AMBROSIA BEETLES (COLEOPTERA: SCOLYTIDAE) IN A VANCOUVER ISLAND DRYLAND SORT: THEIR DAMAGE AND PROPOSED CONTROL

by

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Title of Thesis/Project/Extended Essay

Ambrosia beetles in Vancouver Island dryland sort: their damage and proposed control

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ABSTRACT

Ambrosia beetles (Coleoptera: Scolytidae) cause estimated annual losses of $63.7 million in coastal British Columbia by boring into the sapwood of all commercially valuable conifers. Losses are a result of degraded product quality, exclusion of infested material from certain markets, higher cull factors in scaling, and lower yields due to heavier slabbing.

Damage caused by ambrosia beetle attack on wood processed at the Beaver Cove dryland sort resulted in product degrade of $\$0.89/m^3$ processed, or a total loss in excess of $110,000.00 for a seven-week period in 1980. Fifty-five percent of the loss occurred from beetle attack at the dryland sort; the remainder occurred prior to log arrival at the dryland sort.

Mass trapping in 1981 succeeded in capturing only 10% or 20% of the estimated maximum or minimum population respectively of *Trypodendron lineatum* (Olivier). This combination of an inability to significantly reduce attacking populations through trapping and the constant repopulation resulting from the importing of infested material, together with the occurrence of significant losses outside of the dryland sort area demand a multi-faceted pest management program. This program would encompass inventory management to reduce the amount of vulnerable wood at peak flight times for the beetles, product protection, e.g., by water misting of decked and boomed logs, alteration of overwintering areas, and pheromone-based, mass trapping to suppress the beetle population.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

1.1 Biology

Of the numerous northern hemisphere species of ambrosia beetles, which together have a holarctic distribution (Baker 1963), 5 are found in coastal British Columbia (Richmond 1968) (Table I). *Trypodendron lineatum* (Olivier) is the most serious pest, *Gnathotrichus* spp. are lesser but severe pests and the others are of minor importance on the B.C. coast.

The common name ambrosia beetle is derived from the symbiotic fungi which are the sole food source of young adults and developing larvae (Baker 1963). These fungi include *Ceratocystis* spp., which are similar to blue-stain fungi associated with many bark beetles (Krebill 1975) but are ambrosial in the galleries of *G. sulcatus* (LeConte) (Baker 1963), and *Monilia ferruginea* (Methiesen-Kaarik) in the galleries of *T. lineatum* (Baker 1963).

T. lineatum is holarctic in distribution (Baker 1963). Adults emerge from their overwintering sites in the duff or under the bark of trees in the forest margin when air temperature has reached approximately 16°C (Nijholt 1978a), usually in late March through June. After a brief dispersal flight (Chapman and Nijholt 1980) pioneer female beetles attack recently dead trees or logs from trees

Table I. The ambrosia beetles of coastal British Columbia (Richmond 1968; Furniss and Carolin 1977).

Family	Species	Host Trees
Platypodidae	Platypus wilsoni Swaine	Abies spp., Tsuga heterophylla (Raf.) Sarg., Pseudotsuga menziesii (Mirb.) Franco, occasionally other conifers
Scolytidae	Gnathotrichus retusus (LeConte)	Alnus spp., probably most conifers in its range
	G. sulcatus (LeConte)	Probably all conifers in its range
	Trypodendron lineatum (Olivier)	All conifers in its range, Alnus spp., Betula spp.
	Xyleborus saxeseni (Ratzeburg)	Pinus spp., T. heterophylla, P. menziesii, various deciduous species

felled the previous fall and winter (Christiansen and Saether 1968; Annila 1975). Soon after attack the females produce the aggregation pheromone 4,6,6 lineatin (3,3,7 trimethyl- 2,9 dioxatricylco [3.3.1.0] nonane) (Borden et al. 1979) which attracts both sexes and causes mass attack on a log.

Mating occurs outside the incipient egg gallery (Nijholt 1978a). The gallery is then completed in the springwood between annual rings of the sapwood. Egg niches are made at right angles to the main gallery, which extends through the wood at right angles to the long axis of the bole. Oviposition begins about 2 weeks after mating, eggs hatch in about 10 days and brood emergence begins 8-9 weeks after egg hatch (Prebble and Graham 1957) and continues through July (Shore 1982). Upon emergence from attacked logs young beetles fly directly to their overwintering sites without responding to their aggregation pheromone (W. W. Nijholt[1], pers. comm.). A few parent adults may begin a second brood after completing and leaving their first galleries (Chapman and Nijholt 1980).

G. sulcatus overwinters in all life stages, except the egg, in attacked logs, and can resume activity whenever ambient temperature is suitable (Prebble and Graham 1957). Broods developed from eggs laid after midsummer of the previous year emerge in the spring approximately 2 weeks after T. lineatum (Prebble and Graham 1957).

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[1] Safer Agro Chemicals, Saanichton, B.C.

Pioneer males produce the aggregation pheromone sulcatol, a 65:35 mixture of *S*-(+):*R*-(-)-6-methyl-5-hepten-2-ol (Byrne et al. 1974). Broods developed from eggs laid in early summer emerge in the late summer and fall of the same year and unlike *T. lineatum* are responsive to their aggregation pheromone. They disperse in a second major flight, attacking new logs, and establish overwintering broods (Prebble and Graham 1957; Rudinsky and Schneider 1969).

The life cycle of *G. retusus* (LeConte) is similar to that of *G. sulcatus* (Prebble and Graham 1957). Optically pure *S*-(+)-sulcatol is the aggregation pheromone of *G. retusus* (Borden et al. 1980a). Results of this study show it to be much less common than the other 2 species on the B.C. coast.

1.2 Damage and Management

Ambrosia beetles cause their damage by boring into the sapwood of all commercially valuable conifers in B.C. (McMullan 1956). The black-stained pinholes in attacked timber degrade the quality and value of the lumber and veneer produced from it (Dobie 1978; Borden and McLean 1981; Furniss 1982). Further losses can be incurred through exclusion of infested timber from certain markets, higher cull factors in scaling, lower yields due to heavier slabbing (McBride 1950; McBride and Kinghorn 1960) and resorting and resawing damaged lumber (Richmond 1968). McLean (1985) calculated sawlog degrade alone to result in an annual loss of $63.7 million in coastal

B.C. The trend from water sorting to dryland sorting in recent years has resulted in an increased problem (Nijholt 1978a) due to the additional delay in delivering the logs to the water and the demise of flat-rafted booms which afforded greater protection than the bundles now used. Greater losses can be expected when the forest industry begins to harvest predominantly smaller second growth timber with a larger proportion of sapwood (McBride and Kinghorn 1960).

Although *T. lineatum* is the most common ambrosia beetle in coastal B.C. (Nijholt 1979), characteristics of the *Gnathotrichus* spp. such as their habit of remaining in the host throughout the winter, tendency to attack trees of a greater diameter and penetrate more deeply (Johnson 1958; McLean 1985), ability to attack and survive in great numbers throughout the winter in stumps when not burned (McLean and Borden 1977), overlapping generations (Prebble and Graham 1957), ability to attack trees shortly after they are felled (McLean and Borden 1977), and the ability of *G. sulcatus* to complete its life cycle within freshly sawn lumber (McLean and Borden 1975) may make the *Gnathotrichus* spp. more persistent pests than *T. lineatum* (Borden and Stokkink 1973).

Early ambrosia beetle control measures emphasized the use of chemical insecticides, both in the forest and over log booms (Richmond 1961; Lejeune and Richmond 1975). Benzene hexachloride (BHC) and lindane (the gamma isomer of BHC) were used in the forest in the 1940's, and in the 1950's companies began to spray log booms with lindane from aircraft. Mounting public anti-pesticide sentiments supported by Finegan's (1967) unverified report that BHC levels were higher in sea life in an estuary downstream from ambrosia beetle spraying than in other areas halted the practice in 1970. At the same time the industry was initiating a move to dryland sorting operations (dryland sorts).

Since 1970 control measures have varied. Borden and McLean (1981) proposed 3 principal control strategies:

1) Inventory management (i.e., the reduction of numbers of susceptible logs during peak flight times). Athough a valid consideration, the uncertainty of coastal B.C. weather, market conditions, mechanical breakdowns (Nijholt 1980), and other uncontrollable factors such as labor problems reduce the potential effectiveness of such management.

