treated logs with sticky traps, and was conducted between Apr. 15 and July 9, 1980. Logs were obtained from a stand of vigorous, second growth Douglas-fir logged in Jan. 1980. Twenty-eight, 1.5 m long bolts ($\bar{x}$ diam. = 27.1 cm, range = 21 - 31 cm) were sprayed individually to runoff with a 0.5% aqueous suspension of lindane (Isotox 25 WP, Ortho Agricultural Chemicals, Ltd., Vancouver, B.C.), using a hand pressurized back pack sprayer (Solo Knapsack sprayer 425, Solo Kleinmotoren, GmbH, 7032 Sindelfingen, W.Germany). The bolts were placed around the dryland sort in 1.7 m-long collecting troughs (Fig. 7) made from halves of 200 liter steel drums, welded together end to end. All troughs were painted with Tremclad orange, rust-resistant paint (Tremco [Canada] Ltd., Toronto, Ontario).

A total of 7 completely randomized blocks were set up, each containing 8 treatments: 3 cylindrical wire mesh sticky traps and 3 lindane-treated trap logs, each baited with pheromone for 1 species of ambrosia beetle, and 1 trap and 1 log unbaited as blank controls. Baiting of traps and logs was done on Apr. 15, 1980. The minimum distance between treatments was 40 m.

Lineatin was released as in Experiment 1. The sulcatols were released from open vials (aperture diam. = 4 mm), at a release rate of 1 mg/day. Ethanol was released from an open nalgene bottle (aperture diam. = 12 mm), at 1 g/day (Borden et al. 1981b), and α-pinene as previously described. Baits were placed in traps and on logs as in Experiment 1.

Captured insects on sticky traps were collected and processed biweekly as in Experiment 1, commencing May 1, until separated from debris, counted, and their sex determined. At the termination of the experiment an approximately 10 cm thick disc was cut from the middle of each bolt. The disc was debarked and the attacks were recorded. Forty-eight galleries were dissected to determine brood success.

Data were transformed as in Experiment 1 before factorial analysis of variance and the Newman-Keuls Test ($p<0.05$) as in Exp. 1. Sex ratios for beetles captured by baited traps and logs were analyzed by analysis of variance without transformation.

RESULTS

Experiment 1

The 1st attacks by *T. lineatum* were noted on March 19, 1979. By the 1st sampling date, Mar. 29, baited and control logs of several replicates had sustained heavy attacks, significantly higher than the relatively light catches on traps (analysis of variance, $p<0.05$) (Fig. 8). However, the Newman-Keuls test failed to disclose a significant difference between mean catch of females (the 1st attacking sex) on pheromone-baited sticky traps, and mean attack on either pheromone-baited or blank trap logs. While attractiveness of the trap logs apparently decreased over time, the traps became relatively more efficient (Fig. 8), and were significantly better than logs from Apr. 26 on.

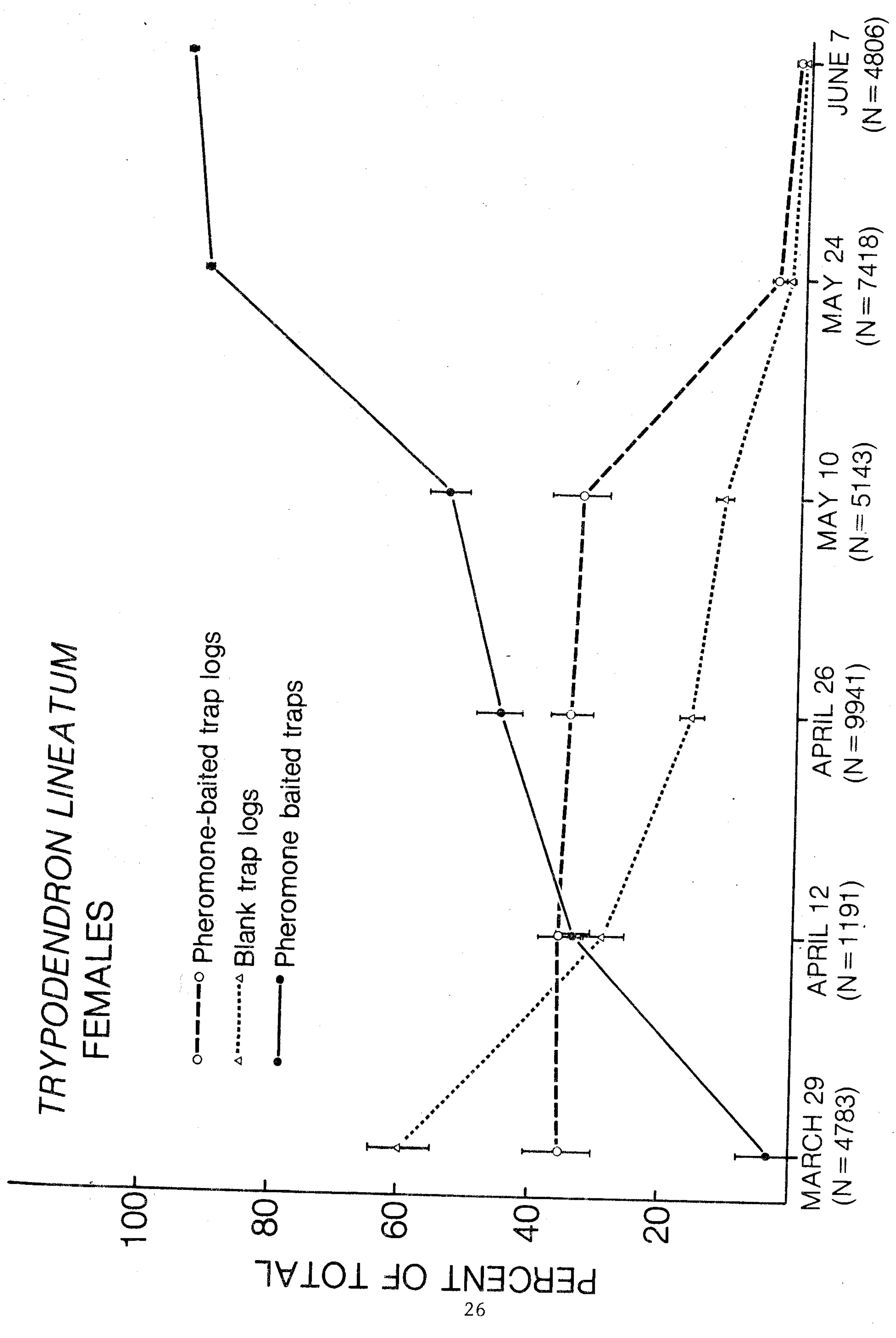
Beetle activity remained high throughout the experimental period, with a decrease in early April. Attacks on trap logs virtually ceased after the initial 8 weeks of the experiment.

Seasonal attacks for *G. sulcatus* and *G. retusus* were not recorded since all trap logs were heavily attacked by *T. lineatum*, and when attacks were pinned, the 3 species could not be separated.

The total attack estimated from pinning was 79% of the estimate from verified attacks, considerably higher than in a similar study on *G. sulcatus* (McLean and Borden 1977b). All 8 galleries assessed on the basis of diameter as being made by *T. lineatum* were confirmed by gallery dissections. Similarly, 6 of 8 and 5 of 15 were correctly identified for *G. sulcatus* and *G. retusus*, respectively. Of the galleries identified as being made by *G. retusus*, 2 were actually made by *T. lineatum*. The remaining 8 for *G. retusus* and 2 for *G. sulcatus* could not be determined since they were abandoned.

The relatively high correlation coefficients for attack densities of *G. retusus* with *G. sulcatus* ($r = 0.60$, $p<0.01$) and

Fig. 8. Biweekly attack (± 1 SE) on trap logs, and catch on traps, of T. lineatum females in Experiment 1 expressed as percentage of estimated total (N). Catch on blank traps <2 % of total for all dates.


TRYPODENDRON LINEATUM
FEMALES
Pheromone-baited trap logs
Blank trap logs
Pheromone baited traps
PERCENT OF TOTAL
100
80
60
40
20
MARCH 29 (N=4783)
APRIL 12 (N=1191)
APRIL 26 (N=9941)
MAY 10 (N=5143)
MAY 24 (N=7418)
JUNE 7 (N=4806)

T. lineatum ($r = 0.46$, $p<0.01$) probably reflect overlap of gallery entrance diameters of G. retusus with the other 2 species. The correlation coefficient for G. sulcatus with T. lineatum was only 0.25 ($p>0.05$), indicating good separation of these 2 species.

Since galleries are initiated by the 1st attacking sex (female T. lineatum and male Gnathotrichus spp.), comparisons between the efficacy of traps and trap logs ignored the opposite sex. For the total, 12-week experiment, pheromone-baited traps captured 19,217 female T. lineatum , 2,997 male G. sulcatus and 1,515 male G. retusus. The traps were more efficient than trap logs for G. retusus, better than blank trap logs for T. lineatum, and as good as trap logs for G. sulcatus (Fig. 9). Table II shows estimated total attacks by all 3 species on all 48 logs.

The presence of synthetic pheromone on trap logs did not affect the horizontal attack distribution. The distribution of attacks on top, bottom, and sides of logs was similar for T. lineatum and G. sulcatus , both of which preferred sides or bottom of logs, whereas G. retusus showed no preference (Table III).

There was a significant correlation between attack density and log diam. for T. lineatum and G. retusus, and between attack density and sapwood depth for G. sulcatus (Fig. 10). However, the fit of the regression was poor for all 3 species. Very low

Fig. 9. Mean total attack (± 1 SE) on trap logs, and catch on traps, of female *T. lineatum*, and male *G. sulcatus* and *G. retusus* in Experiment 1.

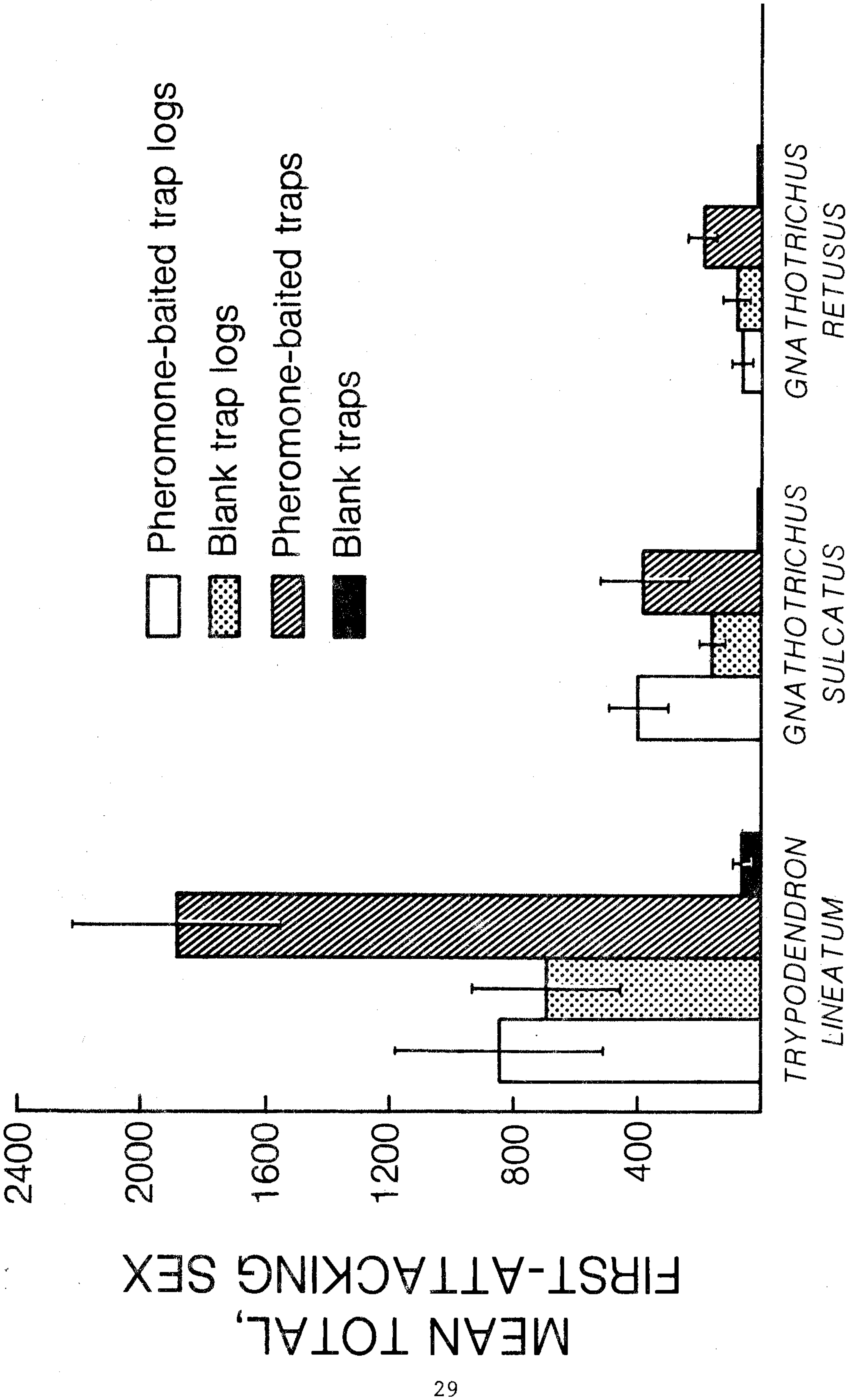

MEAN TOTAL, FIRST-ATTACKING SEX
2400
2000
1600
1200
800
400
□ Pheromone-baited trap logs
▦ Blank trap logs
▨ Pheromone-baited traps
■ Blank traps
TRYPODENDRON LINEATUM
GNATHOTRICHUS SULCATUS
GNATHOTRICHUS RETUSUS

TABLE II. Estimated total number of attacks by 3 species of ambrosia beetles on trap logs in Exp. 1. Dryland sort of MacMillan-Bloedel Ltd., Shawnigan Woodlands Division, Duncan, B.C., 1979.

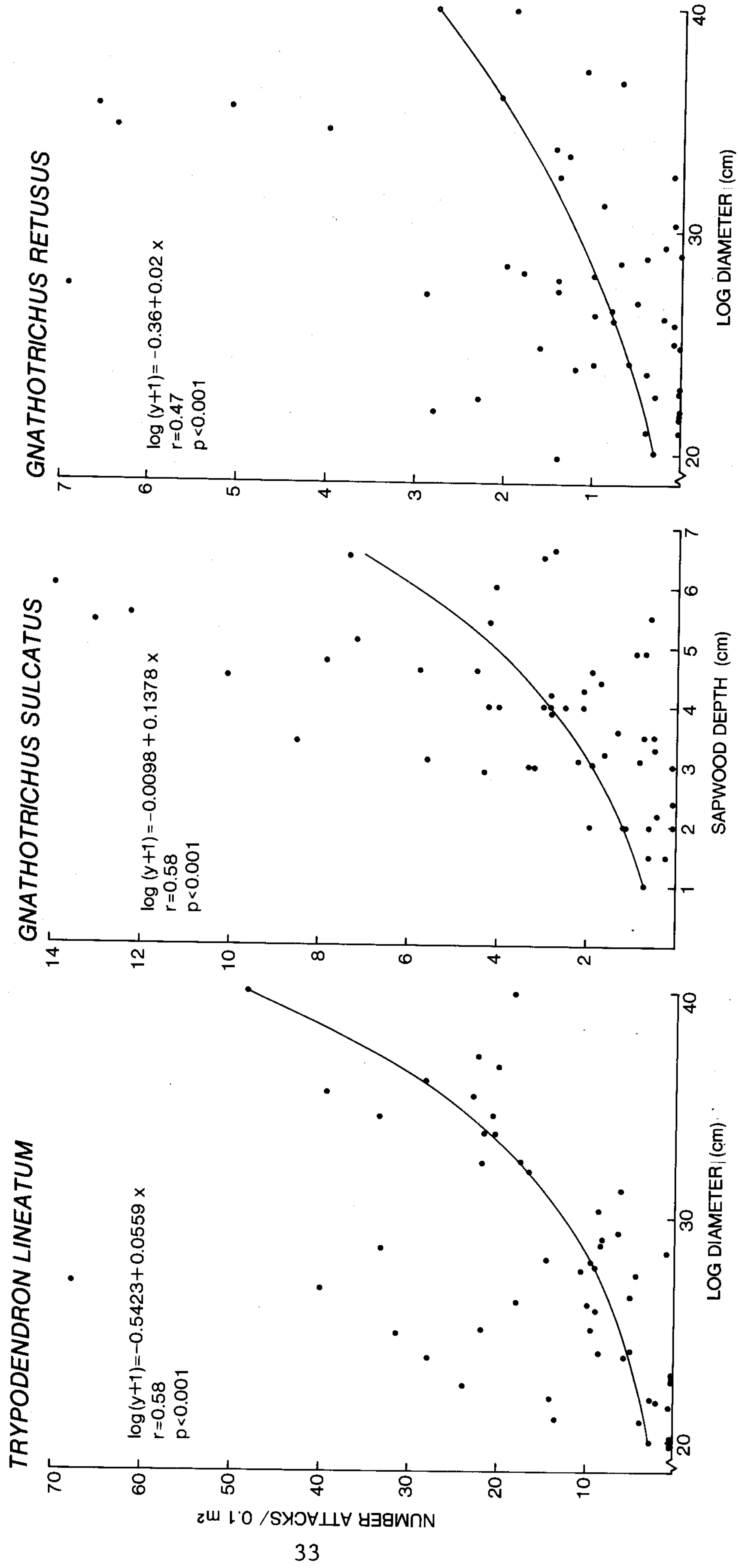
Treatment of Log(N=8)	*Trypodendron lineatum*	*Gnathotrichus sulcatus*	*Gnathotrichus retusus*
Lineatin-baited	6,782	391	239
Blank control	5,734	417	274
(±)-Sulcatol-baited	4,414	3,116	846
Blank control	3,829	1,251	175
S-(+)-Sulcatol-baited	3,340	961	466
Blank control	6,748	941	645

TABLE III. Vertical distribution of ambrosia beetle attacks on Douglas-fir logs[a]. Dryland sort of MacMillan-Bloedel Ltd., Shawnigan Woodlands Division, Duncan, B.C., 1979.

Quadrant	Trypodendron lineatum		Gnathotrichus sulcatus		Gnathotrichus retusus	
	Attacks/m^2	Range	Attacks/m^2	Range	Attacks/m^2	Range
Top	126.1a	0-586	41.5a	0-186	14.8	0-70
Side 1	182.6b	0-679	74.6b	6-196	14.1	0-59
Side 2	193.7b	0-642	76.7b	6-160	16.9	0-99
Bottom	231.6b	0-809	60.7b	11-120	12.3	0-46

[a] Means within columns followed by same letter not significantly different, analysis of variance and Newman-Keuls Test, ($P<0.05$). Means within columns not followed by letters, not significantly different, analysis of variance, ($P<0.05$).

Fig. 10. Relationship between attack density of 3 species of ambrosia beetles and log diameter or sapwood depth of Douglas-fir trap logs in Experiment 1 (N=47).


TRYPODENDRON LINEATUM
log(y+1)=−0.5423+0.0559 x
r=0.58
p<0.001
NUMBER ATTACKS/ 0.1 m²
70
60
50
40
30
20
10
20
30
40
LOG DIAMETER (cm)
GNATHOTRICHUS SULCATUS
log (y+1)=−0.0098+0.1378 x
r=0.58
p<0.001
14
12
10
8
6
4
2
1
2
3
4
5
6
7
SAPWOOD DEPTH (cm)
GNATHOTRICHUS RETUSUS
log (y+1)=−0.36+0.02 x
r=0.47
p<0.001
7
6
5
4
3
2
1
20
30
40
LOG DIAMETER (cm)

attack densities were observed on logs with a sapwood depth of 1.5 - 2.0 cm for all 3 species, whereas high attack densities were associated with sapwood depth of >2.0 cm. High attack densities by _T. lineatum_ and _G. retusus_ were generally associated with log diam. >25 cm.

Experiment 2

On the 1st sampling date, catches of _T. lineatum_ on pheromone-baited traps and lindane-treated trap logs were high for both sexes (Fig. 11). Over the next 4 weeks, catches declined rapidly. They remained low on lindane-treated logs for the remainder of the experiment but increased on sticky traps. The traps were significantly more effective than logs after the initial 4 weeks. Blank (unbaited) lindane-treated trap logs were initially better than blank sticky traps but were equal or inferior to blank traps after 4 weeks.

G. sulcatus catches were moderately high for both sexes during the 1st 4 weeks of the experiment, whereafter they declined (Fig. 11). Catches on pheromone-baited traps were significantly higher than on lindane-treated trap logs throughout the experiment for females, and for males after the initial 4 weeks. Blank traps and logs were inefficient.

Catches of _G. retusus_ were low throughout the experiment, with peak catches in several replicates on June 26 (Fig. 11).