2) Product protection. Water misting (Richmond and Nijholt 1972) has been proven to offer effective protection (Nijholt 1978b). Reluctance to adopt such a system probably stems from the cost of initiating the system, the manpower commitment necessary to ensure continued operation, requirements of water volume and adequate drainage, and the unpleasant working conditions created (W. Coombs[2], pers. comm.). Pine oil and, to a lesser extent, oleic acid have considerable repellent powers (Nijholt 1980) and future control programs may include the use of such chemicals. The

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[2] B.C. Forest Products Ltd., Crofton, B.C.

existence of a male produced anti-aggregation pheromone (Nijholt 1973; Klimetzek et al. 1981) also provides possibilities for log protection.
3) Beetle population suppression. Population suppression may now be possible utilizing synthetic aggregation pheromones and mass trapping techniques. Such a program was proven to be operationally feasible in Vancouver Island sawmills (McLean and Borden 1979) and dryland sorts (Lindgren and Borden 1983) and since 1983 has been offered commercially by Phero Tech Inc., Vancouver, B.C.

1.3 Beaver Cove dryland sort

The Canadian Forest Products Englewood Division dryland sort at Beaver Cove was chosen as a study site after samples of the overwintering habitat in 1976 and 1977 by Chapman's (1974) methods suggested a medium hazard. Established in 1974 at the mouth of the Kokish River, considerable damage by ambrosia beetles was noticed by company personnel in 1978 despite rapid processing of the logs.

1.4 Objectives

The objectives of this study were:

1) To describe the size and distribution of the overwintering population of *T. lineatum* in the forest margin around the dryland sort;

2) To describe the spatial and temporal distribution of 3 attacking species of ambrosia beetle by trapping with pheromone-baited traps;

3) To assess total ambrosia beetle damage in sawlogs of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and peeler logs of Douglas-fir;

4) To divide this total damage into that suffered prior to arrival of logs at the dryland sort (hereafter called forest damage) and that suffered while the logs remained at the dryland sort (hereafter called sort damage); and

5) To use these damage assessments to derive economic loss estimates which might then be used to justify or discourage beetle management programs.

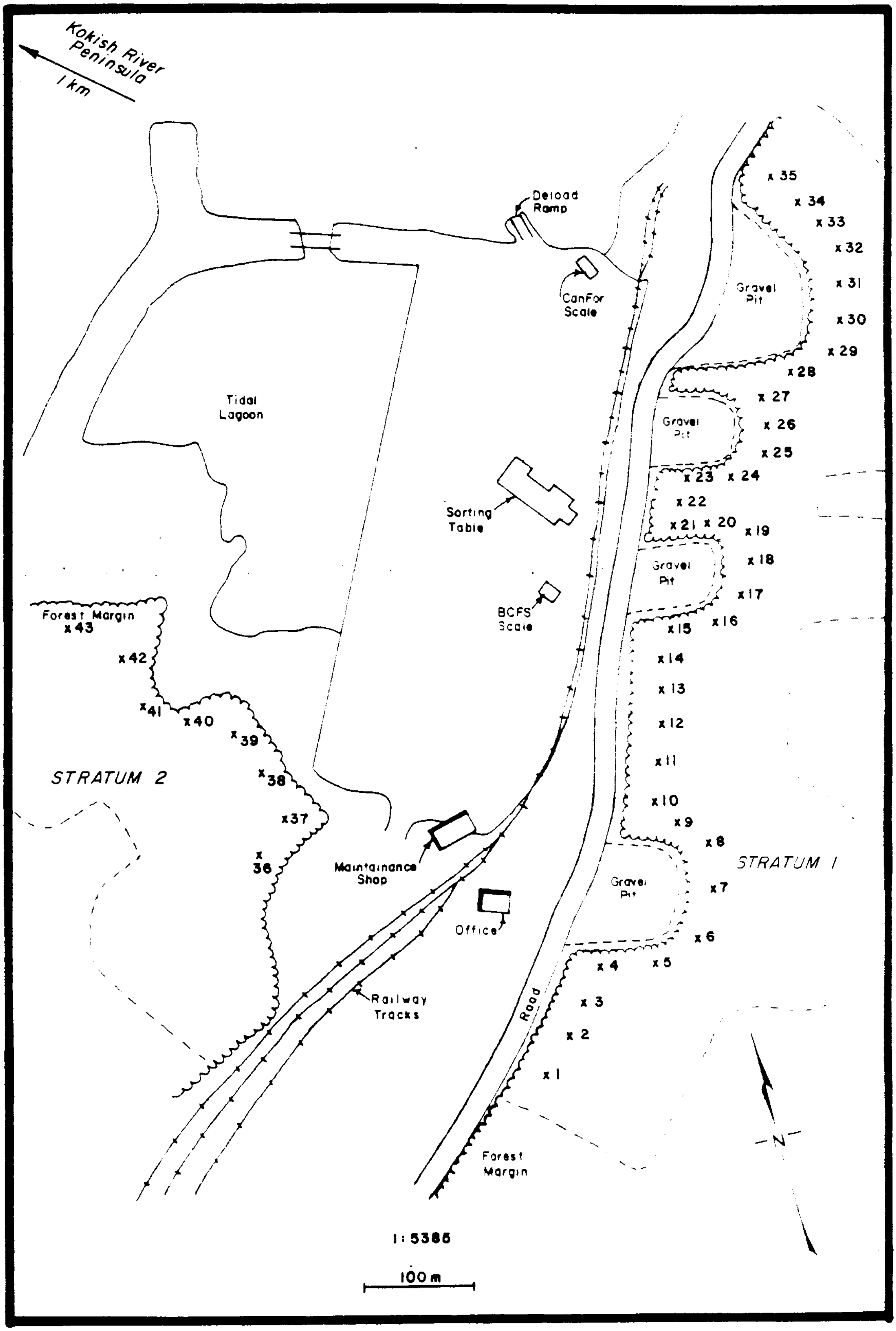
2. OVERWINTERING *T. LINEATUM* ESTIMATES

2.1 Materials and Methods

In January 1980, 51 samples were collected approximately 25 m inside the forest surrounding the dryland sort (Fig. 1). Each sample consisted of all the litter and duff down to the mineral soil from 4, 20 x 20 cm squares spaced evenly around the base, within 0.9 m, of a tree. Samples were placed in black garbage bags, and taken to the laboratory where emergent beetles were collected for 3 weeks in attached glass jars (Nijholt 1976) and counted by sex.

The overwintering sampling was done in 3 areas (strata) (Fig. 1) to reflect different forest types, stocking levels, and distance from the dryland sort. To investigate differences between strata in

Fig. 1. Locations of 43 overwintering sample sites (January 1980) for *T. lineatum* in 2 strata of the Beaver Cove dryland sort. An additional stratum comprising 8 sample sites (Nos. 44-51, not shown on map) was located on the Kokish River Peninsula to the northwest of the dryland sort.


Kokish River Peninsula
1 km
Deload Ramp
CanFor Scale
Tidal Lagoon
Gravel Pit
Gravel Pit
Gravel Pit
Gravel Pit
Sorting Table
BCFS Scale
Forest Margin
STRATUM 2
STRATUM 1
Maintainance Shop
Office
Railway Tracks
Road
Forest Margin
x 1
x 2
x 3
x 4
x 5
x 6
x 7
x 8
x 9
x 10
x 11
x 12
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x 38
x 39
x 40
x 41
x 42
x 43
N
1:5385
100 m

density of overwintering beetles data were analyzed by analysis of variance and the Newman-Keuls test (p 0.05) after transformation of the data by $x'=\log_{10}(x+1)$.

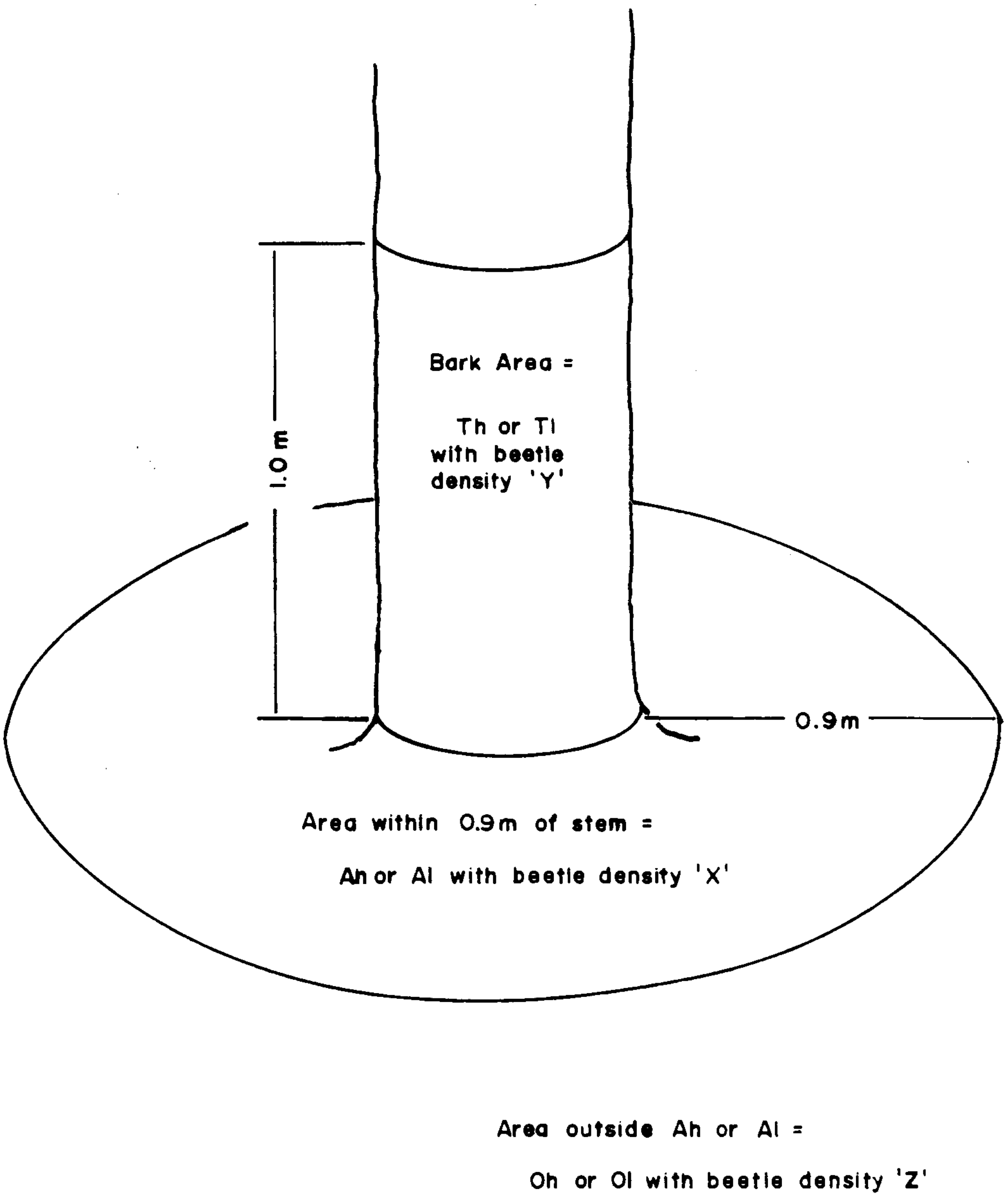
In July 1980 stand cruises of the strata were completed by fixed radius plot sampling and an equation was derived to estimate the 1979/1980 overwintering beetle population in each stratum. Dyer and Kinghorn (1961) described a nonrandom distribution of overwintering *T. lineatum* within a forest. The highest density of overwintering beetles was found within 0.9 m of trees or stumps (Fig. 2). Therefore, the mean density of beetles from the samples of each stratum was assumed to be the maximum density of overwintering beetles in that stratum (X/m^2).

Within the bark of the lower 1.0 m of bole of any tree species (Fig. 2) the density of overwintering beetles was found to be 60% of the encircling duff (Dyer and Kinghorn 1961) ($Y=0.6X/m^2$). Above 1.0 m the density was minimal.

Based on Dyer and Kinghorn (1961) the density of overwintering *T. lineatum* outside the 0.9 m ring around trees and stumps was assumed to be $Z = 0.15X/m^2$ (Fig. 2).

Dyer and Kinghorn (1961) reported that overwintering beetles were recovered 300 m within the forest margin. However, the maximum

Fig. 2 Illustration of distribution of overwintering *T. lineatum* within the forest surrounding the Beaver Cove dryland sort. Adapted from Lindgren and Borden (1983). See text for explanation of symbols and equation estimating total overwintering population.


Bark Area =
Th or Tl with beetle density 'Y'
1.0m
0.9m
Area within 0.9m of stem =
Ah or Al with beetle density 'X'
Area outside Ah or Al =
Oh or Ol with beetle density 'Z'

density of beetles was found approximately 60 m into the forest. For the purposes of this study the overwintering area (H) was assumed to extend a minimum of 75 m (Hl)[3] and a maximum of 150 m (Hh)[3] into the forest.

For the maximum overwintering area, the area in each stratum within 0.9 m of a tree or stump (Ah) was calculated by multiplying the mean basal area of the stems (BA) by the total number of stems in Hh (Sh) and subtracting the product from the area occupied by Sh circles with a 0.9 m greater radius than the mean stem radius. The calculation was repeated using Hl to calculate Al. The numbers of beetles in Ah and Al were X x Ah and X x Al, respectively.

The surface area of trees or stumps (T) available for overwintering in each stratum was calculated by multiplying the surface area of 1 m of a stem of the mean diameter by Sh or Sl stems to give Th or Tl. The number of beetles in Th was Y x Th and in Tl was Y x Tl.

The total area in each stratum outside of Ah (Oh) was calculated by subtracting from Hh the area occupied by Sh circles with a 0.9 m greater radius than the mean stem radius. The calculation was repeated using Al to give Ol. The number of beetles in Oh was Z x Oh and in Ol was Z x Ol.

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[3] l after capital letter refers to "low" estimate and h after capital letter refers to "high" estimate.

The total number of beetles (N) in each statum was then either:

$$Nh=(X \times Ah) + (Y \times Th) + (Z \times Oh)$$

or:

$$Nl=(X \times Al) + (Y \times Tl) + (Z \times Ol)$$

In January 1981 overwintering sampling was repeated by sampling along 6 transect lines at distances of 10, 60, 110, 160, and 210 m from the forest margin to determine the maximum distance from the forest margin where overwintering occurred. However poor labelling of the January 1981 overwintering samples did not permit proper identification of the sample locations and they were discarded.

2.2 Results and Discussion

In total, 294 overwintering *T. lineatum* beetles (1.35 ♂:1♀) were recovered from the January, 1980 samples (Table II). The highest maximum overwintering density was in stratum 1 (Fig. 1) where a good second growth stand of western hemlock and Douglas-fir was present. Stratum 2 (Fig. 1) supported approximately half the maximum density of beetles of stratum 1. This stratum is in a low lying area stocked by small shrubs, skunk cabbage, *Lysichitum americanum*, Hult and St. J., and fewer conifers than stratum 1. In stratum 3, located on the Kokish River peninsula, there was a very low maximum density despite a good second growth stand.

Table II. Overwintering *T. lineatum* in 51 duff samples. Beaver Cove dryland sort. January 1980. Sample size: 4 x 20 cm x 20 cm.

Stratum and sample no.	Number of beetles			$\bar{X}$ no. beetles/ sample ± S.E.[b]
	male	female	total	
Stratum 1				
1	1	0	1	
2	3	3	6	
3	8	4	12	
4	1	2	3	
5	0	3	3	
6	3	3	6	
7	19	15	34	
8	1	1	2	
9	3	2	5	
10	2	1	3	
11	8	6	14	
12	2	1	3	
13	2	2	4	
14	2	1	3	
15	4	1	5	
16	9	5	14	
17	5	4	9	
18	0	1	1	
19	7	8	15	
20	3	3	6	
21	8	7	16[a]	
22	19	9	28	
23	14	11	25	
24	7	1	8	
25	8	6	14	
26	2	1	3	
27	1	6	7	
28	1	1	2	
29	4	2	6	
30	2	2	4	
31	1	0	1	
32	0	0	0	
33	1	0	1	
34	0	0	0	
35	1	0	1	7.57 ± 1.38a

Table II. Overwintering *T. lineatum* in 51 duff samples. Beaver Cove dryland sort. January 1980. Sample size: 4 x 20 cm x 20 cm.

Stratum and sample no.	Number of beetles			$\bar{X}$ no. beetles sample ± S.E.[b]
	male	female	total	
Stratum 2				
36	1	0	1	
37	0	0	0	
38	0	0	0	
39	0	1	1	
40	2	0	2	
41	0	1	1	
42	5	1	6	
43	8	6	15[a]	3.25 ± 1.81b
Stratum 3				
44	0	0	0	
45	0	1	1	
46	0	1	1	
47	0	0	0	
48	0	0	0	
49	0	0	0	
50	0	1	1	
51	0	0	0	0.38 ± 0.18b
Totals	168	124	294[a]	5.76 ± 1.06

[a] Sex of some beetles was not determined due to missing heads.

[b] Numbers within column followed by same letter not significantly different, Newman-Keuls' test $p < 0.05$.