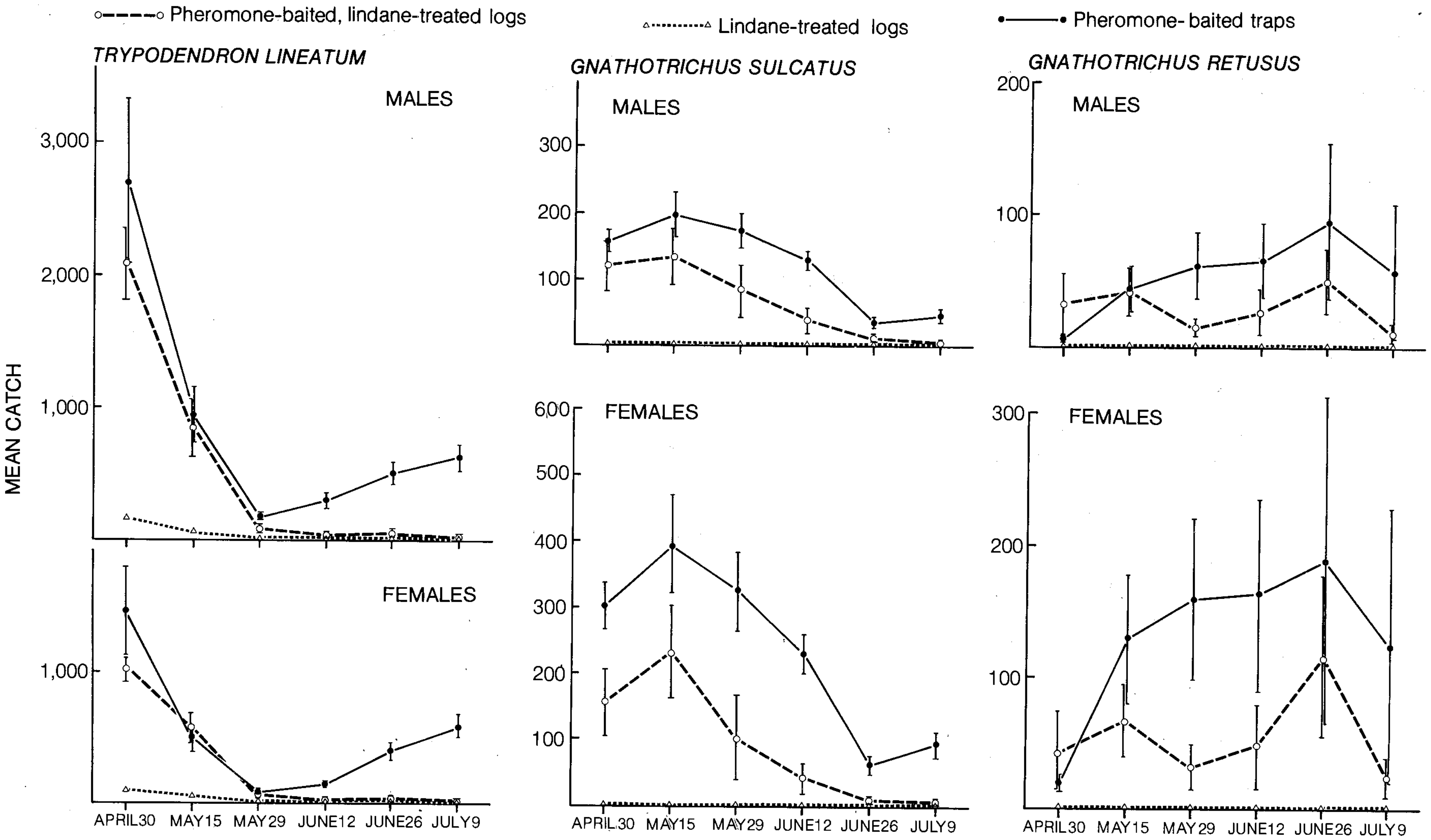
Baited traps caught significantly more beetles of both sexes than lindane-treated logs only for the 4 weeks between May 15 and June 12. There was no difference between blank traps and blank trap logs.

The sex ratios of captured *T. lineatum* showed no consistent trend between traps and lindane-treated trap logs. For both *Gnathotrichus* spp., however, trap logs attracted a higher proportion of males (the first attacking and pheromone producing sex) than traps (Table IV).

The total catches on pheromone-baited traps and logs, respectively, were 59,242 and 34,386 for *T. lineatum*, 14,162 and 6,578 for *G. sulcatus*, and 7,842 and 3,567 for *G. retusus*. There was no significant difference in efficacy between pheromone-baited traps and trap logs for *T. lineatum* and *G. retusus*, whereas the traps were more efficient for *G. sulcatus* (Fig. 12). Blank control traps and logs were largely inefficient, although 1 blank log caught high numbers of *T. lineatum* , probably due to secondary attraction established by breakthrough, i.e. successful attack in spite of the lindane treatment (Table V).

The assessment of breakthrough showed that *T. lineatum* in particular could survive and establish brood (Table V). All logs baited with lineatin as well as some others were attacked by this species.

Fig. 11. Biweekly catch (± 1 SE) of 3 species of ambrosia beetles on lindane-treated trap logs and pheromone-baited sticky traps in Experiment 2.


Pheromone-baited, lindane-treated logs
Lindane-treated logs
Pheromone-baited traps
TRYPODENDRON LINEATUM
GNATHOTRICHUS SULCATUS
GNATHOTRICHUS RETUSUS
MALES
FEMALES
MEAN CATCH
3,000
2,000
1,000
300
200
100
600
500
400
APRIL30
MAY15
MAY29
JUNE12
JUNE26
JULY9

Of the 48 galleries dissected, 19 (39.6%) were established, with egg niches or pupal chambers. Brood success, measured as number of pupal chambers divided by total number of egg niches plus pupal chambers, was 73.7%. All abandoned tunnels were shorter than 25 mm.

The only established G. sulcatus gallery dissected was 170 mm long. The 3 abandoned galleries were 55 mm or shorter. The 2 abandoned G. retusus galleries were 30 and 40 mm long.

DISCUSSION

Comparisons of Trap Logs and Sticky Traps

The decline in efficacy of lindane-treated trap logs after the initial 4 weeks for T. lineatum and G. sulcatus and their continuing effectiveness for G. retusus (Fig. 11), indicated that there was a change in attractive properties of the logs for the former 2 species, rather than a reduced knockdown effect by lindane. This explanation also was supported by the fact that the majority of breakthrough attacks by T. lineatum (Table V) occurred on many logs during the initial 4 weeks.

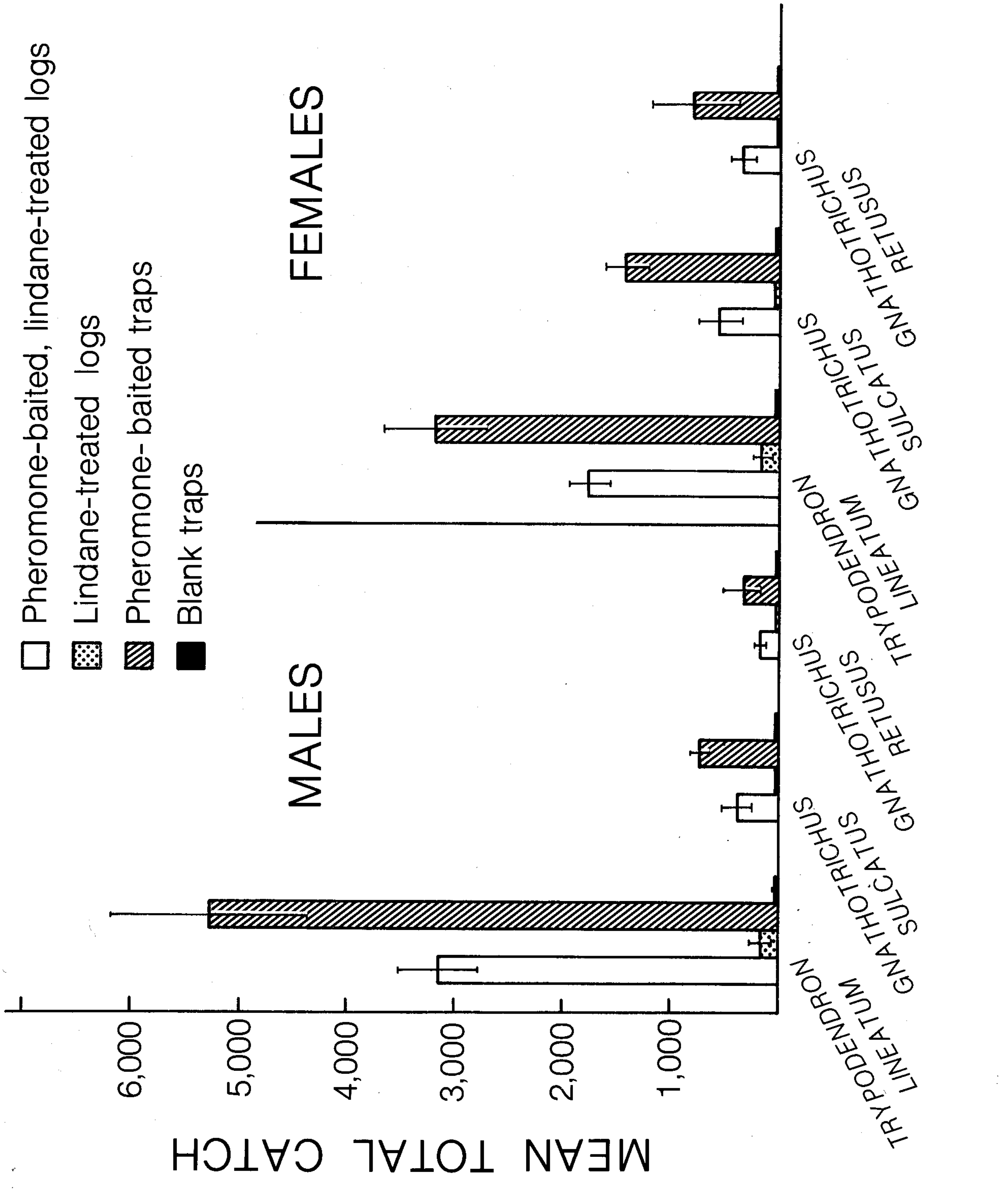
Failure by lindane to protect log decks and booms has been reported by Graham (1953). It is likely that washoff of lindane to some extent contributed to successful breakthrough attacks by

TABLE IV. Responding/first attacking sex ratios (male/female *T. lineatum*, female/male *Gnathotrichus* spp.) of 3 species of ambrosia beetles on pheromone-baited sticky traps and lindane-treated trap logs[a]. Dryland sort of MacMillan-Bloedel Ltd., Shawnigan Woodlands Division, Duncan, B.C., 1980.

Date	*Trypodendron lineatum*			*Gnathotrichus sulcatus*			*Gnathotrichus retusus*		
	Trap		Log	Trap		Log	Trap		Log
Apr. 30	1.86	<	2.07*	1.93	>	1.28***	3.45	>	1.55*
May 15	1.86	>	1.54*	1.98		1.77	2.85	>	1.72***
May 29	1.82		1.71	1.83	>	0.98***	2.83	>	2.05***
June 12	2.01		1.43	1.77	>	1.08*	2.42	>	1.69*
June 26	1.24		1.72	1.75		1.26	1.85		1.58
July 7	1.06	<	1.97	2.03		1.36	2.60		2.06

[a] Comparisons followed by * or ***, different at $P<0.05$ or $P<0.001$, respectively, by analysis of variance.

Fig. 12. Mean total catch (± 1 SE) of 3 species of ambrosia beetles on lindane-treated trap logs and cylindrical sticky traps (N=7) in Experiment 2.



☐ Pheromone-baited, lindane-treated logs
▒ Lindane-treated logs
▨ Pheromone-baited traps
■ Blank traps
MALES
FEMALES
MEAN TOTAL CATCH
1,000
2,000
3,000
4,000
5,000
6,000
TRYPODENDRON LINEATUM
GNATHOTRICHUS SULCATUS
GNATHOTRICHUS RETUSUS
TRYPODENDRON LINEATUM
GNATHOTRICHUS SULCATUS
GNATHOTRICHUS RETUSUS

TABLE V. Breakthrough by 3 species of ambrosia beetles on lindane-treated trap logs (N=28). Dryland sort of MacMillan-Bloedel Ltd., Shawnigan Woodlands Division, Duncan, B.C., 1980.

	Trypodendron lineatum	*Gnathotrichus sulcatus*	*Gnathotrichus retusus*
No. logs attacked:			
Blank	1	-	-
Lineatin	7	-	-
(±)-Sulcatol	2	2	-
S-(+)-Sulcatol	1	-	-
Mean attack density/0.1 m^2	7.3	-	-
No. galleries:			
Initiated	48	4	2
Established	19	1	-
No. egg niches and pupal chambers	270	3	-
No. pupal chambers	199	1	-
% Brood success	73.7	-	-

T. lineatum , since only 2 of the 19 successful galleries were on the bottom quadrant of the logs, with 4 and 13 attacks on the top and sides, respectively. Based on the results from Table III, the expected attack distribution should have been 3, 10, and 6 attacks on top, sides, and bottom, respectively. However, the differences between observed and expected attacks are not significant (X^2 test, $p<0.05$).

The female:male ratio of captured *Gnathotrichus* spp. being lower on logsthan on traps (Table IV) may indicate that stimuli other than the synergized pheromones (Borden et al. 1980b) are important for these 2 species. Such stimuli may include visual perception of host materials, which appears important to *T. lineatum* (Vite and Bakke 1979; Klimetzek et al. 1980; Borden et al. 1981b) and *T. domesticum* (L.) (Kerck 1972) in Europe, and primary attractants emitted by the host, as indicated for *G. retusus* in California (Moeck et al. 1981).

Although the cylindrical sticky traps were more effective than pheromone-baited, lindane-treated logs (Figs. 11, 12), other traps may be even more effective. Vane traps (McLean and Borden 1979) are roughly twice as efficient as cylindrical traps for both *T. lineatum* and *G. retusus*, while vanes and a multiple funnel trap are more efficient for *G. sulcatus* (Chapter III). There is considerable controversy over the use of lindane in forestry (Koerber 1979). Many other pesticides have higher acute toxicity but are not more efficient than lindane against bark beetles in the field (Smith et al. 1977). Therefore, I cannot recommend the use of trap logs treated with lindane, or other pesticides of comparable efficacy, for control of ambrosia beetles in dryland sorts, in spite of their apparent efficacy early in the season.

The unsuitability of several logs caused high variance of the data, with a resulting large error term. Employment of more suitable logs would probably have reduced the variation and accentuated the early season superiority of the logs (Fig. 8). This superiority probably has its basis in the secondary attraction produced by the attacking beetles simply overwhelming the attractive baits in the traps. This phenomenon accentuates the importance of removing competing sources of secondary attraction, e.g. attacked timber in the sort, in order to maintain optimal efficacy of traps.

The decreasing attractiveness with time of trap logs infested by T. lineatum relates to presence of males, which apparently produce a masking or antiaggregation pheromone (Nijholt 1970, 1973b; Borden 1974). Moreover, females may cease production of pheromone in the presence of males, as in Scolytus multistriatus (Marsham) (Elliot et al. 1975). Very high attack densities (>200/0.1 m^2) are sometimes reported (Chapman and Nijholt 1980), and may result in lessened pheromone production per female, as observed in S. scolytus L. (Blight et al. 1978). The relatively constant performance of lineatin-baited trap logs as compared to unbaited trap logs (Fig. 8) suggests that the presence of synthetic pheromones overrides any antiaggregation pheromone or compensates for the lack of continuous pheromone production by females.

<u>Gnathotrichus</u> spp. overwinter in host material (Richmond 1968) stored in the sort or brought in from the forest. Therefore, the synthetic pheromones must compete with established sources of natural secondary attraction and lure emerging beetles away from them. <u>T. lineatum</u>, however, overwinters in the duff and litter of the surrounding forest margin (Kinghorn and Chapman 1959) and could be intercepted on their way into the sort by pheromone-baited trap bundles and traps.

The strikingly high numbers of attacks on several logs recorded in late March and early April 1979, before any major flight had occurred suggest that suitable bundles of pheromone-baited trap logs would be superior to sticky traps early in the season. Since it is crucial to keep the 1st flight of <u>T. lineatum</u> from establishing secondary attraction inside the sort, trap bundles may be extremely important in a suppression program early in the season.

Although fresh trap logs might be more efficient than pheromone-baited traps later in the season, protection of fall-felled logs from attack, for use as replacement trap logs, seems impractical. However, replacement of trap logs would be possible for *G. sulcatus* and *G. retusus*, which attack newly felled logs (Mathers 1935; Cade 1970; McLean and Borden 1977b).

Biological Observations

The distribution of *G. sulcatus* attacks around the circumference of the logs (Table III) supports earlier findings of McLean and Borden (1977b) while the similar distribution of *T. lineatum* attacks supports the data of Dyer (1963). *G. retusus* apparently prefers dryer and warmer habitats than the other 2 species (J.H. Borden[2], pers. comm.) and was the most prevalent ambrosia beetle in a California study (Moeck et al. 1981). Thus, it may be more able than the other 2 species to colonize the warmest, upper quadrant of the logs. *R*-(-)-Sulcatol, produced by *G. sulcatus*, is inhibitory to *G. retusus*, which responds to *S*-(+)-sulcatol (Borden et al. 1980a). However, Table II shows that the 2 species in fact can attack the same log to some extent. The abundance of *G. retusus* attacks on the top of a log (Table III) may reflect its partial displacement to this portion by the pheromone odor of *G. sulcatus* males, which fly earlier in the season (Figs. 24-25, Chapter E) and attack the sides and bottom. The lack of concentration of attacks in the vicinity of the pheromone bait is at variance with the results of McLean and Borden (1977b) for *G. sulcatus*, and probably reflects extremely high populations which saturated all available spaces on the most attractive logs.

The significant correlation between attack density and log diam. or sapwood depth (Fig. 10) indicate the importance of selecting suitable material for trap logs. A threshold for acceptability appears to be a diam. of 20 cm and a sapwood depth of ca. 2 cm. Although some logs with deeper sapwood (4 - 6 cm) had low attack densities, logs with a diam. of >30 cm, and with sapwood of >3 cm generally appear to be susceptible to attack by Gnathotrichus spp., and by T. lineatum provided the trees are felled between October and February the previous winter (Dyer and Chapman 1965). Logs selected by these criteria would be optimally efficient in trap bundles for ambrosia beetles.

Practical Implications

In pest management programs, binary pheromone combinations, lineatin with (±)- or S-(+)sulcatol (Borden et al. 1981a), combined with ethanol and α-pinene at low release rates (Borden et al. 1981b) are feasible as volatile baits. I recommend that untreated (no insecticide) trap bundles or logs baited with such volatile baits be placed in strategic positions, i.e. "hot spots", around dryland sorts 1 month before the first T. lineatum flight is expected. This procedure will take advantage of the early superiority of logs over pheromone-baited traps (Fig. 8). Bundles should be removed, and logs chipped or otherwise destroyed 5 - 6 weeks after initial attack, since brood emergence may begin at this time (Borden and Fockler 1973), and the efficacy of the trap bundles would have then declined. Pheromone-baited traps should complement the trap bundles at all times and also should be used in inaccessible positions. Additional traps should replace the trap bundles as these are removed to maintain a high potential of intercepting beetles emerging from the forest duff and to maintain a strong source of secondary attraction away from the timber to be protected. Any timber attacked within the sort must be recognized and removed without delay.

C. A MULTIPLE FUNNEL TRAP FOR SCOLYTID BEETLES

Hardware cloth, insect screening and various other materials, coated with a sticky material are widely used in research and trapping programs for scolytid beetles (Browne 1978; Lanier 1978; McLean and Borden 1979). These traps are effective, but require time consuming and laborious maintenance. Thus, many attempts to design alternative traps have been made.

Pheromone-baited window flight traps (Chapman and Kinghorn 1955) are relatively efficient for the spruce beetle, *Dendroctonus rufipennis* Kirby, if placed against tree trunks (Dyer and Hall 1980) and for *Ips typographus* L. if placed in a forest rather than in the open (Klimetzek and Vite 1978). For *T. lineatum* window traps are comparable to Scandinavian drainpipe traps (Borden et al. 1981). Several adaptations of the window flight trap have been made (Wilkening et al. 1981; Furniss 1981).