The relationships between overwintering population densities and characteristics of the surrounding forest are given for the 3 strata in Table III.

The mean density of overwintering beetles was significantly greater in stratum 1 than in either of the other 2 strata (Table II). The variation in beetles per sample was large both within a stratum and between strata. Kinghorn and Chapman (1959) pointed to numerous variables that can vary greatly even between samples from a single stand of fairly uniform timber and topography, such as accumulation of duff, presence or absence of moss or decaying woody material, and shade as well as variables such as overall shading and moisture retention of soils that will vary between stands.

It is interesting to note that while results of overwintering beetle sampling suggested that the Kokish River peninsula was not a high priority for trapping, trap number 88 placed on the peninsula had the highest total catch of _I. lineatum_ in 1980 (Sec. 3.2.1).

Table III. Estimates of maximum and minimum overwintering populations of *T. lineatum* and data used in calculation.Beaver Cove dryland sort. January 1980.

	Stratum 1	Stratum 2	Stratum 3	Total
mean beetle density within 0.9 m of stem (beetles/m^2)	47.31	20.31	2.38	
stand density (stems/ha)	2,100	900	3,000	
mean stem diameter (cm)	21.8	32.9	13.3	
Maximum over-wintering area (ha)	14.4	5.4	7.5	27.3
minimum over-wintering area (ha)	7.2	2.7	3.7	13.6
maximum over-wintering population	5,446,059	516,161	173,079	6,135,299
minimum over-wintering population	2,723,029	258,081	86,539	3,067,649

3. DISTRIBUTION OF ATTACKING BEETLES

3.1 Materials and Methods

The temporal and spatial distributions of attacking *T. lineatum*, *G. sulcatus*, and *G. retusus* were determined in 1980 by collecting beetles from 74 pheromone-baited Scandinavian drainpipe traps (Boregaard, S.A., Sarpsborg, Norway) (Figs. 3, 4) placed around the dryland sort (Fig. 5) on March 29, 1980. Eleven traps were baited with *S*-(+)- sulcatol, 95% ethanol, and α-pinene (Borden et al. 1980b); 22 traps with (±)-sulcatol, 95% ethanol, and α-pinene (Borden et al. 1980b); and 41 traps with lineatin. Sulcatol was released from open glass vials (0.50 cm^2 aperture) at a rate[3] of 4.9 mg/day (McLean 1976); α-pinene was released from identical vials at a rate of 40 mg/day (McLean 1976); ethanol was released from uncapped 113.6 ml nalgene bottles (1.5 cm^2 aperture) at an unknown rate; and lineatin was released from 4 Conrel fibres/trap (Albany International Co., Needham, Mass.; .13 mm^2 aperture) at a rate of 8-10 μg/fibre/day (H. D. Pierce, Jr.[4], unpublished data).

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[3] Sulcatol release rate determined at laboratory conditions of 20°C, relative humidity unknown.
Lineatin release rate determined at laboratory conditions of 22°C, 70% relative humidity.

[4] Dept. of Chemistry, Simon Fraser University, Burnaby, B.C.

Fig. 3. Scandinavian plastic drainpipe trap showing collecting jar. Height = 135 cm (without collecting jar). Outside diameter = 12.5 cm.

Fig. 4. Close-up of outside of drainpipe trap showing placement of baits and holes through which beetles crawl prior to dropping into trap.

FIG 3

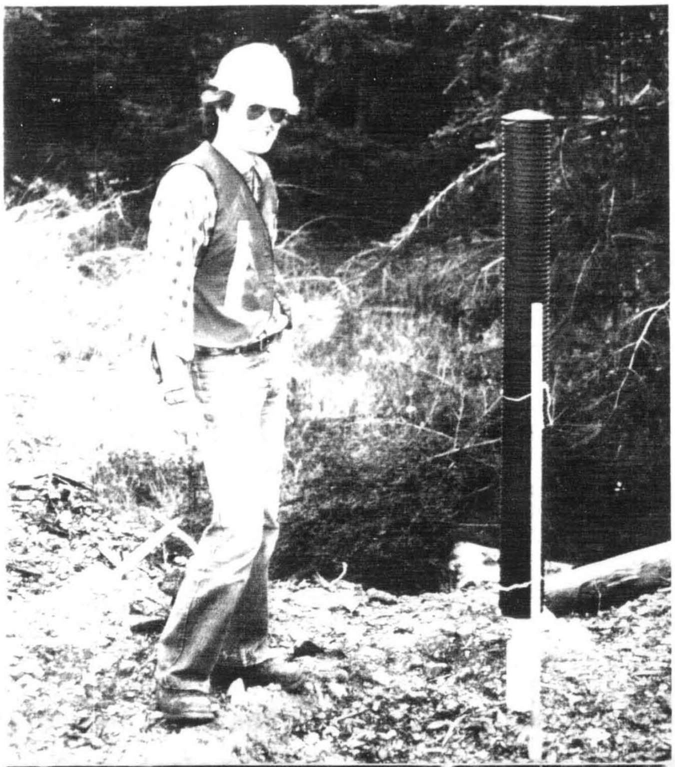
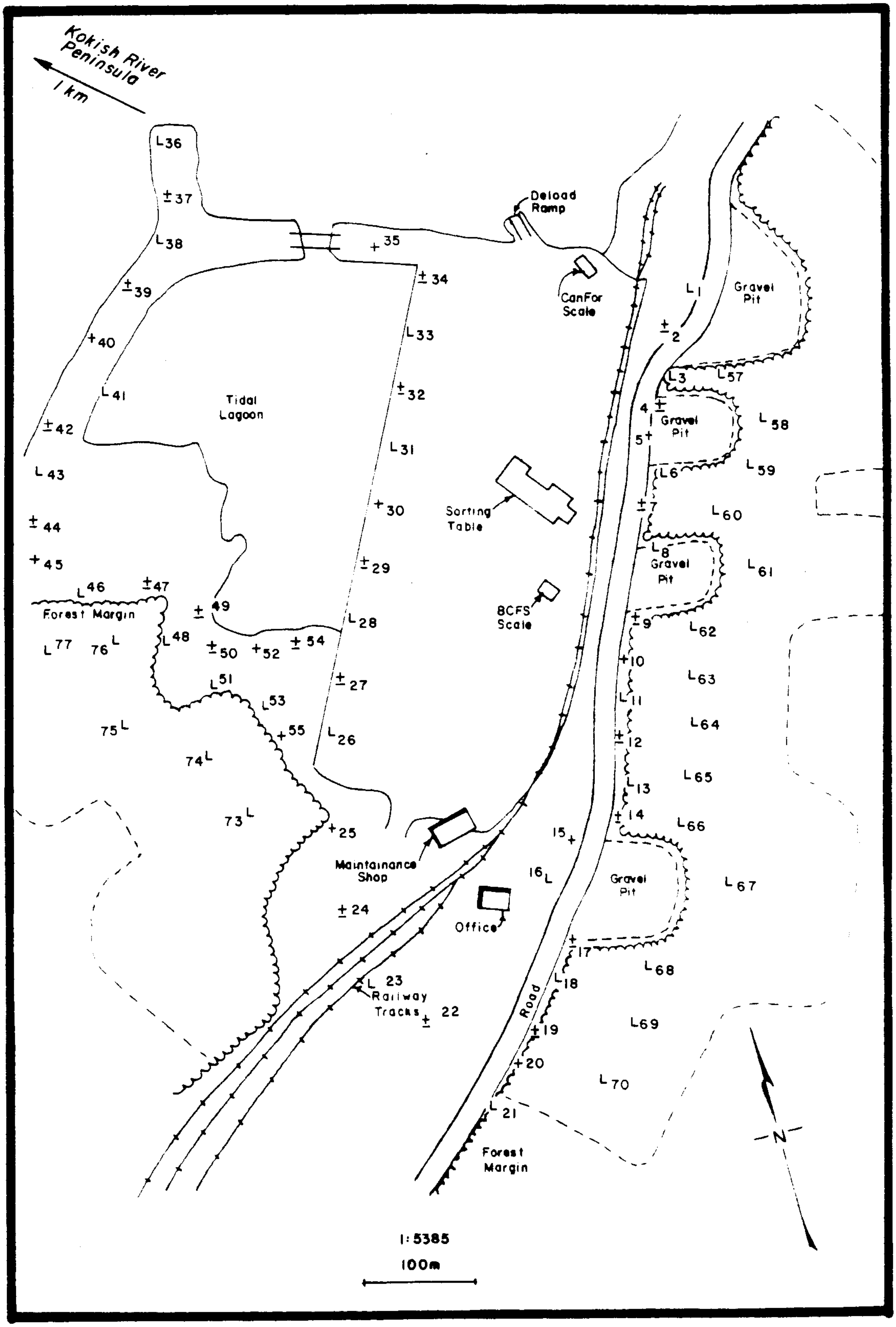


FIG 4

Fig. 5. Locations of 74 Scandinavian drainpipe traps in 1980 at the Beaver Cove dryland sort. L = lineatin-baited trap; ± = (±)-sulcatol-baited trap; + = *S*-(+)-sulcatol-baited trap. Numbers refer to trap number. (Note that there are no trap numbers 56, 71, 72.)


Kokish River Peninsula
1 km
L36
±37
L38
±39
+40
L41
±42
L43
±44
+45
L46
±47
Forest Margin
±49
L48
L77
76L
±50
+52
±54
L51
L53
+55
75L
74L
73L
+25
Tidal Lagoon
+35
±34
L33
±32
L31
+30
±29
L28
±27
L26
Deload Ramp
CanFor Scale
Sorting Table
BCFS Scale
Maintainance Shop
±24
Office
L23
Railway Tracks
±22
Road
L1
±2
Gravel Pit
L3
L57
4±
Gravel Pit
5+
L58
L6
L59
±7
L60
L8
Gravel Pit
L61
±9
L62
+10
L63
L11
L64
±12
L13
L65
±14
L66
15+
16L
Gravel Pit
L67
±17
L68
L18
+19
L69
+20
L70
L21
Forest Margin
N
1:5385
100m

Collecting bottles on the traps contained water, detergent to reduce surface tension, and sodium azide (40 mg/l) to prevent bacterial and fungal growth.

Four additional traps of each bait type were placed in 4 different locations in order to monitor the population of all 3 species at varying locations away from the dryland sort. Location 1 was 800 m east of the dryland sort (trap nos. 78-80); location 2 was 1 000 m north of the dryland sort (trap nos. 81-83); location 3 was 600 m south of the sort (trap nos. 84-86); and location 4 was 1 000 m west of the sort on the Kokish River Peninsula (trap nos. 87-89).

Beetles were collected for the first time in 1980 on April 25 from traps 26-35 (Fig. 5) and from all traps beginning on April 29. Catches for all traps for the periods March 29 to April 25 and April 26-29 were estimated on the basis of the relative catches of traps 26-35 for the 2 periods. Thereafter all traps were monitored on an approximately weekly basis, from April 30 to September 3, 1980. A final collection was made on October 17, 1980. Beetles were stored in 70% ethanol until counted. Very large trap catches were estimated by volumetric measures following sampling to determine volume content for each species ($\bar{X}$ = 126.0 _T. lineatum_/ml, S.D. = 5.6, N = 10; $\bar{X}$ = 139.6 _G. sulcatus_/ml, S.D. = 12.0, N = 10). Sex ratios were estimated every second week by sex determination of not less than 100 beetles/trap.

Daily maximum and minimum temperatures at the dryland sort were recorded from April 3 to September 12, 1980.

Fibreglass mesh vane traps (Fig. 6) were chosen in 1981 as the most efficient trap type available (J. A. McLean[5], pers. comm.). On March 20th, 26 vane traps were positioned around the perimeter of the dryland sort (Fig. 7). Twenty-four were baited with a combination of lineatin, (±)-sulcatol, ethanol, and α-pinene, and 2 were baited with a combination of lineatin, S-(+)-sulcatol, ethanol, and α-pinene to achieve binary trapping systems for T. lineatum and G. sulcatus, and T. lineatum and G. retusus, respectively (Borden et al. 1982).

Ten wire mesh cylinder traps (Fig. 8) were baited with lineatin and placed 30-50 m inside the forest margin to the east of the dryland sort (Fig. 7) to maximize the trapping of T. lineatum (Lindgren 1982). Three additional cylinder traps were baited with lineatin and placed on the peninsula to the west of the dryland sort. All traps were coated with Stikem Special (Seabright Enterprises, Emeryville, California).

Lineatin and sulcatol were released as in 1980. Ethanol and α-pinene were released at "low" release rates of 120 and 17.5 mg/day, respectively (Borden et al. 1982) from capped vials with a 1.77 mm^2 drilled aperture.

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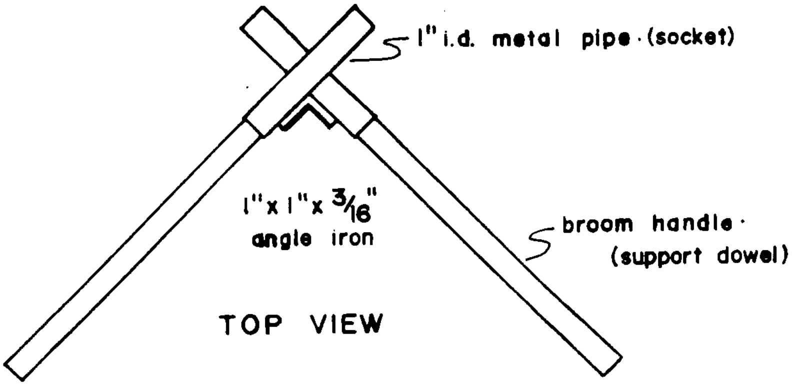
[5] J. A. McLean, Faculty of Forestry, Univ. of B.C., Vancouver, B.C.

Fig. 6. Diagram of vane trap used in 1981 at the Beaver Cove dryland sort.


1" i.d. metal pipe · (socket)
1" x 1" x 3/16"
angle iron
broom handle ·
(support dowel)

TOP VIEW

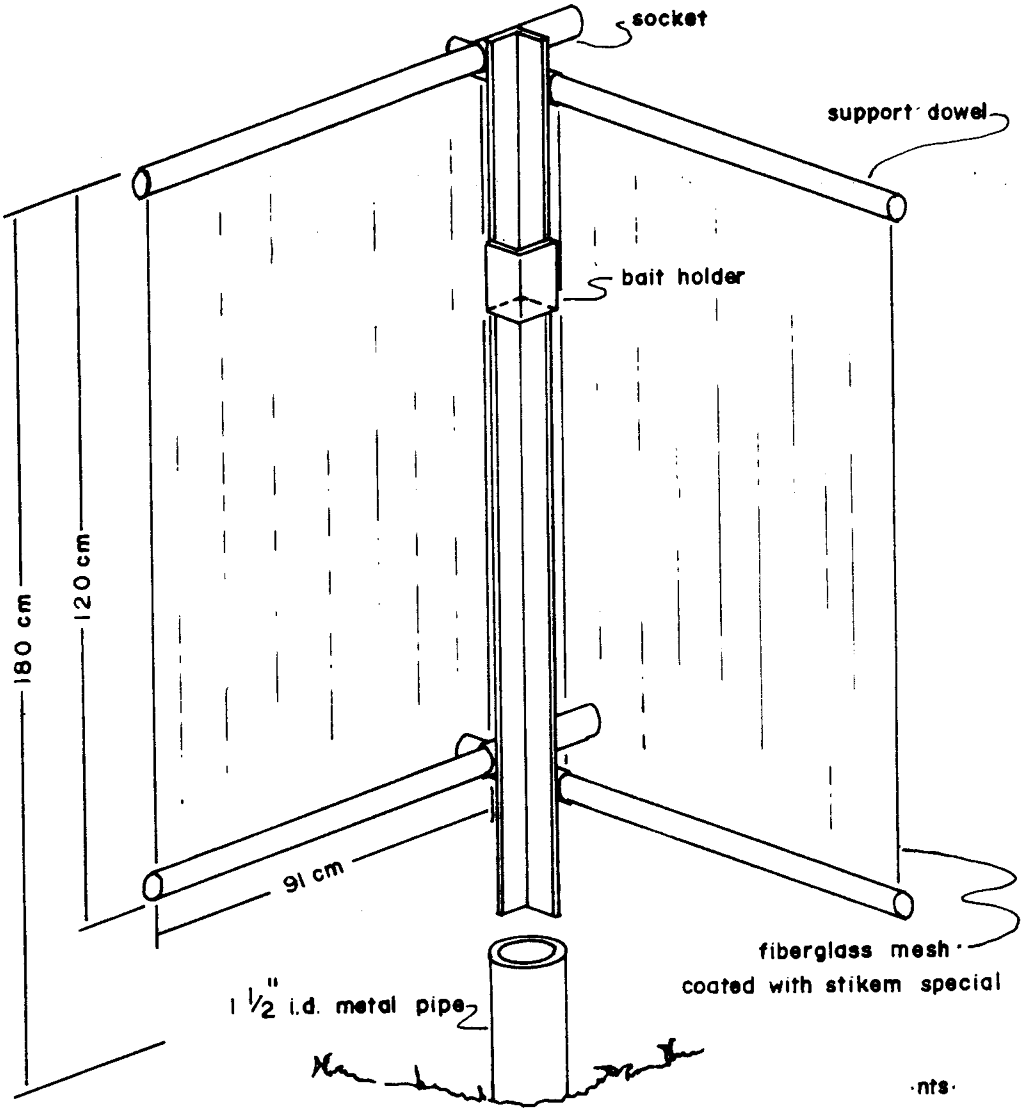

socket
support dowel
bait holder
180 cm
120 cm
91 cm
fiberglass mesh ·
coated with stikem special
1 1/2" i.d. metal pipe
·nts·

Fig. 7. Trap placement in 1981 at the Beaver Cove dryland sort. L = lineatin-baited cylinder trap; L/± = lineatin and (±)-sulcatol-baited vane trap; L/+ = lineatin and *S*-(+)-sulcatol-baited vane trap. Numbers refer to trap numbers.