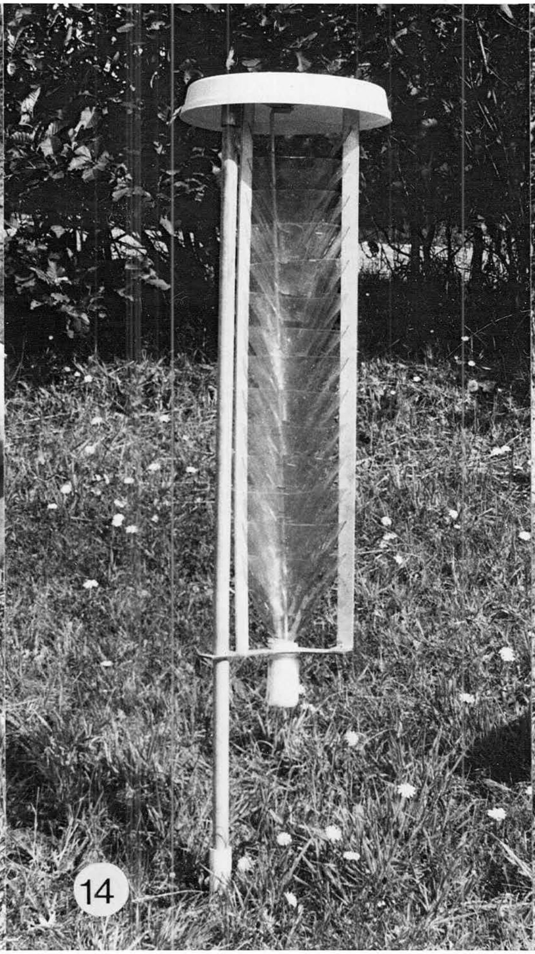
Drainpipe traps (Bakke and Saether 1978) and other traps based on the hypothesis that an optical stimulus, i.e. a prominent, vertical silhouette, is important for the orientation of scolytid beetles to their brood material (Kerck 1972) have recently gained prominence in pheromone research (Klimetzek and Vite 1978; Moser and Browne 1978; Vite and Bakke 1979; Adlung et al. 1979; Borden et al. 1981b). Commercially available drainpipe traps (Borregaard A/S, Sarpsborg, Norway) have been utilized in a mass trapping program for I. typographus initiated in 1979 (O'Sullivan 1979; Lie and Bakke 1981).

The multiple funnel trap described herein (Figs. 13-15) combines the advantages of the traps mentioned above and eliminates some disadvantages. The 1981 prototype trap (Fig. 15) consists of a series of vertically aligned funnels made from 0.2 mm vinyl sheets (American Hoeckst Corp., Sommerville, N.J.) and stapled to 3 twill tapes, making the trap collapsible for storage and transportation. An inverted nursery flower pot drainage tray (Listo Products, Vancouver, B.C.) protects the pheromone bait, and to a certain extent the trap, from rain. A collecting jar (Ampak, Ltd., Vancouver, B.C.) , with a lateral drain hole for excess rain water, is suspended at the bottom of the trap. The jar contains water with a small amount of detergent added to reduce surface tension, and an antibiotic agent (sodium azide or table salt) to prevent mould and bacterial growth. For trapping live insects, the collecting jar can be filled with shredded paper or other material to keep insects apart. The trap is suspended from a hook on a 2.5 cm diam. dowel. The effective trapping surface of this prototype is 0.33 m^2 which can be increased or decreased by changing the size or numbers of funnels.

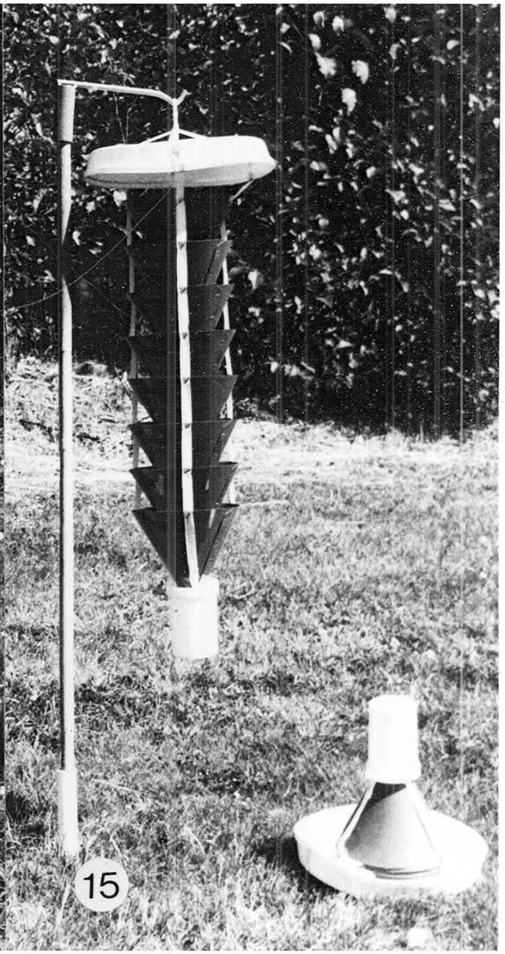
Wind tunnel studies (N.P.D. Angerilli[5] and J.A. McLean[5],unpublished data) suggested that the pheromone should be

Figs. 13-15. Prototype multiple funnel traps used in 1979 (Fig. 13), 1980 (Fig. 14), and 1981 (Fig. 15). Collection of sample at 1979 model is shown in Fig. 13, and the 1981 model is shown in operational and collapsed position (Fig. 15).

13



14



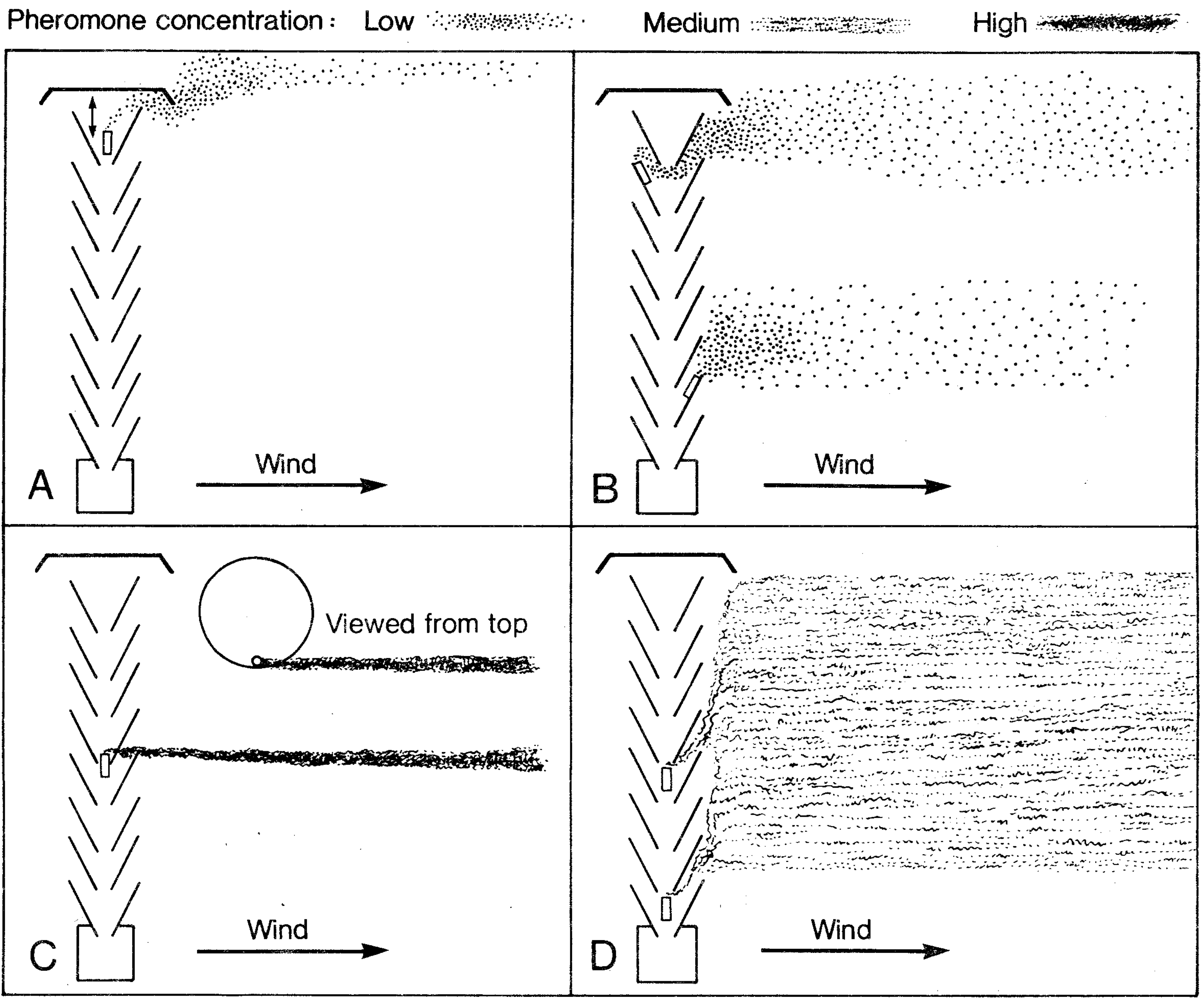
15

released simultaneously from 2 positions in the trap (Fig. 16D). These release positions ensure that the pheromone plume is dispersed to simulate that of an attacked log, as well as providing optimal odor dispersion regardless of wind direction. To date, pheromone placement has been suboptimal as in Fig. 16A-C, and increased efficiency of the funnel trap is expected when its aerodynamic properties are utilized correctly. In preliminary tests, _T. lineatum_ responded better in a wind tunnel to a dispersed pheromone plume rather than to a concentrated one (N.P.D. Angerilli[5], pers. comm.).

Two earlier designs had various limitations. The 1979 prototype (Fig. 13) was rigid on a wooden frame, with a trapping surface of 0.19 m^2 . This trap was too fragile for transportation and storage. The 1980 prototype (Fig. 14) had an aluminum frame, which had to be disassembled for compact transportation and storage. The trapping surface was 0.41 m^2 . Material costs, weight and difficulty in assembling and disassembling of this prototype made it less desirable than the 1981 trap.

All prototype traps effectively caught ambrosia beetles. In Vancouver Island field tests _T. lineatum_, _G. sulcatus_ and _G. retusus_ were caught in response to their aggregation pheromones, with maximum catches for a 2 week period of 15,000, 3,500 and 700 in single traps for the respective species. The traps were competitive with Scandinavian drainpipe traps and 2 types of

Fig. 16. Schematic representations of 1981 trap showing odor plumes (titanium tetrachloride smoke) produced in a wind tunnel at 1.2 m/s wind speed with bait in various positions. A). Movement of bait vertically (double-pointed arrow) will vary release rate. B). Upwind (upper) and downwind (lower) plumes from bait attached to twill tape. C). Bait placement as in B) but rotated 90° relative to wind direction as in top view. D). Double-baiting, utilizing trap aerodynamics for optimal pheromone dispersion.


Pheromone concentration :
Low
Medium
High
A
Wind
B
Wind
C
Viewed from top
Wind
D
Wind

sticky traps (Chapter D). In another experiment, modified 1981 prototype traps with one extra funnel and longer spacing between funnels (0.57 m^2 trapping surface) caught 219 mountain pine beetles, Dendroctonus ponderosae Hopkins, whereas identically baited Scandinavian drainpipe traps only caught 5 (J.E. Conn and J.H. Borden[2], unpublished data).

Incoming beetles have been observed at the traps. Most hit the funnels and fall into the collecting jar immediately, because they cannot land on the slanted funnels. Some do land on the outward slanting funnel below the entry point. However, the funnel above impedes the resumption of flight as the beetles' take off direction is vertical. These beetles are caught after contacting the overhead funnel and folding their wings. Thus, resumption of flight, a problem with window and drainpipe traps, is largely avoided with funnel traps. As with sticky traps, any beetle attempting to land should be caught, but without having to enter holes as in the drainpipe traps. Captured beetles can be quickly collected and processed immediately without the need to remove sticky material.

As with some other nonsticky traps (Wilkening et al. 1981), spiders occasionally cause problems by webbing over the funnels. If the trap is placed in the vicinity of deciduous trees, leaves may plug up individual funnels in the fall.

Insects in numerous orders are caught in the funnel traps, but Coleoptera predominate. The impact of the funnel trap on non target species is small. Checkered beetles (Coleoptera:Cleridae) were only caught occasionally, and in low numbers (1-10) similar to catches in drainpipe traps.

Although the initial investment for this trap may be higher than for sticky traps, the traps should be reusable for many seasons. Moreover, considerable savings are made in handling time, making possible a substantially greater trapping effort.

D. FACTORS INFLUENCING THE EFFICIENCY OF PHEROMONE-BAITED TRAPS FOR THREE SPECIES OF AMBROSIA BEETLES

Many factors can influence the efficiency of pheromone-baited traps for scolytid beetles. Increasing the release rate of the pheromone (±)-sulcatol increased the catch of *G. sulcatus* on sticky cylinder traps even at 100 mg/day (McLean 1976). Other experiments have disclosed synergism by ethanol and α-pinene for sulcatol (Borden et al. 1980b), allelochemic activity between the aggregation pheromones of *T. lineatum*, *G. sulcatus* and *G. retusus* (Borden et al. 1980a, 1981a), and the interaction of aggregation pheromones, ethanol and α-pinene, in the presence or absence of visual stimuli (Borden et al. 1981b). Experiments on trap placement, release rates and bait placement have been conducted for several scolytid species (e.g. Tilden 1976; Tilden et al. 1979; Klimetzek and Vite 1978; Lie and Bakke 1981).

The influence of trap design on trapping efficacy has been investigated for many insects. Sticky traps have been commonly used for scolytid beetles (Browne 1978; Birch 1979; McLean and Borden 1979). Many of these traps are efficient, but the difficulties in removing captured insects as well as in cleaning and reapplying sticky coverings make them prohibitively labor intensive, particularly in large scale operations. Therefore, nonsticky traps of various designs have been tested (Chapman and Kinghorn 1955; Moser and Browne 1977; Bakke and Saether 1978; Klimetzek and Vite 1978; Furniss 1981).

The influence of trap color has also been investigated for many insects. Behavioral and physiological responses by scolytid beetles to colors have been demonstrated in the laboratory (Schonherr 1971; Bennett 1978; Groberman and Borden 1981), and in the field (Entwistle 1963; Bakke and Saether 1978).

The experiments described herein, were conducted as an integral part of optimizing the use of ambrosia beetle aggregation pheromones for suppression programs in timber processing areas.

MATERIALS AND METHODS

Seventeen field experiments (Exp.) were conducted with objectives and methodology as outlined below. Unless otherwise noted, all experiments were conducted at the MacMillan-Bloedel Ltd., Nanoose Division dryland sort at Northwest Bay near Parksville, Vancouver Island, B.C. They were set up as randomized complete blocks, with a minimum distance between traps of 25 m. Sticky traps (vanes or cylinders) were covered with Stikem Special. They were cleaned in Shell Household Solvent. Collecting bottles on nonsticky traps contained water, detergent to reduce surface tension, and sodium azide (40 mg/l water) to prevent mould and bacterial growth. Insects removed from sticky traps were held in Shell Solvent or 70% ethanol until they were separated by species and sex, and counted. Insects captured in other traps were held in 70% ethanol. Pheromone dispensers for cylinder traps were placed as described in Chapter B (Exp. 1); for vane traps on the support pole ca. 30 cm from the top; for funnel traps as in Fig. 16A (Chapter C); and for drainpipe traps suspended inside the pipe ca. 20 cm under the lid. All release rates for pheromones and host volatiles were determined in the laboratory at 22 °C and 70% R.H. Actual release rates in the field may have varied considerably due to environmental conditions. All traps were placed so their effective trapping occurred ca. 30 - 180 cm above ground.

Experiment 1

Exp. 1, conducted May 3 - 15, 1979, at the University of British Columbia Research Forest, Maple Ridge, B.C., determined the optimal release rate for lineatin, the aggregation pheromone of _T. lineatum_. Cylindrical hardware cloth traps (cylinder traps) (Byrne et al. 1974; Browne 1978), 20 cm diam. x 46 cm high, active trapping surface = 0.29 m^2, in 5 replicates, were baited with lineatin released from Conrel fibers, aperture diam. = 0.2 mm, as follows: blank control, 1 fiber (10 $\mu g/24h$), 4 fibers, 8 fibers and 80 fibers.

Experiment 2 - 4

Exp. 2 - 4 were conducted to determine the relative efficacy of 4 trap types for *T. lineatum*, *G. retusus* and *G. sulcatus*. The traps compared were a modified vane trap (Browne 1978; McLean and Borden 1979) with 2 vanes composed of 90 x 70 cm, 6.4 mm mesh hardware cloth, active trapping surface = 2.52 m^2; a cylinder trap; a Scandinavian drainpipe trap (drainpipe trap) 12.5 cm diam. x 135 cm high, active landing surface = 0.5 m^2; and a multiple funnel trap (1979 funnel trap) (Fig. 13, Chapter II), 13 cm diam. x 44 cm high, active trapping surface = 0.18 m^2. Each of 5 blocks consisted of 8 traps, 1 baited and 1 blank control trap of each type.

In Exp. 2, May 4 - 18, 1979, traps were baited with lineatin released from 4 Conrel fibers at 40 μg/24h. In Exp. 3, May 18 - 29, 1979, traps were baited with *S*-(+)-sulcatol and α-pinene released from open glass vials, aperture diam. = 8 mm, at 4.9 and 50 mg/24h, respectively, and ethanol from a glass vial with 1 hole in the cap, aperture diam. = 3 mm, at 180 mg/24h. In Exp. 4, May 29 - June 5 and Aug. 16 - Sept. 5, 1979, (±)-sulcatol was relesed at the same rate as *S*-(+)-sulcatol in Exp. 3, and α-pinene and ethanol as in Exp. 3.

Experiment 5 - 7

Exp. 5 - 7 were conducted to compare the efficacy of the vane trap, the 1979 funnel trap, both used in Exp. 2 - 4, and a larger, modified funnel trap (1980 funnel trap) (Fig. 14, Chapter II), 20 cm diam. x 66 cm high, active catching surface = 0.41 m^2.

In Exp. 5, July 1 - 8, 1980, all traps in 7 replicates were baited with lineatin as in Exp. 2. In Exp. 6, July 8 - 16, 1980, α-pinene and ethanol, released from separate glass vials with 1 hole in the cap, aperture diam. = 1.5 mm, at 17.5 and 120 mg/24h, respectively, were added to lineatin released as in Exp. 2. In Exp. 7, Oct. 1 - 8 , 1980, all traps in 6 replicates were baited with (±)-sulcatol released from open glass vials, aperture diam. = 4 mm, at 2.5 mg/24h. Ethanol and α-pinene were released as in Exp. 6.

Experiment 8

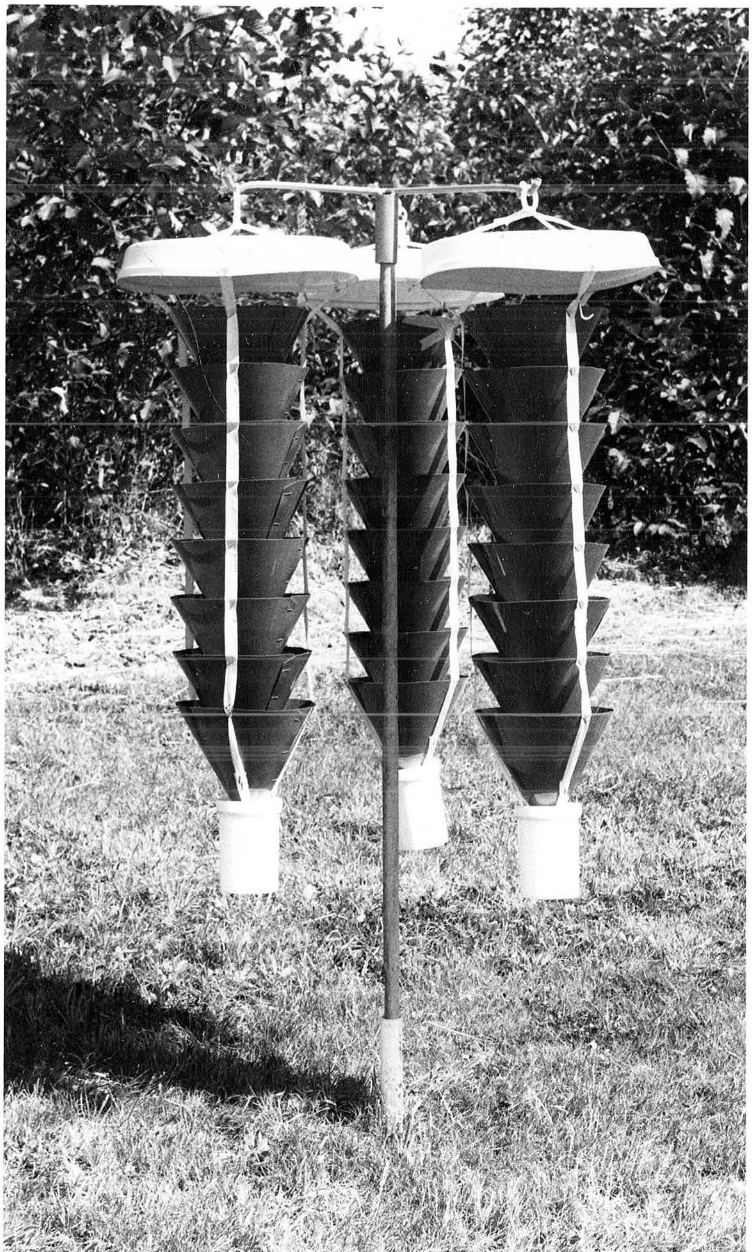
Exp. 8 assessed the effect of diameter of the optical stimulus on the response of T. lineatum and G. sulcatus to multiple funnel traps, with vane traps as controls. It was conducted from June 3 - July 1, 1981, at the Pacific Forest Products, Ltd., Sooke Division dryland sorting area near Sooke, Vancouver Island, B.C. Three nested multiple funnel traps (Fig.