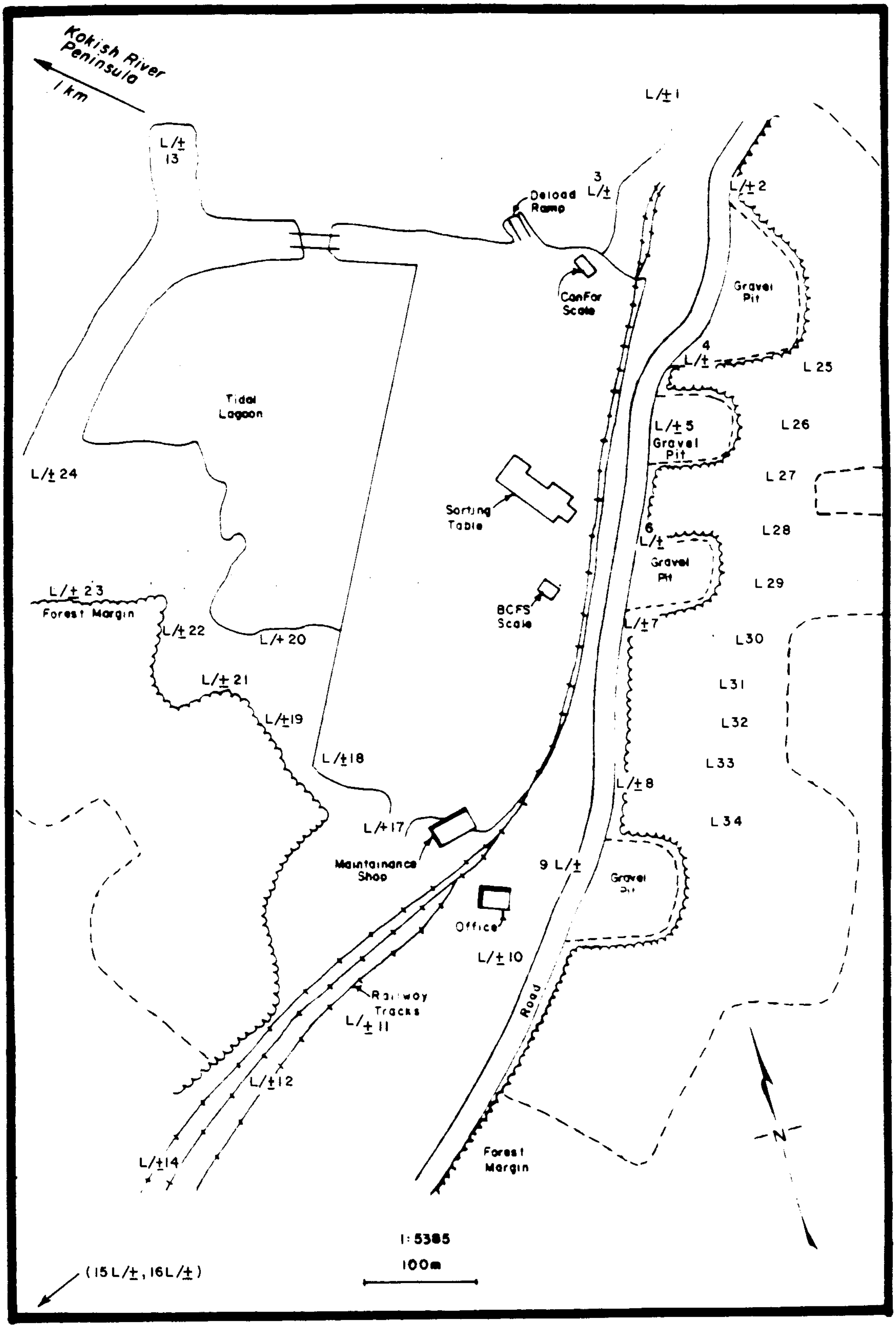
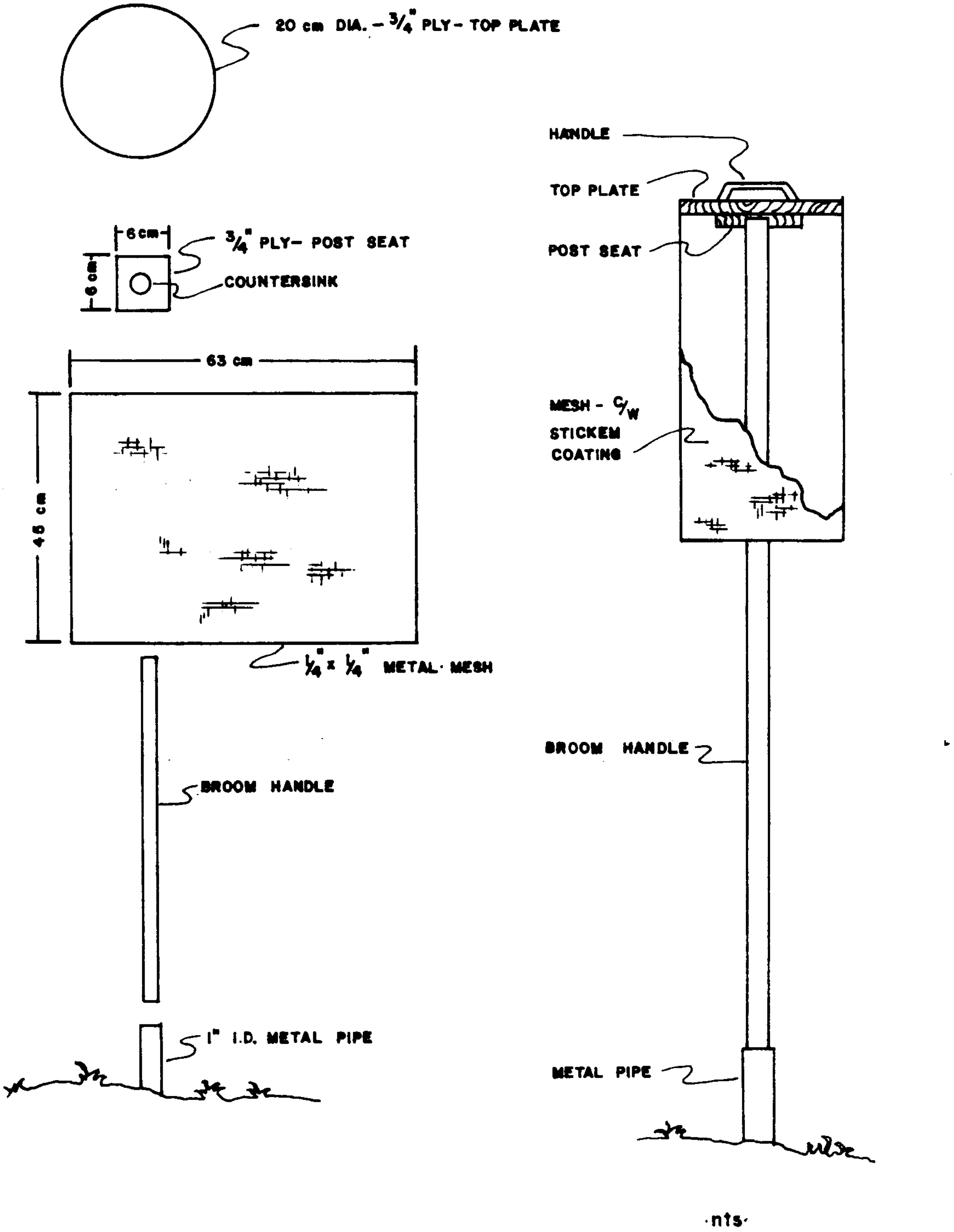

Kokish River Peninsula
1 km
L/± 1
L/± 13
3 L/±
Deload Ramp
L/± 2
ConFor Scale
Gravel Pit
4 L/±
L 25
Tidal Lagoon
L/± 5 Gravel Pit
L 26
L/± 24
L 27
Sorting Table
6 L/±
L 28
Gravel Pit
L 29
L/± 23
Forest Margin
BCFS Scale
L/± 22
L/+ 20
L/± 7
L 30
L/± 21
L 31
L/±19
L 32
L/±18
L 33
L/± 8
L/+17
L 34
Maintainance Shop
9 L/±
Gravel Pit
Office
L/± 10
Railway Tracks
L/± 11
Road
L/± 12
N
Forest Margin
L/±14
1:5385
100m
(15 L/±, 16 L/±)

Fig. 8. Diagram of wire mesh cylinder trap used in 1981 at the Beaver Cove dryland sort.