17), each 20 cm diam. x 53 cm high (1981 funnel traps), total active trapping surface = 1.0 m^2, were compared in 6 replicates with vane traps with 2 fiberglass window screening vanes (Permascreen , Bay Mills, Midland, Ont.), 86 x 120 cm, active catching surface = 4.1 m^2. Pheromone dispensers were suspended from the lid so that they were near the bottom inside a drainpipe attached to the support pole. Each trap (a nested set of funnel traps is considered as one trap) was placed in a 3 - 4 m wide "channel" cut through dense sapling red alder, _Alnus rubra_ Bong, at the edge of the west side of the sort. The traps were baited with lineatin as in Exp. 2, (±)-sulcatol as in Exp. 7, and α-pinene and ethanol as in Exp. 6. For vane traps, the total number of beetles on 5 systematically chosen 3 cm wide strips (x) was counted, and the total not counted (y) was estimated as $(y = 34.40 + 6.32x)(r=0.99,\ p<0.01)$, as determined by linear regression from total counts on 22 vanes. The total for each vane was then $(x + y)$. Species and sex ratios were determined based on a random subsample taken from 1 vane on each trap.

Experiment 9 - 11

Three experiments were run to determine whether ambrosia beetles exhibit a color preference in orienting to traps. Black, blue, clear, green, and red 1980 funnel traps were used.

Fig. 17. Nested 1981 funnel traps used in Experiment 7.



Spectral reflectance for each color vinyl and of the bark of Douglas-fir , *Pseudotsuga menziesii* (Mirb.) Franco, was measured with a Cary 17 spectrophotometer, using magnesium oxide as a standard. Percent reflectance was calculated for wavelength intervals 340 - 360 nm (near UV), 420 - 480 nm (blue), and 510 - 530 nm (green), alone and in combination, since optimal behavioral (Groberman and Borden 1981) and electrophysiological (Bennett 1978) responses occur at these wavelengths.

In Exp. 9, May 13 - June 3, 1980, blocks containing 1 baited and 1 blank control for each color were set up, and rerandomized twice for a total of 12 replicates. Traps were baited as in Exp. 2. In Exp. 10, June 3 - July 2, 4 blocks as in Exp. 9 were set up, and rerandomized once for a total of 8 replicates. Traps were baited with *S*-(+)-sulcatol in the same manner as (±)-sulcatol in Exp. 7, and α-pinene and ethanol as in Exp. 6. In Exp. 11, conducted at MacMillan-Bloedel, Ltd.'s Shawnigan Woodlands Division dryland sorting area near Duncan, Vancouver Island, B.C., Sept. 9 - 24, 1980, 4 blocks as in Exp. 9 in a split plot design were rerandomized once for 8 replicates. Traps were baited as in Exp. 7.

Experiment 12

Exp. 12 assessed the influence of colors on catch in traps double baited (Borden et al. 1981) for *T. lineatum* and *G.*

sulcatus. Black, blue, and red 1981 funnel traps were set up in 8 replicates at the Pacific Forest Products, Ltd., Sooke Division dryland sort on March 11, 1981. All traps were baited as in Exp. 8. Collections of insects were done biweekly until June 3.

Experiment 13

Exp. 13, conducted June 29 - July 16 at MacMillan-Bloedel, Ltd.'s Shawnigan Woodlands Division dryland sort, Duncan, B.C., assessed the influence of pheromone concentration at 1981 funnel traps (6 replicates) and drainpipe traps (4 replicates) on the catch of T. lineatum. Traps were baited with lineatin released from Conrel fibers as follows: 1 fiber (10 μg/24h); 1 fiber in trap, and an additional 3 fibers placed 1.5 - 2 m away from the trap ca. 30 cm from the top on a 2.5 cm diam. and 120 cm high dowel for a total of 40 μg/24h). All traps were baited with ethanol and α-pinene as in Exp. 6.

Experiment 14 - 16

Exp. 14 - 16, evaluated the importance of trap position on catch of T. lineatum. In Exp. 14, conducted April 25 - May 2, 1979, and Exp. 15, June 1 - 7, 1979, 10 cylinder traps were placed in pairs, 1 trap at the forest margin, and the other 15 - 25 m inside the margin. All traps were baited with lineatin as in Exp. 2. In Exp. 16, conducted April 22 - 29, 1980, 12 drainpipe traps were placed in pairs as in Exp. 14 - 15. All traps were baited with lineatin as in Exp. 2, α-pinene as in Exp. 3, and ethanol from an open nalgene bottle, aperture diam. = 14 mm, at 1 g/24h.

Experiment 17

Exp. 17, May 27 - June 10, 1981, assessed the importance of pheromone dispenser placement in drainpipe traps. Twenty-four traps were baited as in Exp. 8, with baits placed at the bottom, middle or top inside the trap for 8 replicates.

All data were transformed as $[x' = \log10\ (x + 1)]$ before analysis of variance and the Newman-Keuls Test ($p<0.05$). The analyses of variance used were: 2-way analysis of variance for Exp. 1, 5-8, and 12-17; factorial analysis of variance as in Chapter B (Exp. 1) for Exp. 2-4, and 9-10; and a split plot analysis of variance for Exp. 11.

RESULTS AND DISCUSSION

Experiment 1

An optimal release rate for lineatin in cylinder traps was reached at 40 μg/24h (Table VI). This release rate was

TABLE VI. Mean numbers of T. lineatum caught and mean sex ratios in evaluation of release rates in cylindrical sticky traps. University of British Columbia Research Forest, Maple Ridge, B.C., 1979.

Release Rate (μg/24h)	Mean Catch[a]			Mean Ratio Male/Female
	Male	Female	Total	
0	0.0a	0.0a	0.0a	-
10	6.4b	6.4b	12.8b	0.81
40	27.0c	16.2b	43.2c	1.17
80	19.8c	9.6b	29.4c	0.98
800	37.0c	18.0b	55.0c	1.19

[a] Means within columns followed by same letter not significantly different, analysis of variance and Newman-Keuls Test, ($P<0.05$). Means within columns not followed by letters, not significantly different, analysis of variance, ($P<0.05$).

subsequently used for all further experiments. It is much lower than that used for other highly volatile scolytid pheromones, such as *exo*-brevicomin and frontalin for *Dendroctonus brevicomis* LeConte at 2 mg/24h (Bedard and Wood 1981). The response of *G. sulcatus* increased even when the release rate of sulcatol reached 100 mg/24h (McLean 1976). Apparently, lineatin is so potent that optimal levels are reached much sooner.

Experiment 2 - 4

For *T. lineatum*, vane traps were more efficient than nonsticky traps (Tables VII, VIII). There was no difference in catch by vane and cylinder traps, or between cylinder traps and funnel traps. Funnel traps caught more female *T. lineatum* than drainpipe traps. Male:female ratios were lower on vane traps than in drainpipe traps, whereas ratios of catches from cylinder or 1979 funnel traps were not different from other traps.

For *G. sulcatus*, 1979 funnel traps were more efficient than cylinder traps, whereas neither of these was different from vane or drainpipe traps (Table VII). Vane traps were better than other traps for male *G. retusus*, but were no better than 1979 funnel and drainpipe traps for females.

TABLE VII. Mean number of beetles caught and mean sex ratios in evaluation of 4 trap types for 3 species of ambrosia beetles. MacMillan-Bloedel, Ltd., Nanoose Division dryland sort, Northwest Bay, B.C., 1979. N=5 replicates for *Trypodendron lineatum* and *Gnathotrichus retusus* and 10 for *G. sulcatus*.

Trap	*Trypodendron lineatum*[a]				*Gnathotrichus sulcatus*[a]				*Gnathotrichus retusus*[a]			
	Male	Female	Total	M/F	Male	Female	Total	F/M	Male	Female	Total	F/M
Cylinder	441.4bc	214.4bc	655.8bc	2.24ab	12.9a	26.4	39.3a	1.86	4.6a	12.0a	16.6a	3.69
Funnel	260.0ab	117.8b	377.8ab	2.26ab	41.2a	82.3	123.5b	2.04	3.2a	18.4ab	21.6a	4.27
Drainpipe	131.6a	51.6a	183.2a	3.40b	16.2a	40.7	56.9ab	2.31	4.0a	22.4ab	26.4a	4.33
Vane	676.6c	420.4c	1.097.0c	1.66a	43.2a	63.0	106.2ab	1.46	41.6b	103.2b	144.8b	2.56

[a] Means within columns followed by same letter not significantly different, analysis of variance and Newman-Keuls Test, ($\underline{P}<0.05$). Means within columns not followed by letters, not significantly different, analysis of variance, ($\underline{P}<0.05$).

TABLE VIII. Mean number of beetles caught and mean sex ratios in evaluation of 3 trap types for 2 species of ambrosia beetles. MacMillan-Bloedel, Ltd., Nanoose Division dryland sort, Northwest Bay, B.C., 1980. N=7 replicates for *Trypodendron lineatum* and 6 for *G. sulcatus*.

Trap	*Trypodendron lineatum*[a]								*Gnathotrichus sulcatus*[a]			
	lineatin				lineatin, α-pinene, ethanol							
	Male	Female	Total	M/F	Male	Female	Total	M/F	Male	Female	Total	F/M
1979 Funnel	302.6a	190.3a	492.9a	1.60a	48.6a	54.7a	103.3a	0.86	133.0	249.8	382.8	1.91a
1980 Funnel	355.9a	274.0a	629.9a	1.30a	81.1ab	93.1b	174.3b	0.87	137.2	271.2	408.3	2.10a
Vane	588.1b	786.3b	1,374.4b	0.78b	159.3b	205.6c	364.9c	0.75	184.3	172.2	356.5	0.95b

[a] Means within columns followed by same letter not significantly different, analysis of variance and Newman-Keuls Test, ($P<0.05$). Means within columns not followed by letters, not significantly different, analysis of variance, ($P<0.05$).

Experiment 5 - 7

Vane traps baited with lineatin alone caught more *T. lineatum* than 1979 or 1980 funnel traps, but in the presence of ethanol and α-pinene, the difference in catch between vane traps and 1980 funnel traps was not significant for males (Table VIII). This result indicates that there is an interaction between semiochemicals and trap form for male *T. lineatum*. Such a phenomenon could not be demonstrated in other North American experiments (Borden et al. 1981), as opposed to several experiments in Europe (Vite and Bakke 1979; Borden et al. 1981) Female:male ratios for *G. sulcatus* and male:female ratios for *T. lineatum* (ratios calculated as responding sex:first attacking sex) were lower on vane traps than in funnel traps in the absence of ethanol and α-pinene.

Experiment 8

In Exp. 8 vane traps were superior to nested 1981 funnel traps for *T. lineatum* (Table IX). There were no differences for *G. sulcatus* or for sex ratios of either species.

The results of Exp. 2 - 8 indcate a difference in response to trap form by *G. sulcatus* compared to *T. lineatum* and *G. retusus*. These results support those in Chapter B (Exp. 1), where I found a significant, positive correlation between host

TABLE IX. Mean number of beetles caught and mean sex ratios in evaluation of nested multiple funnel traps and vane traps for 2 species of ambrosia beetles. Pacific Forest Products, Ltd., Sooke Division dryland sort, Sooke, B.C., 1981. (N=6)

Trap	*Trypodendron lineatum*[a]				*Gnathotrichus sulcatus*[a]			
	Male	Female	Total	M/F	Male	Female	Total	M/F
Vane	1,743.8a	1,445.9a	3,189.7a	1.46a	484.1a	516.6a	1,000.7a	1.07a
Nested Funnel	428.9b	299.1b	728.0b	1.59a	381.9a	398.0a	779.9a	1.14a

[a] Numbers within columns followed by same letter not significantly different, analysis of variance ($\underline{P}<0.05$).

diameter and attack density for the latter 2 species, but between sapwood depth and attack density for *G. sulcatus*. When orienting to the host, olfactory and visual cues may be coupled (Borden 1977) to a larger extent for *G. sulcatus* than for *T. lineatum* and *G. retusus*. *G. sulcatus* can attack trees from 2 weeks to 2 years after felling (Mathers 1935; Cade 1970), indicating wide tolerance to host conditions. The positive orientation of *G. sulcatus* to small diameter facsimile hosts, e.g. drainpipe and funnel traps, may be explained by this tolerance, since small diameter logs will dry out relatively fast. For *T. lineatum*, which normally attacks fall-felled logs (Dyer and Chapman 1965), selection would occur against a habit of attacking small diameter hosts, due to the narrower range of host conditions acceptable to this species for successful brood establishment. However, Exp. 8 did not reveal any superiority of a larger diameter visual image for the orientation of *T. lineatum*.

Pheromone plume characteristics may be of importance to *T. lineatum*. Vane traps release the pheromone from the entire surface of each vane (J.A. McLean[5], unpublished data), which may create a close approximation of the pheromone plume from attacked logs. Similarly, funnel traps will release a dispersed pheromone plume when the bait is suspended as in Fig. 16D (Chapter C).

Experiment 9 - 12

In Exp. 9 - 12, there were no significant differences in numbers of beetles caught by traps of the 5 colors tested for any of the 3 species. However, in Exp. 9 for T. lineatum the mean female:male ratio was significantly lower in clear 1980 funnel traps ($\bar{x}$ = 1.57) than in red or black (both $\bar{x}$ =2.05), whereas there was no difference in sex ratios between blue ($\bar{x}$ = 1.73) and green ($\bar{x}$ = 1.78) traps compared with any other color.

Between May 20 and June 3 in Exp. 12, red 1980 funnel traps caught more male G. sulcatus ($\bar{x}$ = 667.3) than black traps ($\bar{x}$ = 453.4), whereas blue traps ($\bar{x}$ = 485.3) were not different from the other 2 colors. During the same period, female:male ratios for this species were lower in red traps ($\bar{x}$ = 1.67) than in blue ($\bar{x}$ = 1.90) or black ($\bar{x}$ = 1.99) traps. However, these differences were not evident for the experiment as a whole.

Calculations of percent reflectance showed that clear, green and blue vinyl, all of which caught T. lineatum in relatively low male:female ratios in Exp. 9, reflected more light than vinyl of other colors or Douglas-fir bark. However, the spectral reflectance curves showed that the colors used reflected relatively little light over a wide range. Cross et al. (1976) found that the response of the boll weevil, Anthonomus grandis Boheman, to traps increased as the intensity of reflected light was increased, and also when the pigment more closely approached the 500 - 525 nm region of the spectrum. Use of cleaner colors in my experiments might have yielded positive results. Bark, which appears brown-grey to the human eye, depending on the amount of lichen growing on it, does not appear to have any reflectance characteristic which would facilitate visual orientation.

Experiment 13

The results of Exp. 13 (Table X) indicate that for *T. lineatum*, it does not matter whether all of the pheromone is released directly from the trap, as long as the pheromone release from the immediate vicinity of the trap is sufficient. Therefore, lineatin is important for both short and long distance orientation, but other cues, e.g. a visual silhouette and host volatiles, are probably more important for initiating landing on the host. Tilden (1976) found that changes in the release rate of 3 chemicals attractive to the western pine beetle, *D. brevicomis*, as well as relative change among the 3 compounds, affected the catch of beetles on silhouette traps at various distances from the pheromone source. Placement of traps in relation to the pheromone source affected catch and sex ratio of *D. brevicomis* (Tilden et al. 1979).

TABLE X. Mean catch and mean sex ratios of *T. lineatum* in multiple funnel traps and Scandinavian drainpipe traps baited to evaluate the effect of pheromone concentration at and near the trap. MacMillan-Bloedel, Ltd., Shawnigan Woodlands Division dryland sort, Duncan, B.C., 1981. (N=10)

Pheromone Release Rate/24h		Mean Catch[a]			Mean Ratio Male/Female
In Trap[b]	1.5-2m from Trap	Male	Female	Total	
10 μg	--	212.3a	220.0a	432.3a	0.99a
10 μg	30 μg	615.7b	554.5b	1,170.2b	1.22b
40 μg	--	625.0b	524.2b	1,149.2b	1.21b

[a] Means within columns followed by same letter not significantly different, analysis of variance and Newman-Keuls Test, (*P*<0.05). Means within columns not followed by letters, not significantly different, analysis of variance, (*P*<0.05).

[b] Ethanol and α-pinene released from all traps at 120 and 17.5 mg/24h, respectively.

Experiment 14 - 16

In Exp. 14 - 16 (Table XI) more *T. lineatum* were caught early in the season on traps placed 15 - 25 m into the forest, where a majority of the population overwinters (Kinghorn and Chapman 1969), than on traps at the margin. Later in the season, after the main flight, there was no difference in catch on cylinder traps between the 2 positions. These results indicate that a large portion of the *T. lineatum* population will respond to lineatin soon after they emerge from their overwintering site. Thus, the flight exercise required by *T. lineatum* and other scolytid beetles before they become host and pheromone-positive (Graham 1959; Bennett and Borden 1971; Choudhury and Kennedy 1980) can be fulfilled in the immediate vicinity of the overwintering site.

Klimetzek and Vite (1978) reported that, when placed inside a forest, window flight traps were more efficient than silhouette pipe traps for trapping *Ips typographus* L., whereas the pipe traps were more efficient in the open. Lie and Bakke (1981) recommend that drainpipe traps for *I. typographus* be placed at ground level in groups in the open. Placing traps in artificial flight "channels" cut through dense underbrush, as described in Exp. 8, appear to improve their efficiency. These observations coupled with the results of Exp. 14 - 16 suggest that more attention should be given to placement of individual

TABLE XI. Mean catch and mean sex ratios of _Trypodendron lineatum_ in evaluation of trap placement. MacMillan-Bloedel, Ltd., Nanoose Division dryland sort, near Parksville, B.C. N=5 for cylindrical sticky traps, and 6 for Scandinavian drainpipe traps.

Date	Trap Type	Trap Position	Mean Catch[a]			
			Male	Female	Total	Male/Female
Apr. 25-May 2, 1979	Cylindrical Sticky Trap	At forest margin	1,058.6a	494.4a	1,553.0a	2.12a
		15-25 m inside margin	2,675.8b	1,125.4b	3,801.2b	2.53a
Apr. 22-29, 1980	Scandinavian Drainpipe Trap	At forest margin	101.5a	47.8a	149.3a	2.18a
		15-25 m inside margin	270.7b	102.2b	372.8b	2.66b
June 1-7, 1979	Cylindrical Sticky Trap	At forest margin	171.8a	117.4a	289.2a	1.52a
		15-25 m inside margin	218.2a	158.2a	376.4a	1.39a

[a] For each date, means within columns followed by same letter not significantly different, analysis of variance and Newman-Keuls Test, ($\underline{P}<0.05$). Means within columns not followed by letters, not significantly different, analysis of variance, ($\underline{P}<0.05$).

traps in order to optimize their efficiency.

Experiment 17

Bait placement in drainpipe traps strongly influenced the catch of both *T. lineatum* and *G. sulcatus* (Table XII). These results suggest that the efficiency of drainpipe traps in Exp. 2 - 4 (Table VII) was underestimated since the baits were placed in the top of the traps. Comparative studies on odor plumes with various bait placements in funnel traps (Chapter C) indicate that bait placement in these traps was not optimal in Exp. 2 - 4. Therefore, the efficiency of funnel traps may have been underestimated as well.

Lie and Bakke (1981) recommend that pheromone dispensers be placed low in drainpipe traps for *I. typographus*. Convection currents rising within the traps, the temperature of which may exceed ambient temperatures by 10 °C on a sunny day (Lie and Bakke 1981), probably make a low bait placement preferable. The difference in response between *T. lineatum* and *G. sulcatus* may be due to differences in evaporation characteristics between lineatin and sulcatol, the latter being less volatile, or to behavioral differences between the 2 species in response to their pheromone and the visual stimulus of the drainpipe.

Very few ambrosia beetles were caught on any blank control trap, showing that volatile attractants are essential for

TABLE XII. Mean number of beetles caught and mean sex ratios in evaluation of bait placement in Scandinavian drainpipe traps. MacMillan-Bloedel, Ltd., Nanoose Division dryland sort, near Parksville, B.C., 1981. (N=8)

Bait Placement	*Trypodendron lineatum*[a]				*Gnathotrichus sulcatus*[a]			
	Male	Female	Total	M/F	Male	Female	Total	F/M
Top	145.1a	98.3a	243.4a	1.91	108.5a	114.8a	223.3a	1.14
Middle	336.1b	187.4b	523.5b	2.05	212.5b	236.1b	448.6b	1.09
Bottom	696.8c	421.3c	1,118.0c	1.73	204.1b	214.5b	418.6b	1.11

[a] Means within columns followed by same letter not significantly different, analysis of variance and Newman-Keuls Test, ($P<0.05$). Means within columns not followed by letters, not significantly different, analysis of variance, ($P<0.05$).

orientation to the traps.