20 cm DIA. – 3/4" PLY – TOP PLATE
6 cm
6 cm
3/4" PLY – POST SEAT
COUNTERSINK
63 cm
45 cm
1/4" x 1/4" METAL MESH
BROOM HANDLE
1" I.D. METAL PIPE
HANDLE
TOP PLATE
POST SEAT
MESH – C/W STICKEM COATING
BROOM HANDLE
METAL PIPE
·nts·

Traps were replaced as their condition required and finally removed on October 13, 1981. Catches on vane traps were estimated, without regard to species or sex, by a regression estimation equation (Fig. 9) developed from a sample of 9 vanes selected to give a wide range of beetle catches. These vanes were divided into 144 squares (10 X 10 cm). Beetles counted on 4 squares/vane, each located 3 squares down and 3 squares across from a corner of the vane, gave a highly significant regression estimate.

3.2 Results and Discussion

3.2.1 Catches in 1980

A total of 456,959 beetles, composed of 327,182 *T. lineatum*, 125,593 *G. sulcatus*, and 4,184 *G. retusus* were captured in pheromone-baited traps between March 29 and October 17, 1980. Periods of highest catch rate were April 30 to May 6 for *T. lineatum* (Table IV), July 17 to 25 for *G. sulcatus* (Table V), and June 3 to 10 for *G. retusus* (Table VI). The male:female ratio of captured *T. lineatum* showed a definite declining trend through the season, from a high of 3.83:1 (April 26-April 29) to a low of 0.69:1 (Aug. 20-Aug. 25) (Table IV), while the sex ratio of captured *G. sulcatus* remained more constant ($\bar{X}$ = 0.67:1) (Table V). An irregular trend in the sex ratio of captured *G. retusus* throughout the summer ($\bar{X}$ = 0.78:1) (Table VI) may be attributable to the small numbers caught.

Fig. 9. Regression estimate and equation from 9 sample vanes.

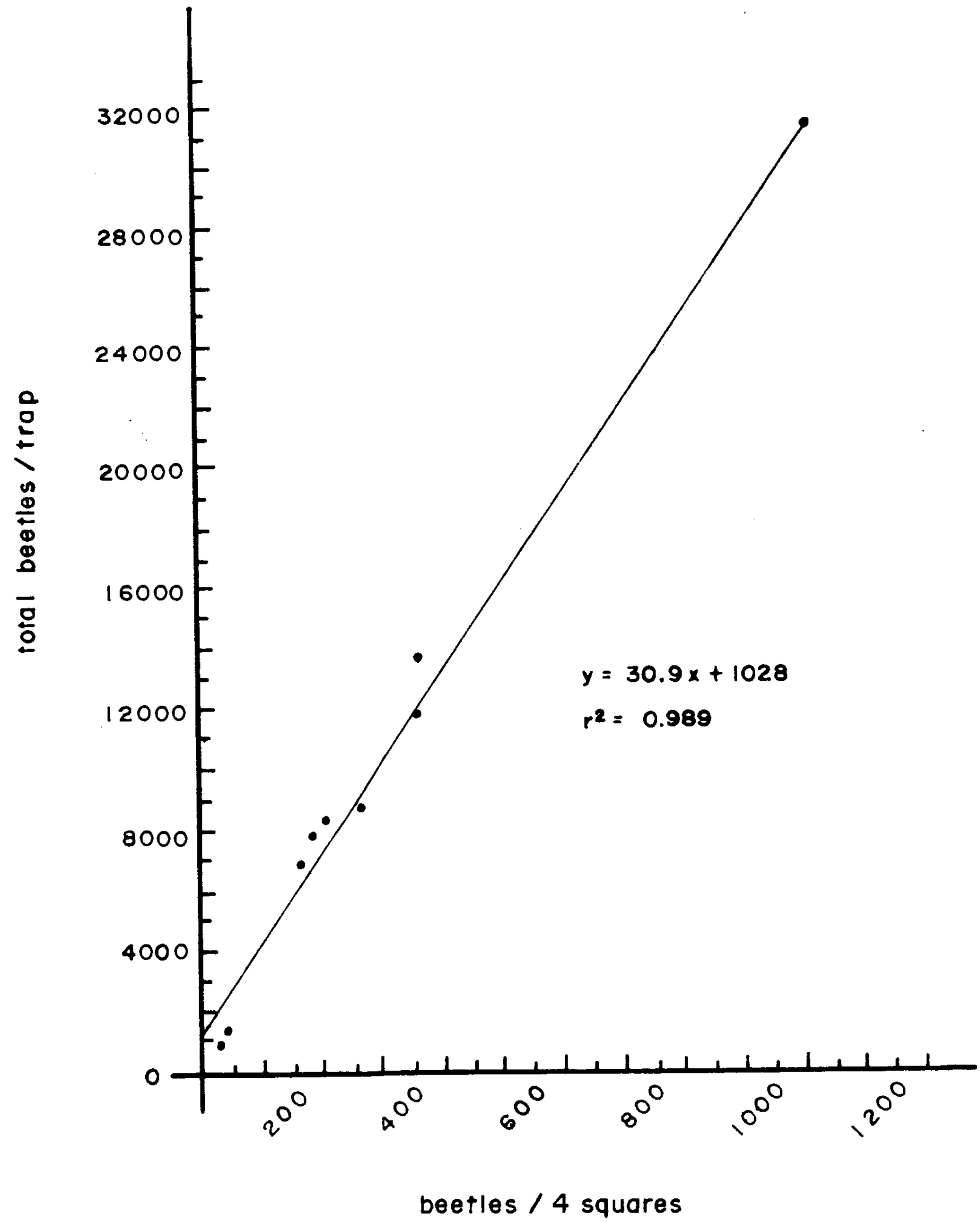

total beetles / trap
32000
28000
24000
20000
16000
12000
8000
4000
0
200
400
600
800
1000
1200
beetles / 4 squares
y = 30.9 x + 1028
r² = 0.989

Table IV. Results of pheromone trapping of *T. lineatum*.
March 29-October 17, 1980. Beaver Cove dryland sort.

Catch period	No. of beetles captured	Catch/day	Sex ratio (♂:♀)
March 29-April 25	16,383	585	3.70
April 26-April 29	789	197	3.85
April 30-May 6	97,147	13,878	3.10
May 7-May 13	67,922	9,703	-
May 14-May 20	6,249	893	1.94
May 21-May 27	4,738	677	-
May 28-June 2	3,350	558	2.49
June 3-June 10	69,078	8,635	-
June 11-June 17	11,230	1,604	1.95
June 18-June 24	14,546	2,078	-
June 25-July 2	8,693	1,087	1.40
July 3-July 9	3,383	483	-
July 10-July 16	1,519	217	1.62
July 17-July 25	16,618	1,846	-
July 26-Aug. 1	2,074	296	1.25
Aug. 2-Aug. 6	767	153	-
Aug. 7-Aug. 13	2,051	293	1.02
Aug. 14-Aug. 19	199	33	-
Aug. 20-Aug. 25	28	5	0.69
Aug. 26-Sept. 3	33	4	-
Sept. 4-Oct. 17	385	9	1.97
Total	327,182		2.70

Table V. Results of pheromone trapping of *G. sulcatus*. March 29-October 17, 1980. Beaver Cove dryland sort.