Practical Implications

The vane trap is the most efficient trap type available for *T. lineatum* and *G. retusus* (Tables VII-IX). This trap is used for suppression of *G. sulcatus* in a commercial sawmill (McLean and Borden 1979). However, drainpipe traps and funnel traps are competitive with vane traps for *G. sulcatus*. Studies with drainpipe traps in the field (Table XII) and with funnel traps in a wind tunnel (Chapter C) indicate that judicious bait placement may greatly improve the efficiency of these 2 trap types relative to vane traps.

Optimal utilization of pheromone-based mass trapping of ambrosia beetles in dryland sort should include a large number of traps that are easy to set up and maintain, e.g. 1 funnel or drainpipe trap/10 m of sort perimeter where beetle "hot spots" occur, and 1 trap/25 or more m where catches are small. These traps should be double baited with lineatin and (±)-sulcatol (Borden et al. 1981) to catch *T. lineatum* and *G. sulcatus* throughout the season. In large numbers these traps can intercept beetles flying into, or draw beetles out of, the sorting area. Such a barrier strategy has been employed with some success in elm groves against the smaller European elm bark beetle, *Scolytus multistriatus* (Marsham) (Peacock et al. 1981).

Early in the season, pheromone- baited trap bundles can effectively complement traps for intercepting *T. lineatum* (Chapter I). During the main flight of *T. lineatum* and *G. retusus* 10 - 20 vane traps double baited with lineatin and *S*-(+)-sulcatol should be strategically placed around the sort in areas of the highest abundance of these species. The high efficiency of vane traps can thereby be optimally utilized, without incurring excessive labor costs.

E. SURVEY AND MASS TRAPPING OF AMBROSIA BEETLES IN TIMBER PROCESSING AREAS ON VANCOUVER ISLAND

Aggregation pheromones of scolytid beetles have been utilized for surveys (McLean and Borden 1975; McLean 1980a), and for mass trapping(McLean and Borden 1979; Bedard and Wood 1974, 1981; Lanier 1981; Lie and Bakke 1981). In timber processing areas survey traps have been used to determine the spatial and seasonal occurrence of ambrosia beetles, for subsequent implementation of a mass trapping strategy aiming at population suppression (McLean 1980).

Overwintering populations of _T. lineatum_ in the forest floor can easily be surveyed (Chapman 1974). Comparisons of population estimates over several years may reveal trends and be helpful in assessing the impact of mass trapping. However, many _T. lineatum_ are brought into dryland sorts and sawmills with infested timber (Gray 1980), and contribute to the overwintering population each year. Moreover, _Gnathotrichus_ spp. overwinter in logs and cannot be enumerated easily. Therefore, damage assessment will provide the most meaningful measure of mass trapping efficacy. McLean and Borden (1975) used test loads of green lumber to assess the efficacy of mass trapping of _G. sulcatus_ in a commercial sawmill. Similar methods have been attempted in dryland sorts (D.L. Overhulser[6], unpublished data), but are less reliable there due to the presence of log decks in the immediate vicinity of traps.

My objectives in this study were: 1) to develop a method for sampling and estimating the total overwintering population of *T. lineatum* at 4 dryland sorts for comparisons with annual catches in pheromone traps, 2) to determine the spatial distribution of overwintering *T. lineatum* in 4 dryland sorts and to compare yearly samples to determine population trends, 3) to determine the spatial and temporal distribution of 3 species of ambrosia beetles in 3 dryland sorts by utilizing pheromone-baited traps throughout a season, 4) to attempt a mass trapping program aiming at population suppression in one dryland sort, 5) to sample incoming logs to estimate the relative importance of imported and resident beetles at one dryland sort.

MATERIALS AND METHODS

Overwintering Samples

In order to establish spatial distribution of overwintering *T. lineatum*, duff samples 20 x 20 cm square and 2 - 4 cm deep, above which approximately 90 % of all *T. lineatum* overwinter (Dyer and Kinghorn 1961), were taken at 10 points 15 - 20 m inside the forest margin around each sort, except at China Creek where 8 sample points were established. At each sample point 4 such samples were taken at the base of a designated tree. Each of the 4 subsamples was taken within a quadrant (Appendix I), so that quadrant 1 was always toward the sort. In 1979 samples were brought to the laboratory and placed in black garbage bags, as described by Nijholt (1976), but from 1980 on samples were placed in 2 l milk cartons with an emergence jar attached. Emergent beetles were collected, counted and their sex determined every day for 1 week, and every other day for another week. In order to compare the 2 systems with each other, 5 paired 2 l samples were taken from pooled duff samples in 1981, and 7 paired 1 l samples in 1982, each pair consisting of 1 sample in a milk carton and 1 in a black plastic bag. Data on emergence was analyzed by Paired t-test without transformation.

In order to follow the trends of the overwintering populations at the 4 dryland sorts, data between years on emergence from spatial distribution samples were analyzed by 2-way analysis of variance and the Newman Keuls Test($p<0.05$) after transformation of data as $[x' = \log10(x + 1)]$.

Based on information in Dyer and Kinghorn (1961), a rough method for estimating the total overwintering population of *T. lineatum* was devised (Appendix I). The estimates based on this method were used to estimate % suppression by comparison with annual catches of *T. lineatum* on pheromone-baited traps.

In 1980 at Shawnigan and in 1982 at Sooke, 20 x 20 cm duff samples were taken along 14 and 10 transects, respectively, at 0, 30, 60, and 90 m into the forest from the margin, to establish an estimate of the total overwintering area. Based on these data, low and high estimates of population size were made (Appendix I). Estimates at Port Renfrew and China Creek were made by assuming that the transect data from Sooke and Shawnigan would be generally applicable.

Survey for Temporal and Spatial Distribution

Surveys were conducted at 3 dryland sorts in 1979 to establish temporal and spatial distribution of 3 species of ambrosia beetles. Twelve cylindrical sticky traps were set up around the margin of the dryland sorts at Sooke and Port Renfrew on Apr. 28, 1979. At each of 4 locations one trap was baited with lineatin only, one with (±)-sulcatol, and one with S-(+)-sulcatol; the latter 2 were also baited with ethanol and α-pinene. All chemicals were released as described in Exp. 1 (Chapter B). The traps were replaced weekly or biweekly, and the baits checked and replaced or refilled if necessary.

In order to determine if all 3 species of ambrosia beetles were present at the MacMillan-Bloedel Ltd. dryland sort at China Creek, near Port Alberni, B.C., 12 traps baited as described above were set up on Apr. 28 and removed after one week.

At the termination of Exp. 1 at Shawnigan (Chapter B), 12 traps, baited as described above, were left for survey purposes. On Aug. 1 an additional 12 traps, baited with (±)-sulcatol, ethanol and α-pinene as in Exp. 1 (Chapter B), were set up as part of a pilot study of lindane-treated trap logs. Data from this trap log study and Exp. 1 (Chapter B) were included in survey data for Shawnigan.

All traps were removed on Nov. 1. Processing of samples was done as described for Exp. 1 (Chapter B).

Continued Survey and Preliminary Mass Trapping

Surveys were conducted at 2 dryland sorts to determine population trends from the previous year. At Shawnigan data from Exp. 2 (Chapter B) were used for survey. Trapping was discontinued at the termination of this experiment on June 4, with the exception of trapping of <u>G. sulcatus</u> in Exp. 11 (Chapter D), Sep. 9-24. These data were also included in the survey.

On Mar. 1, 1980, 4 cylinder traps were set up at Port Renfrew and baited with lineatin as described above. Another 8 traps, 4 baited with (±)-sulcatol and 4 with <u>S</u>-(+)-sulcatol, all with ethanol and α-pinene, were set up on Mar. 15. All chemicals were released as in Exp. 5-7 (Chapter D).

At Sooke a preliminary mass trapping was attempted. Forty cylinder traps baited with lineatin were set up 15-30 m inside the forest margin on Mar. 1, and 40 drainpipe traps, 25 baited with (±)-sulcatol and 15 with S-(+)-sulcatol, were set up at the margin around the sort on Mar. 15. Up to May 26 cylinder traps were progressively moved out to the margin in an attempt to obtain optimal efficiency. Fifteen cylinder traps were removed on July 23 and S-(+)-sulcatol in drainpipe traps was replaced by lineatin. The remaining 25 cylinder traps were removed Aug. 21. Collections were made biweekly, and samples were processed as described for Exp. 2-4 (Chapter D). All drainpipe traps, and cylinder traps at Port Renfrew, were removed on Oct. 18.

Mass Trapping 1981

A mass trapping program utilizing the most efficient traps, as determined in Chapter D, was conducted at Sooke in 1981. Trap placement was optimized based on the experience from the preliminary mass trapping in 1980. On Mar. 11 - 12, 1981, 30 1981 funnel traps and 15 drainpipe traps attached to vane trap stands were set up. On Mar. 25, vanes were attached to the stands to make combined drainpipe/vane traps. Baits for drainpipe/vane traps were suspended low in the drainpipe, and in funnel traps as in Fig. 4A (Chapter C). All traps were baited with lineatin released as in Exp. 2 (Chapter D) and ethanol and α-pinene as in Exp. 6 (Chapter D). Also on Mar. 11 - 12, 24 of the funnel traps and 12 of the vane traps were baited with (±)-sulcatol as in Exp. 7 (Chapter D), and on May 6 the remaining 6 funnel traps and 3 vane traps were baited with S-(+)-sulcatol released in the same manner as (±)-sulcatol. Funnel traps were placed initially 15 - 30 m inside the forest margin, and up to June 3, progressively moved out to the margin. Vane traps were set up in areas with high populations of *T. lineatum* and placed in "channels" cut through sapling stands of red alder or other vegetation as described in Exp. 8 (Chapter D). As funnel traps were moved out, these were also placed in channels wherever possible. All vane traps were removed on Aug. 12, and S-(+)-sulcatol in 6 funnel traps was replaced with (±)-sulcatol. All funnel traps were removed on Oct. 21. Collections were made biweekly, and processed as in Exp. 2 - 4 (Chapter D). Vanes were brought to the laboratory, and total catch estimated as described in Exp. 8 (Chapter D). Linear correlations between catches on vane traps and in drainpipe traps were determined for each species to establish whether catches in drainpipe traps could be used to estimate vane trap catches. One correlation was determined for each trap and species, using the 7 sample dates as replicates (N), with the objective of detecting different responses at different sites. One correlation was also determined for each date for *T. lineatum* and *G. sulcatus*, using the number of traps baited with their respective pheromones as replicates, to establish whether the proportional response to the trap combination was due to trap shape or pheromone release, regardless of trap location and orientation relative to the sort.

In early to mid-Mar., 5 trap bundles were placed on the W edge of the sort by company personnel. They were baited with lineatin, ethanol and α-pinene, as described for the traps, on Mar. 11 and 25. Three of these bundles were removed by mistake on May 6, and in spite of repeated requests, the remaining 2 were never removed. Intentions to place more trap bundles around the edge of the sort did not materialize. Only subjective observations of attacks on the trap bundles were made.

No trapping was done at Shawnigan or Port Renfrew.

Log Sampling

In 1981 a small number of incoming logs were sampled on 7 occasions as they were placed in log decks. From each of 2 logs/bundle sampled, a 20 x 20 cm area of bark on an accessible end of the log was cut out with a chainsaw, removed with a chisel, and the number of attacks counted and recorded. The same log, or other logs in the same bundle depending on accessibility, were resampled weekly or biweekly May 7 to July 2, and finally on Sep. 23. New bundles were sampled on each occasion until July 2. In this manner the bundles were sampled a minimum of 1 and a maximum of 7 times, depending on when they arrived in and were brought out of the sort.

RESULTS AND DISCUSSION

Assessment of Sampling Technique for Overwintering *T. lineatum*

Comparison of 2 methods for assessing *T. lineatum* in duff samples revealed that there was no difference in emergence of *T. lineatum* from 2 l samples, although more beetles emerged from the garbage bag than from the milk carton in 4 out of the 5 pairs (Paired t-test, $p<0.05$). However, when 1 l samples were compared over 2 weeks, the milk cartons were superior (Paired t-test, $p<0.05$). Very few beetles emerged from the garbage bags, possibly because they could not reach the emergence jar due to folds in the plastic.

Large numbers of milk cartons can easily be stacked on shelves, providing constant light for all samples. Garbage bags are excellent for bulky samples, but require too much space in extensive programs.

My experiments show that small samples taken at the base of trees, are as efficient for detecting ambrosia beetles as the method described by Chapman (1974). Where populations of *T. lineatum* are low it is easy to increase the number of samples to improve precision.

The majority of the *T. lineatum* population will overwinter where light intensity drops approximately 50% over 50 m (Dyer and Kinghorn 1961), and preferably in dark places (Chapman 1960a). Comparison of the 4 sample quadrants around trees showed that significantly fewer beetles overwinter in quadrant 1 (14%), which faces the sort, than in any other quadrant (29, 34, and 32% for quadrants 2, 3, and 4, respectively) (X^2 test, $P<0.01$, $N = 545$). Samples could therefore be taken on the far side of the tree relative to the sort (quadrant 3), and more sample plots could be established for higher precision.

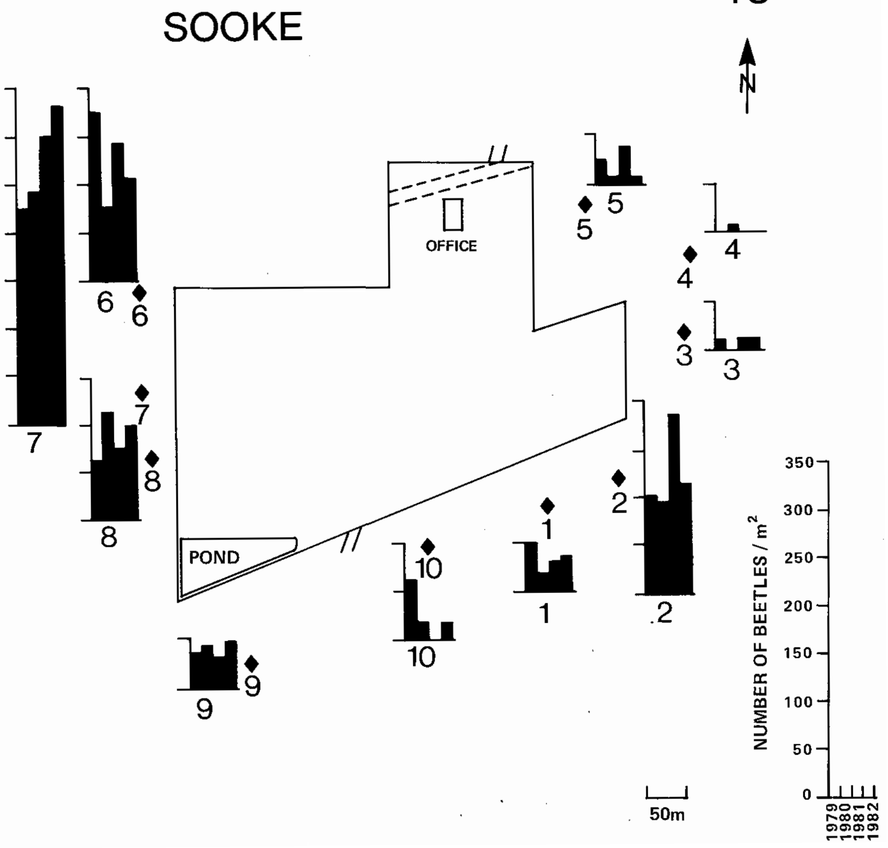
Spatial Distribution and Population Trends of Overwintering *T. lineatum*

The spatial distribution of overwintering beetles (Figs. 18-21) was fairly even at Shawnigan and China Creek (Figs. 19, 21), but localized in "hot spots" at Sooke (Fig. 18) and to some extent at Port Renfrew (Fig. 20). At Sooke, where this clumping was most evident, hot spots in 1981 coincided with areas where heavy attacks were noted the previous year. Thus, the notable increase of overwintering beetles at site 2 (Fig. 18) was probably due to heavily infested "boom sticks", which were left in the SW corner of the sorting area until late fall.

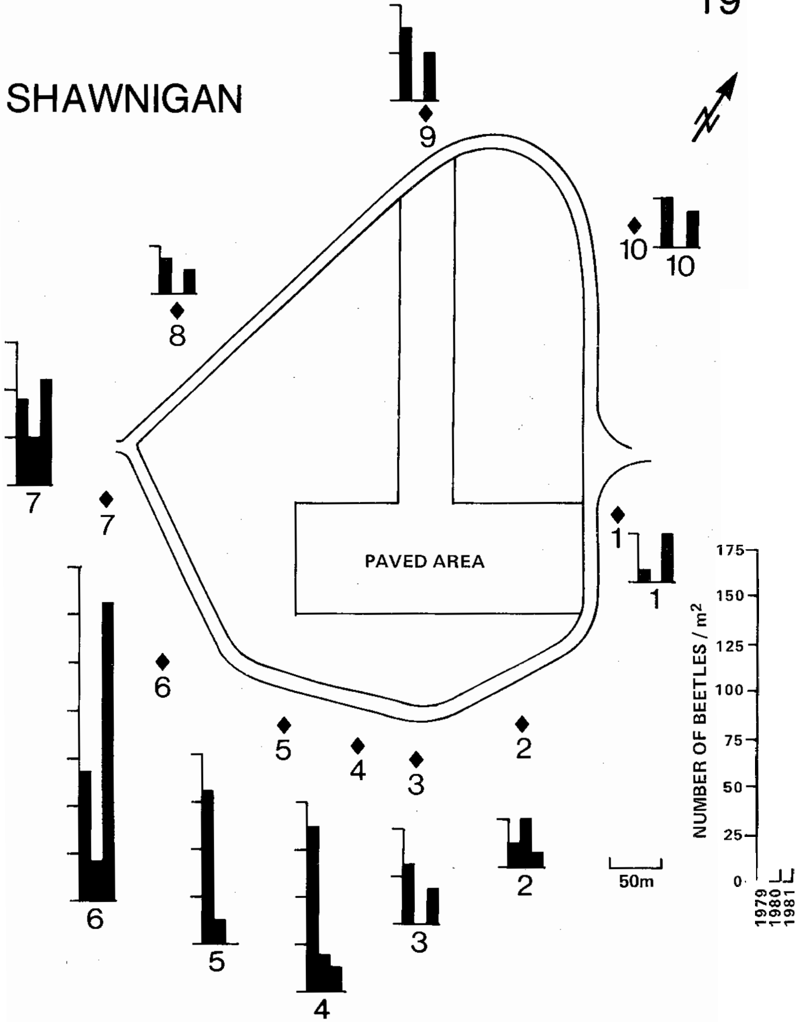
Emergence of overwintering *T. lineatum* from samples collected in 1979 was high at Sooke, moderate at Shawnigan, and

Figs. 18-19. Spatial distribution of overwintering *T. lineatum* collected at the dryland sorts at Sooke (Fig. 18), and Shawnigan (Fig. 19) on Vancouver Island, B.C. Numbered diamond symbols indicate approximate position of sampling site for overwintering beetles shown in correspondingly numbered histograms. Scale for each histogram and year shown to the right of each figure.

18


SOOKE
N
OFFICE
POND
1
2
3
4
5
6
7
8
9
10
NUMBER OF BEETLES / m^2
0
50
100
150
200
250
300
350
1979
1980
1981
1982
50m

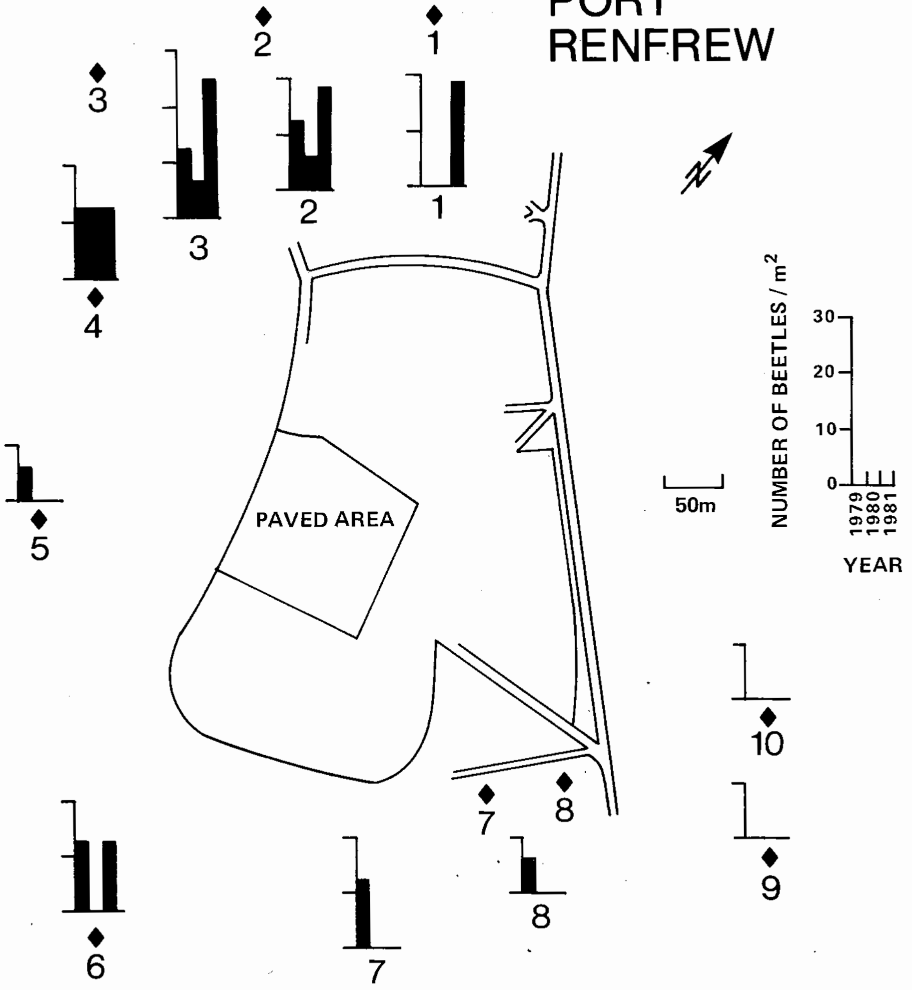
19


SHAWNIGAN
N
PAVED AREA
1
2
3
4
5
6
7
8
9
10
NUMBER OF BEETLES / m^2
0
25
50
75
100
125
150
175
1979
1980
1981
50m

Figs. 20-21. Spatial distribution of overwintering *T. lineatum* collected at the dryland sorts at Port Renfrew (Fig. 20), and China Creek (Fig. 21) on Vancouver Island, B.C. Numbered diamond symbols indicate approximate position of sampling site for overwintering beetles shown in correspondingly numbered histograms. Scale for each histogram and year shown to the right of each figure.

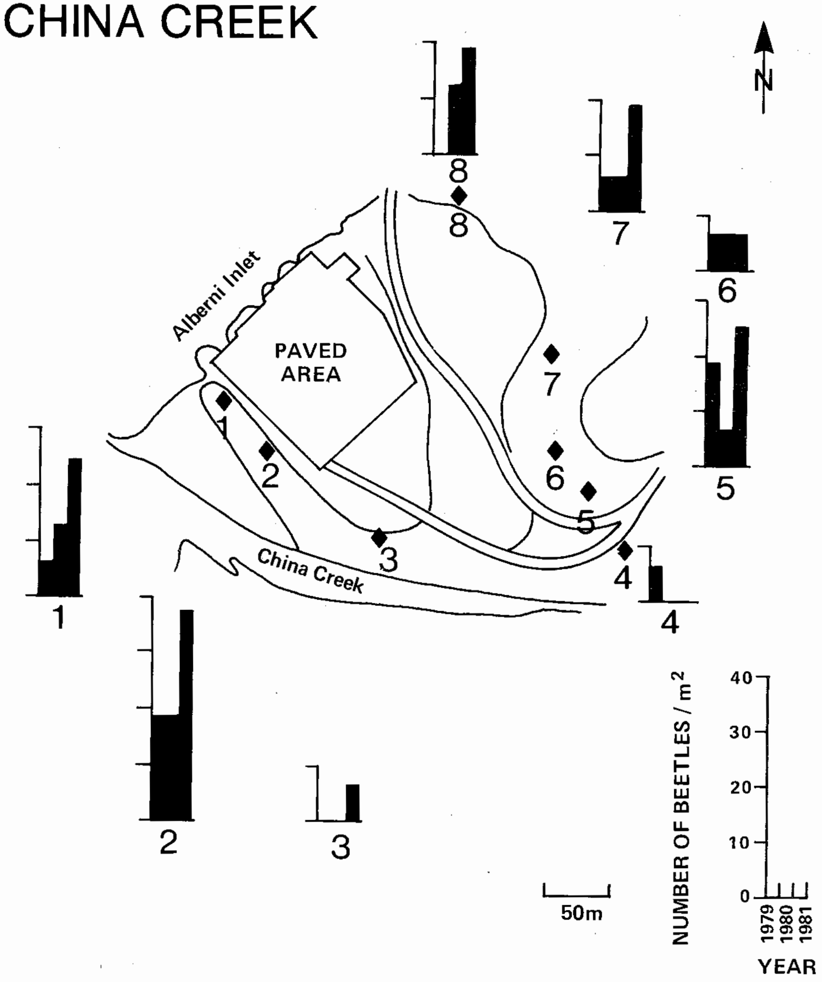
20

PORT RENFREW



21

CHINA CREEK



low at Port Renfrew and China Creek (Table XIII). The following year the emergence of males from overwintering samples was reduced at Shawnigan and Port Renfrew, and total emergence was reduced at Shawnigan (Table XIII). In 1981 emergence from samples taken at these 2 sorts were similar to that of 1979. At the newly opened dryland sort at China Creek (Apr. 1979) the total emergence in 1981 had increased over that of previous years, indicating that the population was increasing, possibly because of the sort operation. However, there may have been other reasons for the increase, since very little log storage occurs at China Creek. There was no change in emergence from samples taken at Sooke between 1981 and 1982 (Table XIII) in spite of an estimated 2.2 million *T. lineatum* caught on pheromone-baited traps in 1981. These data show that, with the exception of 1980, the numbers of *T. lineatum* emerging from infested logs within the sorts were relatively stable. In sorts such as Shawnigan, with a relatively low log inventory and high turnover, most emerging beetles are probably brought into the area with infested timber. At Sooke, with a high log inventory at most times, and with logs commonly remaining in the sort for 6 months or more, it is possible that a substantial proportion of the brood is made up of offspring from previous year's overwintering population.

TABLE XIII. Mean emergence and sex ratios of *T. lineatum* from overwintering samples collected at 4 dryland sorts on Vancouver Island, 1979-1982[a].

Sort	Year	Mean Emergence/Sample			Male/Female Ratio
		Male	Female	Total	
Sooke	1979	7.3	4.7	12.0	1.39
	1980	5.5	4.4	9.9	1.12
	1981	7.1	6.0	13.1	1.16
	1982	7.2	5.2	12.4	1.18
Shawnigan	1979	3.8b	2.8	6.6b	1.63
	1980	0.8a	0.8	1.6a	1.25
	1981	2.6b	2.8	5.4b	1.35
Port Renfrew	1979	0.8b	0.4	1.2a	1.40
	1980	0.1a	0.3	0.4a	0.98
	1981	0.9b	0.5	1.4a	1.32
China Creek	1979	0.6	0.9	1.5a	0.96
	1980	0.8	0.5	1.3a	1.31
	1981	1.6	1.1	2.8b	1.50

[a] For each area, means within columns followed by same letter not significantly different, analysis of variance and Newman-Keuls Test, ($P<0.05$). Means within columns not followed by letters, not significantly different, analysis of variance, ($P<0.05$).

Population Estimates of Overwintering *T. lineatum*

Sample transects from Shawnigan and Sooke in 1980 and 1982, respectively, showed that *T. lineatum* will fly up to 90 m into the forest to overwinter (Fig. 22). Since the regular overwintering samples were biased for high population areas, 60 m was chosen to calculate total overwintering area. (Appendix I). This distance was also used for Port Renfrew and China Creek although separate studies should be done for these areas if overwintering samples are to be used for population estimates in the future.

Population estimates of overwintering *T. lineatum* indicated an extremely high population at Sooke and low to moderate populations at the other 3 sorts (Table XIV). Visual inspection for attack on log decks indicated that the population at Port Renfrew was underestimated, since the attacks at this sort were as heavy or heavier than those at Shawnigan. The forest margin at Port Renfrew is not very distinct, except to the W, where beetles were never found (Fig. 20), and it is likely that brood beetles leaving this sort to overwinter disperse more than they do at Sooke or Shawnigan.

Overwintering samples are less reliable in areas with ill defined forest margins since the beetles are not as concentrated, and where logging operations within a few miles of the sort provide a source of immigrating beetles. *T. lineatum*

Fig. 22. Mean distributions of overwintering *T. lineatum* along transects sampled at 0, 30, 60, and 90 m into the forest from the margin around the dryland sorts at Sooke and Shawnigan.

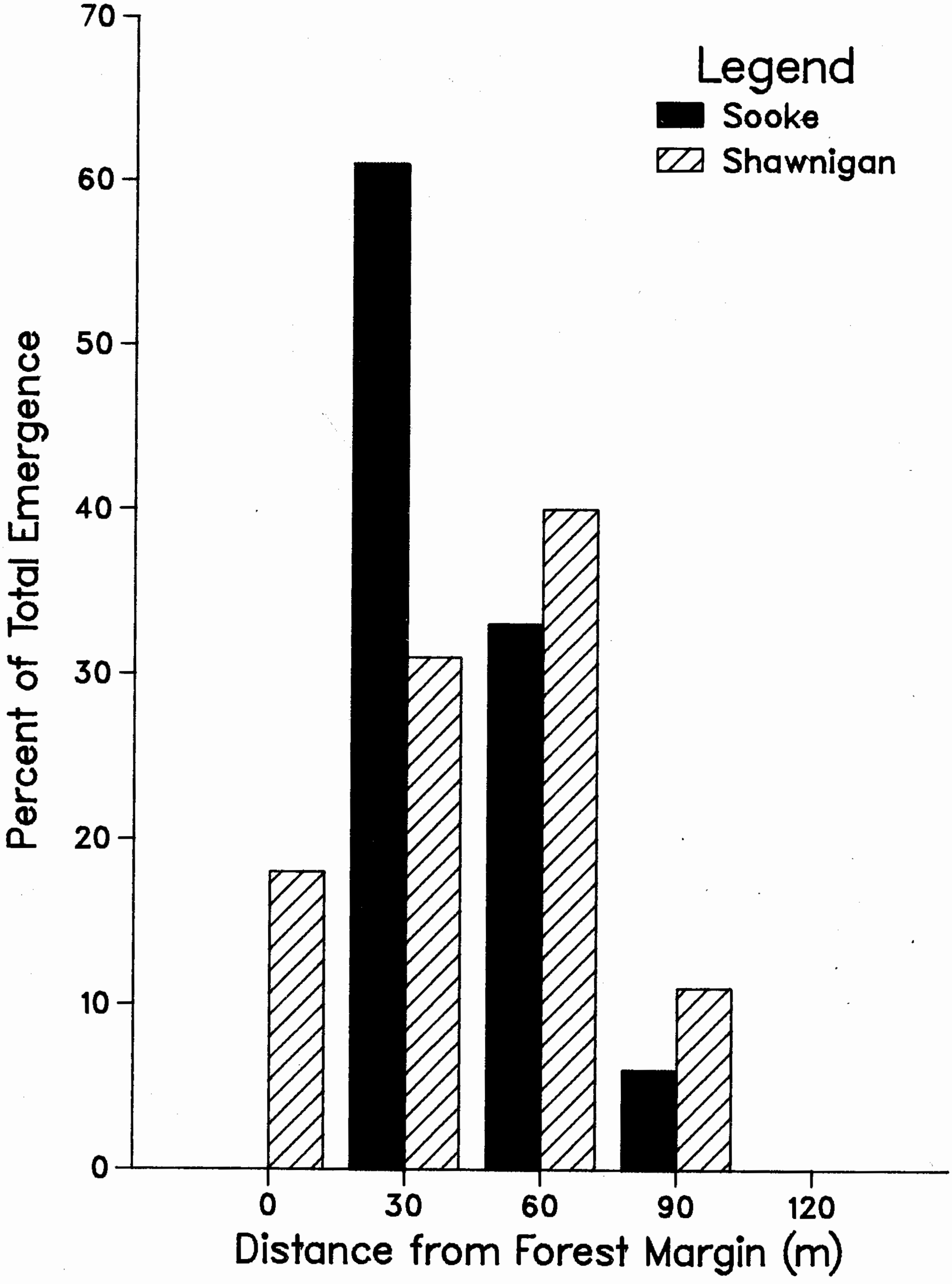

Legend
Sooke
Shawnigan
Percent of Total Emergence
0
10
20
30
40
50
60
70
0
30
60
90
120
Distance from Forest Margin (m)

TABLE XIV. Low and high estimates of overwintering populations[a], catches on traps, and estimated population suppression of *T. lineatum* at 4 dryland sorts on Vancouver Island, 1979-82.

Sort	Year	Population Estimate[b]		Catch[b]	Suppression (%)
		High	Low		
Sooke	1979	4,725,000	2,680,000	67,000	1- 3
	1980	3,898,000	2,205,000	458,000	12- 21
	1981	5,162,000	2,925,000	2,257,000	44- 77
	1982	4,946,000	2,837,000	---	---
Shawnigan	1979	1,256,000	804,000	128,000	10- 16
	1980	304,000	195,000	94,000	31- 48
	1981	1,029,000	659,000	---	---
Port Renfrew	1979	199,000	131,000	47,000	24- 36
	1980	68,000	46,000	31,000	46- 67
	1981	235,000	155,000	---	---
China Creek	1979	372,000	196,000	---	---
	1980	311,000	165,000	---	---
	1981	683,000	361,000	---	---

---

[a] See Appendix I for method.

[b] Rounded to nearest 1,000.

has been shown to fly up to 4 km (Dyer 1961), and a limited immigration to the sorting area from the adjacent forest is likely.

Overwintering samples could be used to assess the efficacy of trapping if infested timber was not brought into the sort or remained there only for brief periods, i.e. 1 to 2 weeks, and if timber attacked in the sort would be removed before 6 weeks after first attack. However, log management is dependent on market conditions and a large inventory, as at Sooke, facilitates the build-up of a large population of T. lineatum. This build up was probably promoted by closure of the sort in mid-summer, 1981 due to poor market conditions, leaving a large inventory of infested logs. Therefore, overwintering samples should only be used to estimate the minimum potential for damage the following season. A simple hazard index for that purpose was devised by Chapman (1974), although this did not provide an estimate of the total population.

The estimates of overwintering populations may at present be unreliable, but by comparing trap catches, damage and overwintering estimates over several years, it should be possible to adjust these estimates to provide a reliable index of actual population size.

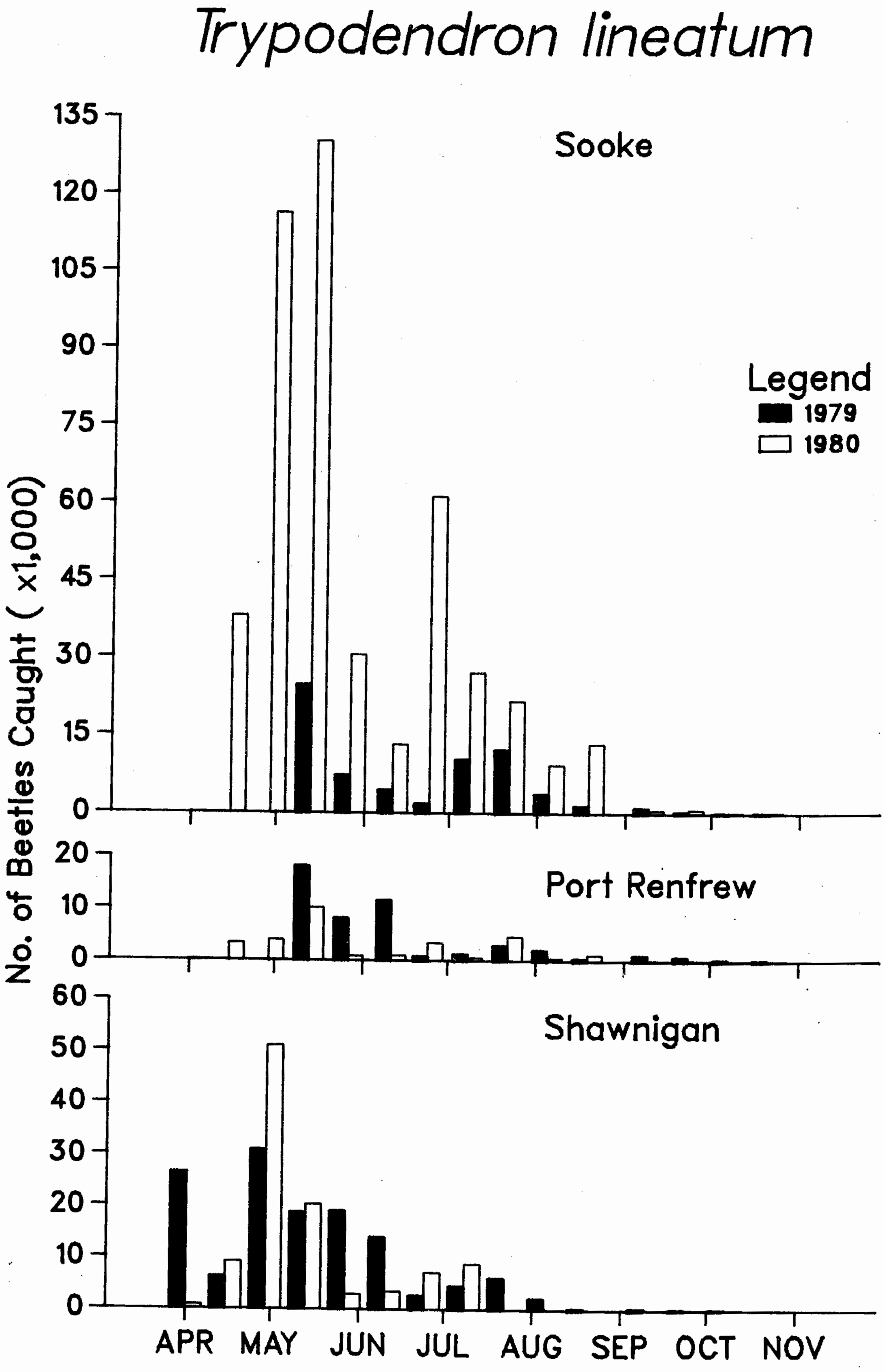
Survey for Temporal and Spatial Distribution

Catches of all 3 species at Port Renfrew and Shawnigan, where trapping efforts in 1979 and 1980 were relatively constant, showed similar trends between the 2 years (Figs. 23 - 25). The somewhat lower catches at Port Renfrew can largely be explained by trap placement. In 1979 traps at this sort were placed in the open, where some were repeatedly destroyed by black bears, *Ursus americanus* Pallas, residing on a nearby garbage dump. In 1980 all traps were placed near or inside sapling red alder, *Alnus rubra* (Bong.), stands, where the bears were unlikely to encounter them. However, this placement also decreased the trapping efficiency as *T. lineatum* prefer to fly over any obstacle, such as dense brush, regardless of height (T.L. Shore[5], unpublished data).

At Shawnigan, high "catches" in late Mar. 1979 (Figs. 23 - 25) consist mainly of attacks on trap logs, including an assumption that each attacking beetle was joined by a beetle of the opposite sex, i.e. the histograms for 1979 at Shawnigan show catch on traps + twice the estimated number of attacks on trap logs. For *T. lineatum* this assumption may not be valid since Shore et al. (1981) found that in 15 of 35 galleries failing to produce brood one or both sexes were missing.

For both *T. lineatum* and *G. retusus* 95% of the total catch in 1979, when trapping of all species was continued through

Fig. 23. Temporal distribution of *T. lineatum* caught at 3 dryland sorts on Vancouver Island, 1979-80.



Trypodendron lineatum
Sooke
Port Renfrew
Shawnigan
Legend
■ 1979
☐ 1980
No. of Beetles Caught (x1,000)
135
120
105
90
75
60
45
30
15
0
20
10
0
60
50
40
30
20
10
0
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV

Fig. 24. Temporal distribution of G. sulcatus caught at 3 dryland sorts on Vancouver Island, 1979-80.

Gnathotrichus sulcatus

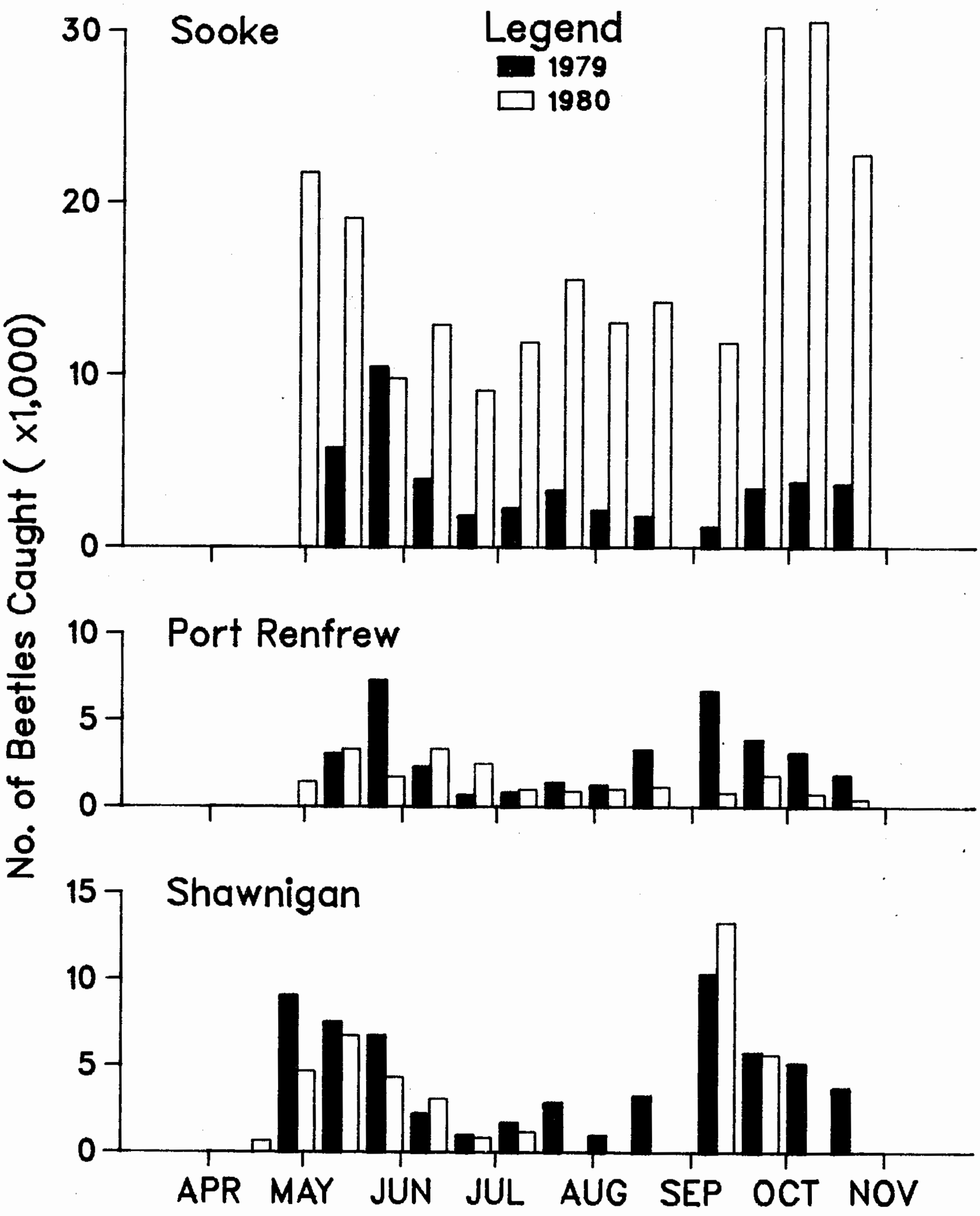
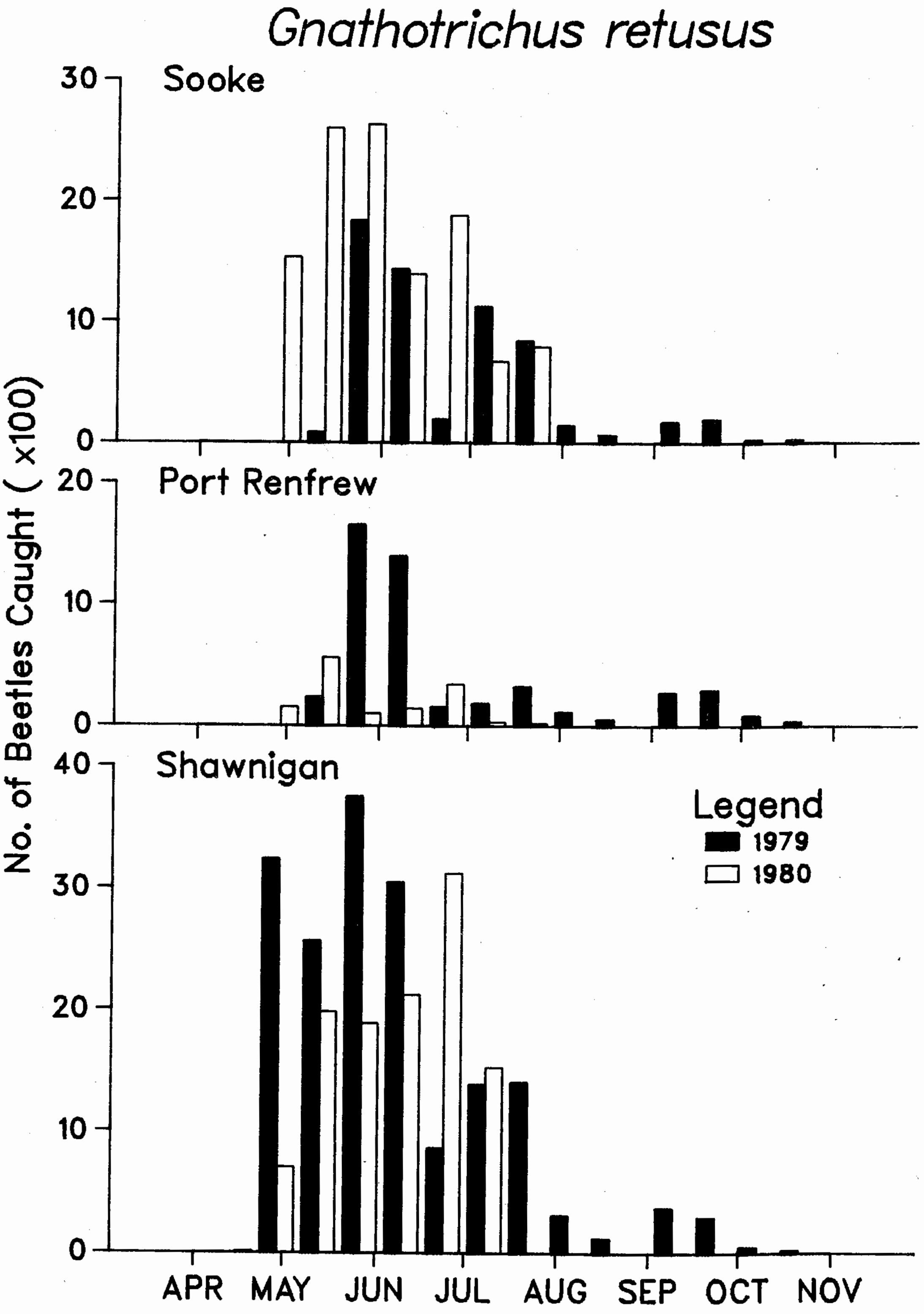


Fig. 25. Temporal distribution of *G. retusus* caught at 3 dryland sorts on Vancouver Island, 1979-80.


Gnathotrichus retusus
Sooke
Port Renfrew
Shawnigan
No. of Beetles Caught (x100)
30
20
10
0
20
10
0
40
30
20
10
0
Legend
■ 1979
□ 1980
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV

October, had been caught by mid Aug. at Sooke, late Aug. at Port Renfrew, and early Aug. at Shawnigan. For G. sulcatus the 95% level was not reached until mid Oct. at all sorts. These data mean that trapping for G. retusus and T. lineatum can be terminated by early Aug. This would minimize the use of S-(+)-sulcatol and lineatin, both of which are expensive.

Populations of G. retusus were relatively low at all areas surveyed. In 1979 the catch of this species at Shawnigan was 8% of the total catch of all 3 species, whereas it was 5% at Port Renfrew and Sooke.

The spatial distribution of T. lineatum caught on traps at Sooke, Port Renfrew and Shawnigan corresponded fairly well to the overwintering samples, although "hot spots" were less obvious at Sooke and Shawnigan. At Sooke (Fig. 18) most T. lineatum were caught in the margin to the W, where most of the timber is stored, and in the SE corner, where boom sticks are stored. Vane traps were concentrated in these positions in 1981. Similarly, G. sulcatus were prevalent at the same sites, and along the NE margin. G. retusus were caught in 3 "hot spots" in the NW corner, along the NE margin near the N exit road, and along the S margin, E of the S exit road. Timber is not normally stored close to the latter 2 areas. At Shawnigan (Fig. 19), T. lineatum was fairly evenly distributed around the entire margin. G. sulcatus was most prevalent along the S margin without any marked concentration at the W exit road as reported by McLean

(1980). *G. retusus* was most common along the S and E margins. At Port Renfrew (Fig. 20) all species were concentrated along the NW margin.

Mass Trapping 1980 and 1981

At Sooke the increased number of traps in 1980 improved the trapping results substantially (Figs. 23 - 25, Table XIV). Approximately 458,000 *T. lineatum*, 219,000 *G. sulcatus*, and 11,500 *G. retusus* were caught. Heavy attacks on log decks near the W margin and on boom sticks in the SE corner of the sort were observed after the spring flight, showing that any impact on damage as a result of removing these beetles was not evident. The increase in catch of *T. lineatum* was not due to a higher overwintering population, which remained constant between 1979 and 1980 (Table XIV). Brood beetles of this species do not respond to lineatin (W.W. Nijholt[1], unpublished data). Hence, only overwintered beetles, and some re-emergent adults abandoning their first gallery (Chapman and Kinghorn 1958), are caught in pheromone-baited traps, whereas brood beetles emerging from infested timber contribute only to the catch of the following year.

Utilization of the more efficient vane traps for *T. lineatum* and *G. retusus*, and increasing the overall trapping effort at Sooke in 1981, led to increased catches of all 3 species (Figs. 26 - 27). The extremely heavy flight of *T. lineatum* in May and early June made up 79% of the total catch of this species. On May 13 a massive flight simply overwhelmed the traps, and logs in the sort were literally covered by the beetles. In spite of this "failure" a total of more than 2.2 million *T. lineatum*, 0.5 million *G. sulcatus* and 15,000 *G. retusus* were caught. More than 81% of all *T. lineatum*, 36% of *G. sulcatus*, and 63% of *G. retusus*, were caught on vane traps (including the attached drainpipe traps).

One trap bundle had sustained heavy attacks on Apr. 9. By Apr. 22 all trap bundles were attacked, and many log decks in the sort were also damaged.

Estimates of Suppression

Comparison of trap catches with high and low estimates of overwintering populations of *T. lineatum* (Table XIV) indicated that a very low proportion was caught at Sooke in 1979, but that the efficacy of the trapping increased with the higher trapping efforts in 1980 and 1981. The high proportion of the overwintering beetles caught at Shawnigan and Port Renfrew in 1980 was probably a result of low population estimates due to poor emergence from the overwintering samples, which were wet since they were collected during a rainy period. The high percentage of the overwintering population caught at Sooke in

Fig. 26. Temporal distribution of *T. lineatum* caught in a mass trapping program at the dryland sort at Sooke, 1981.

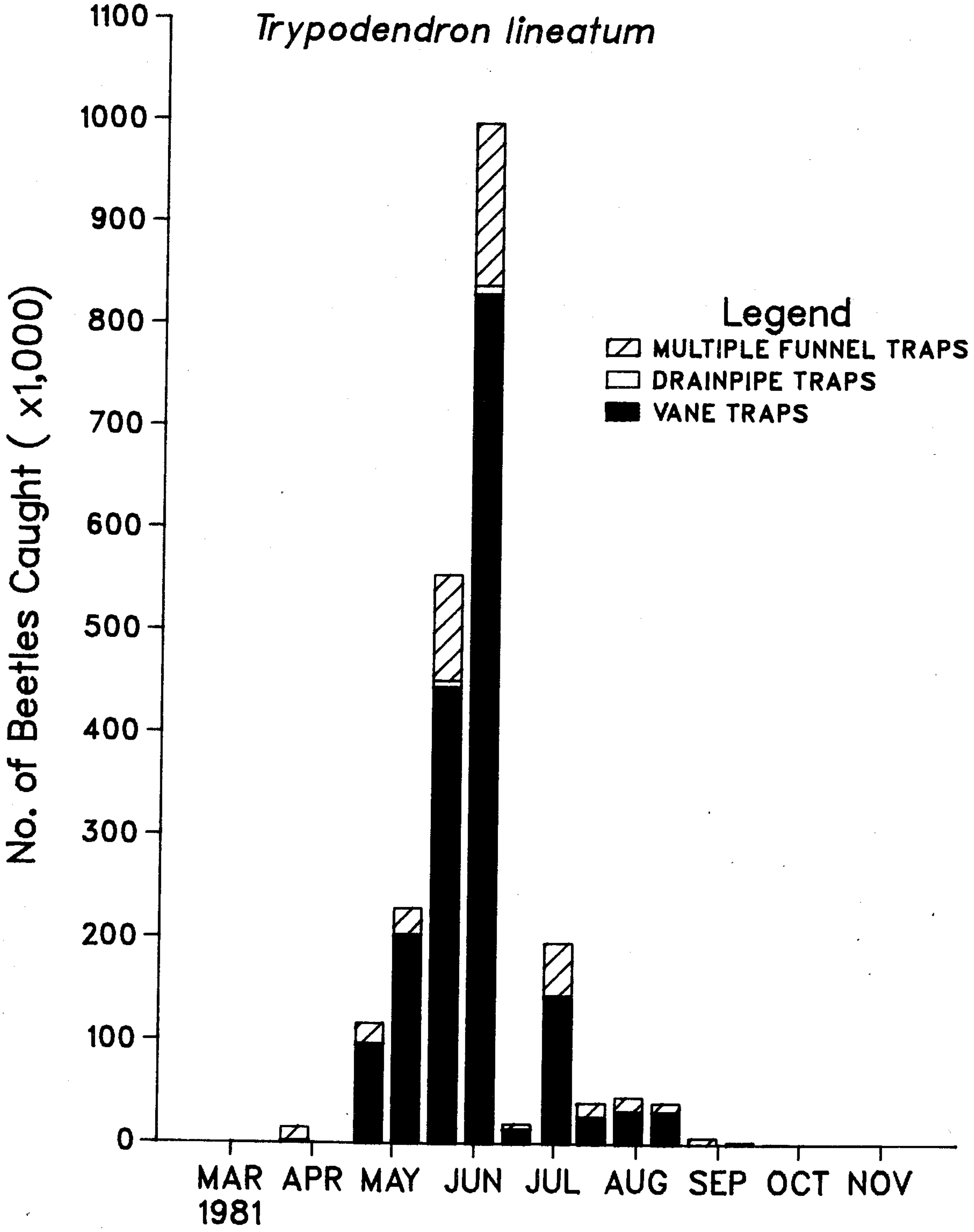
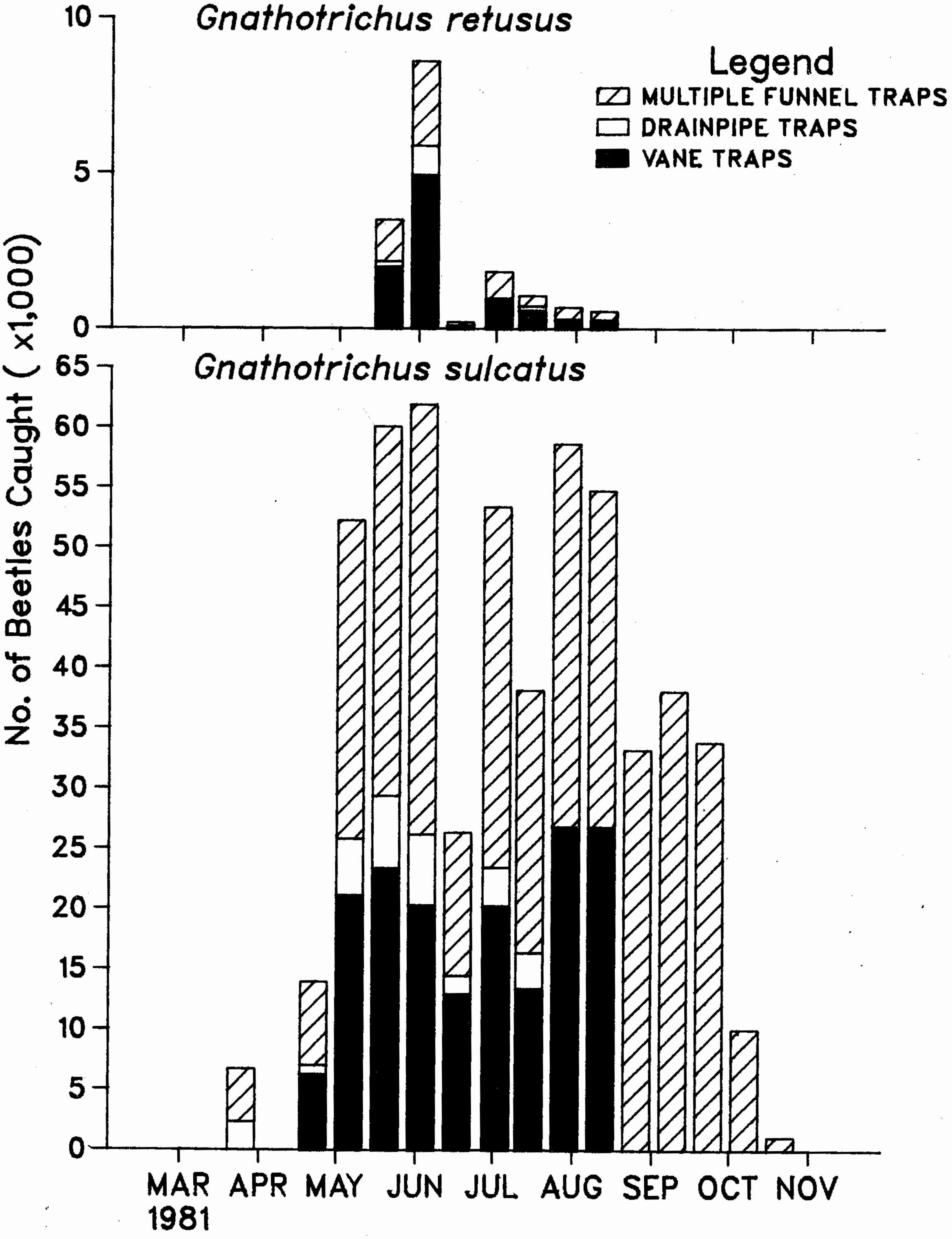

Trypodendron lineatum
No. of Beetles Caught (x1,000)
1100
1000
900
800
700
600
500
400
300
200
100
0
MAR
1981
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
Legend
MULTIPLE FUNNEL TRAPS
DRAINPIPE TRAPS
VANE TRAPS

Fig. 27. Temporal distribution of 2 *Gnathotrichus* spp. caught in a mass trapping program at the dryland sort at Sooke, 1981.


Gnathotrichus retusus
Legend
▨ MULTIPLE FUNNEL TRAPS
☐ DRAINPIPE TRAPS
■ VANE TRAPS
10
5
0
Gnathotrichus sulcatus
65
60
55
50
45
40
35
30
25
20
15
10
5
0
No. of Beetles Caught (x1,000)
MAR
1981
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV

1981, using the low population estimate in the calculation, suggests that the high population estimate should be used, since observations of a heavy flight in May indicated that a substantial number of beetles flew past the traps. Heavy attacks in the sort confirmed this.

Drainpipe Traps for Estimates of Catch on Vane Traps

The coefficient of correlation (r) for the correlation between catches on vane traps and in drainpipe traps was low for *T. lineatum* (range 0.44 - 0.68, $r=0.514$ for $p=0.05$, $N = 15$) on 5 of 7 dates, whereas they were high for 12 of 15 traps (range 0.89 - 0.98, $r=0.754$ for $p=0.05$, $N = 7$), indicating that trap placement affected the relative catch of the 2 components of the trap. The correlation coefficient for *G. sulcatus* was generally low (range 0.35 - 0.90 for 12 traps, $r=0.754$ for $p=0.05$, $N = 7$; range 0.20 - 0.85 on 7 dates, $r=0.756$ for $p=0.05$, $N = 12$). For *G. retusus* r was high for all 3 traps (range 0.96 - 0.99, $r=0.756$ for $p=0.05$, $N = 7$). Thus, this method for estimating total catch on vane traps would be useful if a prediction equation were calculated for each individual trap, if the trap position was permanent and the environment in this position not altered from one year to the next.

Log Sampling

Very few attacks could be detected on incoming logs. Of 42 logs sampled, only 2 were attacked, and had sustained 2.5 and 7.5 attacks/0.1 m^2, respectively. Gray (1980) reported attacks on 14 and 21% of the volume of Douglas-fir and western hemlock, respectively, arriving by train at the Canadian Forest Products, Ltd., dryland sort at Beaver Cove on northern Vancouver Island. It is possible that the sample size used in my study was too small to detect low levels of attack.

Gray (1980) also reported substantial increases in attacks on logs assembled in booms at the sort. Similarly, on logs remaining at Sooke for a week or more, attacks/0.1 m^2 increased from a mean of 18.3 (range 2.5 - 35.0) on 6 of 10 logs sampled on May 28, to 24.6 (range 2.5 - 35.0) on 7 of 14 logs sampled on June 14, and 40.0 (range 7.5 - 85.0) on 6 of 14 logs sampled on July 2. These data indicate that the bulk of the damage caused by ambrosia beetles at Sooke in 1981 was due to the very large resident population of *T. lineatum*. It is difficult to assess to what extent *G. sulcatus* contributed to the damage while it is probably safe to assume that *G. retusus* is of very little importance at Sooke.

Only the ends of logs sticking out of bundles at ground level could be sampled. Although the attack densities observed while sampling may not be representative, it is clear that heavy attacks occurred on logs in the Sooke dryland sort in 1981.

Attacks on logs brought into the sort were too few to be detected by the small sample size used. However, even 1 attack/log could constitute a substantial import of beetles into the sort, since more than 1,000 logs may be brought in each day. Many of these logs would remain in the sort long enough for brood beetles to emerge.

In order to assess the level of attack on incoming logs it would be of interest to have logs sampled regularly as they are graded. Sampled logs could be marked and resampled at the sawmill. In this way, problem areas in the forest could be identified and appropriate measures taken to deal with them. Where ambrosia beetle management is in operation, the efficacy of the management measures could be reliably assessed.

ECOLOGICAL IMPLICATIONS

Mortality of ambrosia beetles by large scale pheromone-based trapping is undoubtedly an extremely important mortality factor acting on the adult life stage.

Overwintering mortality of _T. lineatum_ has been estimated at 5 - 10 % (Chapman and Neitsch 1959; Chapman 1960b). Very little is known about the impact of predators and parasites of ambrosia beetles, or even their presence in North America (Nijholt 1979). Although traps baited with certain bark beetle pheromones yield very high catches of clerid and trogositid beetles (Dyer 1973; Bedard and Wood 1974; Bakke and Kvamme 1978), very few predators were caught throughout my study. Furthermore, predaceous beetles were rarely seen on attacked logs, indicating that they are of little significance in ambrosia beetle population regulation.

Other natural enemies, such as nematodes, are rare. Unlike other scolytids, which may be the victims of many nematodes (Massey 1974), T. lineatum collected in B.C. were only occasionally parasitized by 1 species of nematode (Thong 1973).

Bark beetles utilize an essentially 2-dimensional resource for their reproduction, and optimize the utilization of that resource by olfactory and/or acoustic spacing mechanisms (Borden 1982). Ambrosia beetles inhabit the 3-dimensional sapwood, and can effectively populate a host at extremely high densities, particularly as the larvae are stationary in niches (cradles), minimizing the chance of larvae encountering and preying on each other. Attack-limiting mechanisms would be of adaptive advantage for T. lineatum under natural conditions. Suitable logs are scarce since this species is limited to recently dead trees for successful establishment of its ambrosial fungus, which in turn determines reproductive success (Dyer and Chapman 1965; Christiansen and Saether 1968). Accordingly, T. lineatum males have been shown to produce an antiaggregation pheromone (Nijholt 1970, 1973b; Borden 1974; Klimetzek et al. 1981). No such mechanism has been detected in *Gnathotrichus* spp. (J.H. Borden[2], pers. comm.), which infests logs up to 2 years after felling (Mathers 1935). However, environmental conditions which affect host suitability, e.g. drying to suboptimal moisture levels (McLean and Borden 1977a) due to exposure to the sun, would be important to beetles in both genera.

In a dryland sort, suitable logs are readily available in large numbers, and only extraordinarily high populations in either genus of beetle would be affected by density dependent mortality. The beetles normally aggregate in high attack densities even when suitable logs are abundant. Therefore, it is unlikely that the impact of pheromone-based trapping could be offset by a favorable effect on the reproductive success of those beetles that escaped capture.

Although *G. retusus* is presently of little importance in any of the dryland sorts I studied, it is possible that by exerting heavy trapping pressure on *G. sulcatus*, population regulation of *G. retusus* by competition, e.g. inhibition of response to *R*-(-)-sulcatol produced by *G. sulcatus* (Borden et al. 1980a, 1981a), may be removed. This could lead to increased *G. retusus* populations. Therefore, it is important that this species not be ignored altogether.

"Resistance" to aggregation pheromones has not been discussed previously. In a large scale pheromone-based trapping program that continues over many generations of the target insect, it would be conceivable that selection could occur for beetles responding less to the synthetic pheromone than the majority of the population. For example, a population might contain individuals which only respond to one enantiomer of a pheromone and are repelled by the antipode.

It is not known if such variability exists in *T. lineatum* or *Gnathotrichus* spp. A geographic variability in pheromone production and response exists in populations of the bark beetle, *Ips pini* (Say). California populations produce and respond to *R*-(-)-ipsdienol and are inhibited from responding by its antipode (Birch et al. 1980). New York populations produce *R*-(-)- and *S*-(+)-ipsdienol and require both to respond (Lanier et al. 1980). These data suggest that continued artificial selection pressure could alter the nature of pheromone production and response mechanisms of natural populations of other scolytids, including ambrosia beetles. However, the mass trapping of ambrosia beetles in dryland sorts deals largely with immigrant populations from logging areas. The parents of overwintering beetles should not have been exposed to the pheromones used in mass trapping, provided that they stem from logs brought into the sort and not from logs attacked there. Thus, the chance for pheromone induced selection is remote at present. Should massive trapping programs ever be implemented at logging sites, as well as at dryland sorts, it may be of interest to collect overwintering beetles from areas with and without an active pheromone-based trapping program, and to do comparative studies on the nature of the pheromone produced and the response of these beetles to synthetic pheromones.

IMPACT ASSESSMENT

The lack of routine sampling procedures for ambrosia beetle attack in dryland sorts makes it very difficult to directly assess the impact of pheromone-based trapping on damage. Although the distribution of attacks on individual logs is known (Dyer 1963; Chapter B), there is no documentation on the distribution of attacks within a dryland sort. Visual inspections of the sort at Sooke in 1980 and 1981 indicated that heavy attacks occur near overwintering hotspots, particularly on log ends facing the margin, whereas attacks on top of and between log decks were few or moderate. It was not possible to estimate attack densities within the decks.

The results of overwintering samples in 1981 and 1982 show that there is no difference in overwintering population before and after the mass trapping program (Table XIII), but these data are measures of *T. lineatum* brood emergence from attacked logs in the sort. It is possible that the impact of the 2.2 million *T. lineatum* caught at Sooke in 1981 (Table XIV) prevented an increase in the overwintering population, since a shutdown of operations at the sort allowed attacked logs to remain in the area throughout the main period of brood emergence.

There are no reliable methods for damage assessment available. D.L. Overhulser[6] (unpublished data) used lineatin-baited Douglas-fir billets placed inside and outside the trap barrier around 2 dryland sorts in Washington State. Fewer attacks were recorded inside the barrier than outside, but those results could be explained as a location effect (Dyer 1963), since the billets inside the sort were exposed to the sun whereas those outside the sort were shaded by trees. Moreover, there were far more potential hosts to compete with the baited logs inside than outside the sort.

A simplistic extrapolation may partially exemplify the impact of removing 2.8 million ambrosia beetles, 1.25 million of which were of the first attacking sex, from the population at Sooke. At attack densities of 1 (estimated), and 13.5 attacks/0.1 m^2, which approximately correspond to pinholes allowed on No. 2 and 3 Common Douglas-fir boards (McLean 1980b; National Lumber Grades Authority 1970), with uniformly distributed attacks on 0.75 m diam. by 10 m long logs, a total of 5,360 and 396 logs, respectively, would sustain attack. If the attack were limited to 1/3 of the log, representing the ends in a log deck, the number of attacked logs at each density would be 16,080 and 1,190.

Indirect economic assessment of the impact of pheromone-based mass trapping at Sooke could be attempted, but might be misleading since many assumptions would have to be made. Without extensive data on the species and grade of log attacked, it would be impossible to attach a dollar value to such an assessment, since the amount of degrade depends on the quality of the wood and the attack density (Dobie 1978). A study designed to address these problems is under way (T.L. Shore[5], unpublished data). Even this study will not disclose the economic impact of reprocessing or remanufacturing of lumber, or rejection of otherwise acceptable products from the export market, due to ambrosia beetle attack. The problem with loss of clear facestock in the plywood industry is being addressed in another study (J.A. McLean[5], pers. comm.).

F. CONCLUSIONS AND RECOMMENDATIONS

My studies exemplify the need for innovative approaches to trap design, and the necessity of proper evaluation of traps and trapping techniques before they are operationally employed in pheromone-based management of scolytid beetles.

Logs baited with pheromone and treated with lindane were not better than pheromone-baited traps. Lindane-treated logs are deemed unsuitable for use in dryland sorts. Untreated trap logs were efficient early in the season, but gradually lost their attractiveness, becoming less efficient than sticky traps after 4 weeks. Selection of fall or winter felled logs of >30 cm diam. and >3.0 cm sapwood depth assures the suitability for ambrosia beetle trap logs. Thus, placement of untreated trap log bundles around a dryland sort is recommended, provided the bundles can be removed no later than 6 weeks after initial attack, i.e. before brood emergence.

Previously untried traps, including the multiple funnel trap, a new design, were tested against sticky traps. Wind tunnel studies (N.D.P. Angerilli^5 and J.A. McLean^5, unpublished data) suggested the importance of trap aerodynamics and bait placement in achieving optimal trap efficiency. Although a sticky vane trap was superior to all other trap types for _T. lineatum_ and _G. retusus_, optimization of non-sticky traps through the study of beetle behavior as it relates to bait placement, trap aerodynamics and further field tests, has yet to be accomplished. The multiple funnel trap is easily maintained and transported, making it more desirable than sticky traps for mass trapping operations. This trap type is now being produced commercially (PMG-Stratford Ltd., Vancouver, B.C. V5Z 1C6), and will be used for mass trapping of ambrosia beetles in several dryland sorts in southern British Columbia and tried on a limited scale in Washington State in 1982 (M.G. Banfield[7], S. Burke[7], and P. Mumby[7]; R.H. Heath[8], pers. comm.)

Spatial and temporal distribution were established by overwintering samples for T. lineatum and pheromone-based trapping for all 3 species. Trap placement for mass trapping at Sooke was based on this information. A limited damage assessment at Sooke in 1981 suggested that the bulk of attacks occurred by resident beetles in the sort during this time.

Routine sampling of damage on randomly chosen incoming logs, and preferably marking these logs so that they can be resampled at the sawmill, would greatly aid in identifying problem areas quickly and thus allow for appropriate action to be taken, e.g. altered log movement to prevent brood from infested logs emerging in the sort, and trapping for containment the following spring to prevent infestation of new logging sites.

Pheromone-based trapping is not a panacea for the ambrosia beetle problem. Infested logs are continuously brought into a sort and often left long enough for brood beetles to emerge. G. sulcatus brood can be caught as they emerge whereas T. lineatum will not respond to lineatin until the following spring. Improved logging hygiene, rapid turnover of logs in the sorts, and protective measures such as water misting (Richmond and Nijholt 1972) or use of repellents (Nijholt 1980) may all have to be used along with pheromone-baited traps to alleviate the threat posed by ambrosia beetles.

My studies show that employment of large numbers of pheromone-baited traps strategically placed as a barrier around a sort provides an effective means of trapping large numbers of ambrosia beetles, and should be a valuable part of ambrosia beetle management. Where high populations are present, as at Sooke, it is unlikely that damage can be prevented or even reduced significantly by trapping alone. It is extremely important that infested timber be removed from the sort within 6 weeks of initial attack if the population is to be reduced. Further operational mass trapping is necessary to develop, and thereby fully realize, the potential of pheromone-based management of ambrosia beetles in dryland sorts.

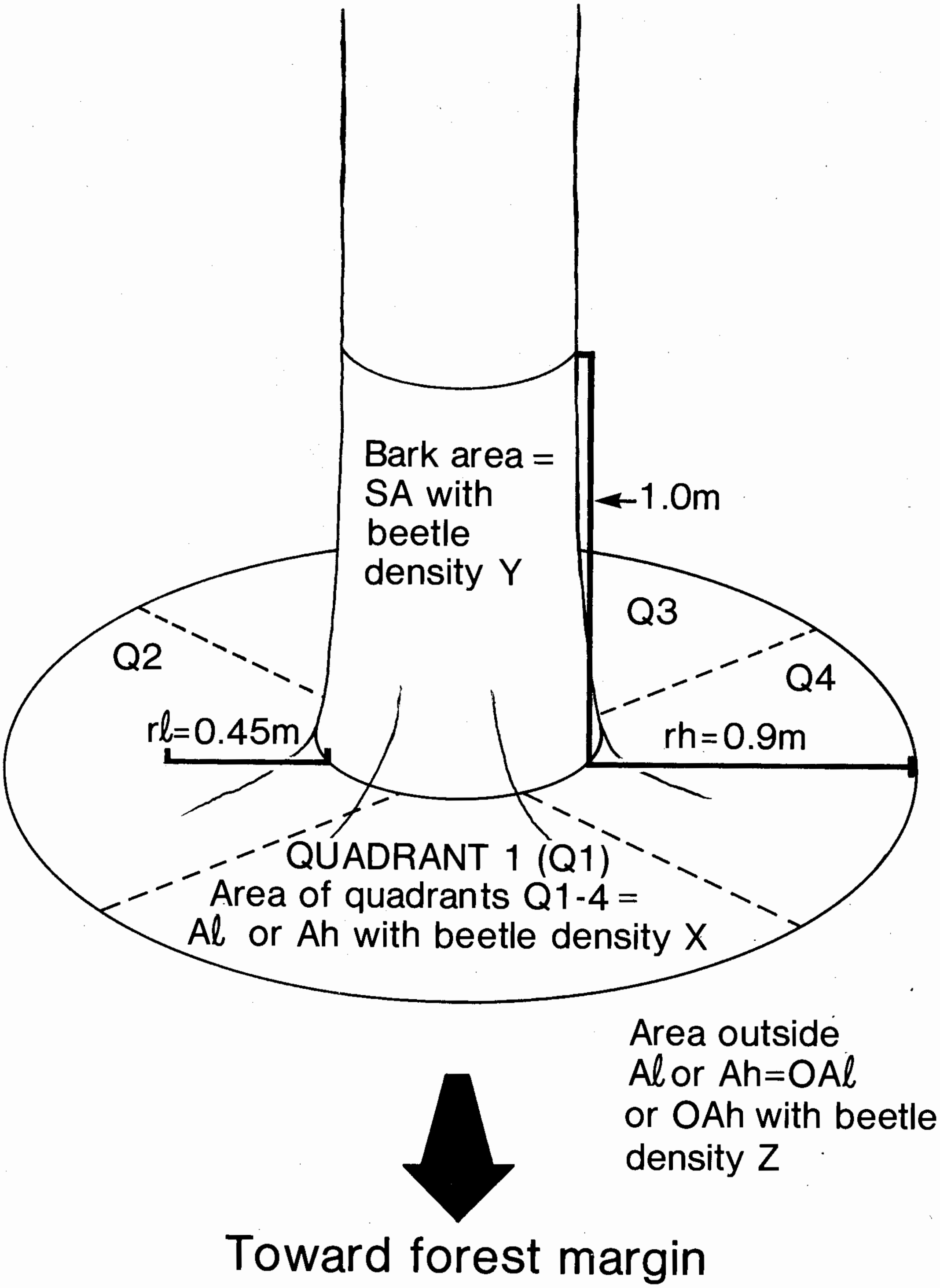
APPENDIX I

A METHOD FOR ESTIMATING OVERWINTERING POPULATIONS OF THRYPODENDRON LINEATUM

The factors influencing the distribution of overwintering *T. lineatum* have been thoroughly investigated (Dyer and Kinghorn 1961). Based on data from that study, an equation for estimating the total population (N) of overwintering beetles around a dryland sort was derived. Fig. 28 illustrates the information used in deriving this equation.

Depending on light intensity, *T. lineatum* may overwinter up to 150 m into the forest from the stand margin (Dyer and Kinghorn 1961). At Sooke and Shawnigan beetles may overwinter at least 90 m into the forest (Fig. 22). In order to estimate the total overwintering area (TOA) for these 2 sorts, 3 beetle densities from transect samples (DT) were calculated by dividing total number of beetles from transect samples by sample area, where sample area was the total from 0, and 30 m (0.08 m^2); 0, 30, and 60 m (0.12 m^2); or 0, 30, 60, and 90 m (0.16 m^2) samples. DT's were then compared with the mean density of overwintering beetles from permanent overwintering samples (DP) from that sort and year, and the equation which yielded a value of DT closest to DP, but still smaller, was chosen. The distance

Fig. 28. Diagram illustrating areas used for estimating overwintering populations of *T. lineatum* at 4 dryland sorts on Vancouver Island.


Bark area =
SA with
beetle
density Y
1.0m
Q3
Q2
Q4
rℓ=0.45m
rh=0.9m
QUADRANT 1 (Q1)
Area of quadrants Q1-4 =
Aℓ or Ah with beetle density X
Area outside
Aℓ or Ah=OAℓ
or OAh with beetle
density Z
Toward forest margin

used (60 m) to calculate TOA was the maximum included in the total sample area for that equation. With the aid of maps, a TOA was then estimated for each area, assuming that this distance was applicable to all sorts.

Overwintering _T. lineatum_ were found at the highest densities in litter (duff) within 0.9 m of trees (Dyer and Kinghorn 1961). Therefore, all duff samples were taken as close to trees as possible, and the mean number of beetles/m^2 from the samples at each sort were considered the maximum density of beetles (X) at that sort. A high (Nh) and a low (Nl) estimate of the population was made by varying the area (A) within which the population density was X. For Nh it was assumed that the density X extended to 0.9 m from each tree within TOA, and for Nl to 0.45 m. To calculate the actual A, the mean basal area (BA) multiplied by the total number of stems (S) within TOA was deducted from the area of S circles with the radius 1 m + mean radius of trees for Ah and 0.5 m + mean radius of trees for Al. The total number of beetles within A was then (Al x X) for Nl, and (Ah x X) for Nh.

Regardless of tree species, the density of _T. lineatum_ overwintering in the bark on trees was found to be ca. 60 % of the density in the adjacent duff (Dyer and Kinghorn 1961). The density fell sharply at 0.9 m and above. Thus, it was assumed that the density of overwintering beetles in the bark of trees was ($Y = 0.6X$). The mean area of 1 m of stem was calculated and multiplied by S for the total stem area (SA) with beetle density Y. The total number of beetles overwintering in bark was then calculated as $(SA \times Y)$.

No direct information is available on the relative density of *T. lineatum* in duff more than 0.9 m from trees. Based on Fig. 3 in Dyer and Kinghorn (1961), it was assumed that the density of overwintering beetles in the area OAl or OAh, outside the perimeter of Al and Ah, respectively, was $(Z = 0.15X)$. OAl and OAh were calculated by deducting the area of S circles with the radius 0.5 m + mean radius of trees and 1 m + mean radius of trees, respectively, from TOA. The total number of beetles within OAl was calculated as $(OAl \times Z)$, and within OAh as $(OAh \times Z)$.

The final 2 equations used were then:

$$Nl = (Al \times X) + (SA \times Y) + (OAl \times Z)$$

and

$$Nh = (Ah \times X) + (SA \times Y) + (OAh \times Z).$$

TABLE XV. Data used for calculating estimated overwintering populations of _T. lineatum_ in 4 dryland sorts on Vancouver Island.

	Sooke	Shawnigan	Port Renfrew	China Creek
Stand density [a] (stems/ha)	1,330	744	610	1,550
Basal area [a] (m^2/ha)	161	82.6	49.1	34.6
Mean tree diameter (m)	.35	0.38	0.39	0.18
Length of margin (m)	2,000	1,000	2,200	1,100
Overwintering area (ha)	10	7	7.5	6.6

[a] I am indebted to company personnel, who provided stand density and basal area data.

NOTES

[1] Safer Agrochem, Ltd., Saanichton, B.C. V0S 1M0.

[2] Department of Biological Sciences, Simon Fraser University, Burnaby, B.C. V5A 1S6.

[3] All release rates were determined in the laboratory at 22 °C and 70 % R.H. Actual release rates in the field may vary considerably due to environmental conditions.

[4] Department of Chemistry, Simon Fraser University, Burnaby, B.C. V5A 1S6.

[5] Faculty of Forestry, University of British Columbia, Vancouver, B.C. V6T 1W5.

[6] Weyerhaeuser Company, Western Forest Research Centre, Centralia, Wash. 98531, unpublished report.

[7] PMG-Stratford, Ltd., 545 W. 8th Ave., Vancouver, B.C. V5Z 1C6.

[8] Pacific Forest Products, Ltd., Forestry Office, Saanichton, B.C. V0S 1M0.

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