Catch period	No. of beetles captured	Catch/day	Sex ratio (♂:♀)
March 29-April 25	368	13	0.90
April 26-April 29	520	130	0.48
April 30-May 6	16,883	2,412	0.54
May 7-May 13	4,884	698	-
May 14-May 20	5,911	844	0.58
May 21-May 27	1,372	196	-
May 28-June 2	9,276	1,546	0.65
June 3-June 10	15,338	1,917	-
June 11-June 17	2,445	349	0.88
June 18-June 24	5,164	738	-
June 25-July 2	2,570	321	0.74
July 3-July 9	3,498	500	-
July 10-July 16	7,292	1,042	0.67
July 17-July 25	23,991	2,666	-
July 26-Aug. 1	1,500	214	0.64
Aug. 2-Aug. 6	1,146	229	-
Aug. 7-Aug. 13	1,886	269	1.02
Aug. 14-Aug. 19	1,181	197	-
Aug. 20-Aug. 25	339	57	0.70
Aug. 26-Sept. 3	1,594	177	-
Sept. 4-Oct. 17	18,435	419	1.60
Total	125,593		0.67

Table VI. Results of pheromone trapping of G. retusus. March 29-October 17, 1980. Beaver Cove dryland sort.

Catch period	No. of beetles captured	Catch/day	Sex ratio (♂:♀)
March 29-April 25	4	1	1.00
April 26-April 29	4	1	∞
April 30-May 6	421	60	0.52
May 7-May 13	282	40	-
May 14-May 20	164	23	0.66
May 21-May 27	32	5	-
May 28-June 2	166	28	1.04
June 3-June 10	1,895	237	-
June 11-June 17	197	28	1.11
June 18-June 24	307	44	-
June 25-July 2	223	28	0.73
July 3- July 9	82	12	-
July 10-July 16	48	7	0.88
July 17-July 25	253	28	-
July 26-Aug. 1	14	2	0.75
Aug. 2-Aug. 6	10	2	-
Aug. 7-Aug. 13	17	2	1.83
Aug. 14-Aug. 19	12	2	-
Aug. 20-Aug. 25	3	1	2.00
Aug. 26-Sept. 3	3	1	-
Sept. 4-Oct. 17	47	1	4.33
Total	4,184		0.78

A comparison of the mean maximum and mean minimum temperatures for each trapping period with the catch rate for that period (Fig. 10) supports the flight temperature threshold of 16°C for *T. lineatum* reported by Nijholt (1978a) and suggests a similar threshold temperature for *G. sulcatus* (Fig. 11), and *G. retusus* (Fig. 12). Thus what appears to be 2 separate spring flights of *T. lineatum* is actually a single flight interrupted by cool weather. June 10 marked the true end of the main flight and numbers captured declined thereafter despite temperatures above 16°C except for a small peak from July 17-25 probably due to re-emergent parent beetles.

Similarly, the *G. sulcatus* spring flight was interrupted by below threshold temperature and appears as 2 separate flights (Fig. 11). The large summer peak probably represents progeny from the first spring "flight", while the majority of the progeny from the second spring "flight" probably overwintered in their host logs.

G. retusus appeared to have only one major flight in the spring, a similar result to that found by Lindgren and Borden (1983) in southern Vancouver Island. This flight was also interrupted by cool temperatures during trapping periods from May 7 to May 27 (Fig. 12).

Lineatin-baited traps placed along or within the forest margin at the northeast corner of the dryland sort were among those with the highest total catches of *T. lineatum*. Trap numbers 1, 6, 57, 64, 63, and 62 (Fig. 5) had 6 of the 8 highest total catches of *T. lineatum*.

Fig. 10. Comparison of the catch/day of *T. lineatum* with the mean maximum and mean minimum temperature for each trapping period. March 29-October 17, 1980. Beaver Cove dryland sort. Temperatures were not available for the September 4-October 17 period.

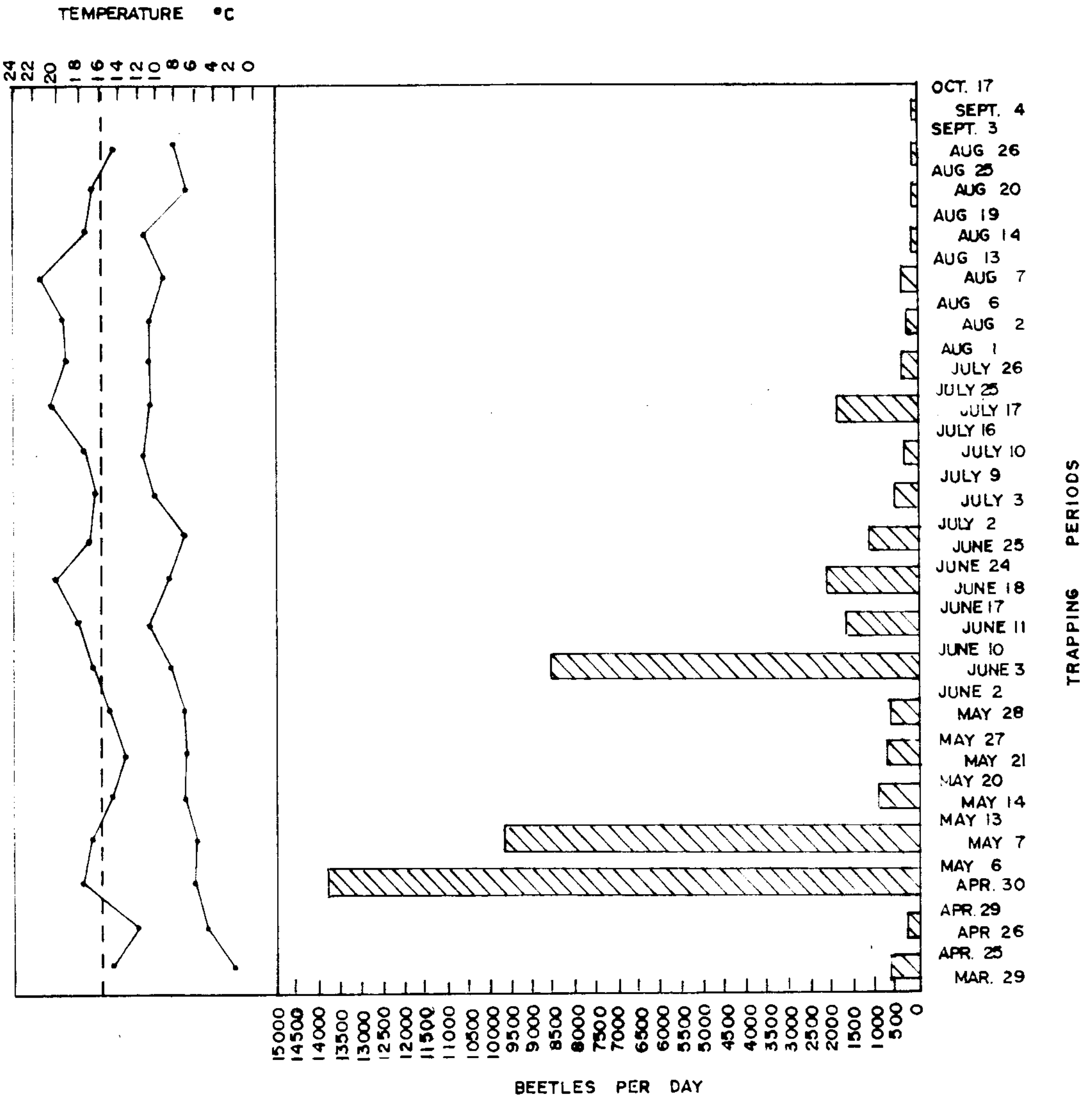

TEMPERATURE °C
24 22 20 18 16 14 12 10 8 6 4 2 0
OCT. 17
SEPT. 4
SEPT. 3
AUG 26
AUG 25
AUG 20
AUG 19
AUG 14
AUG 13
AUG 7
AUG 6
AUG 2
AUG 1
JULY 26
JULY 25
JULY 17
JULY 16
JULY 10
JULY 9
JULY 3
JULY 2
JUNE 25
JUNE 24
JUNE 18
JUNE 17
JUNE 11
JUNE 10
JUNE 3
JUNE 2
MAY 28
MAY 27
MAY 21
MAY 20
MAY 14
MAY 13
MAY 7
MAY 6
APR. 30
APR. 29
APR 26
APR. 25
MAR. 29
TRAPPING PERIODS
15000 14500 14000 13500 13000 12500 12000 11500 11000 10500 10000 9500 9000 8500 8000 7500 7000 6500 6000 5500 5000 4500 4000 3500 3000 2500 2000 1500 1000 500 0
BEETLES PER DAY

Fig. 11. Comparison of the catch/day of _G. sulcatus_ with the mean maximum and mean minimum temperature for each trapping period. March 29-October 17, 1980. Beaver Cove dryland sort. Temperatures were not available for the September 4-October 17 period.

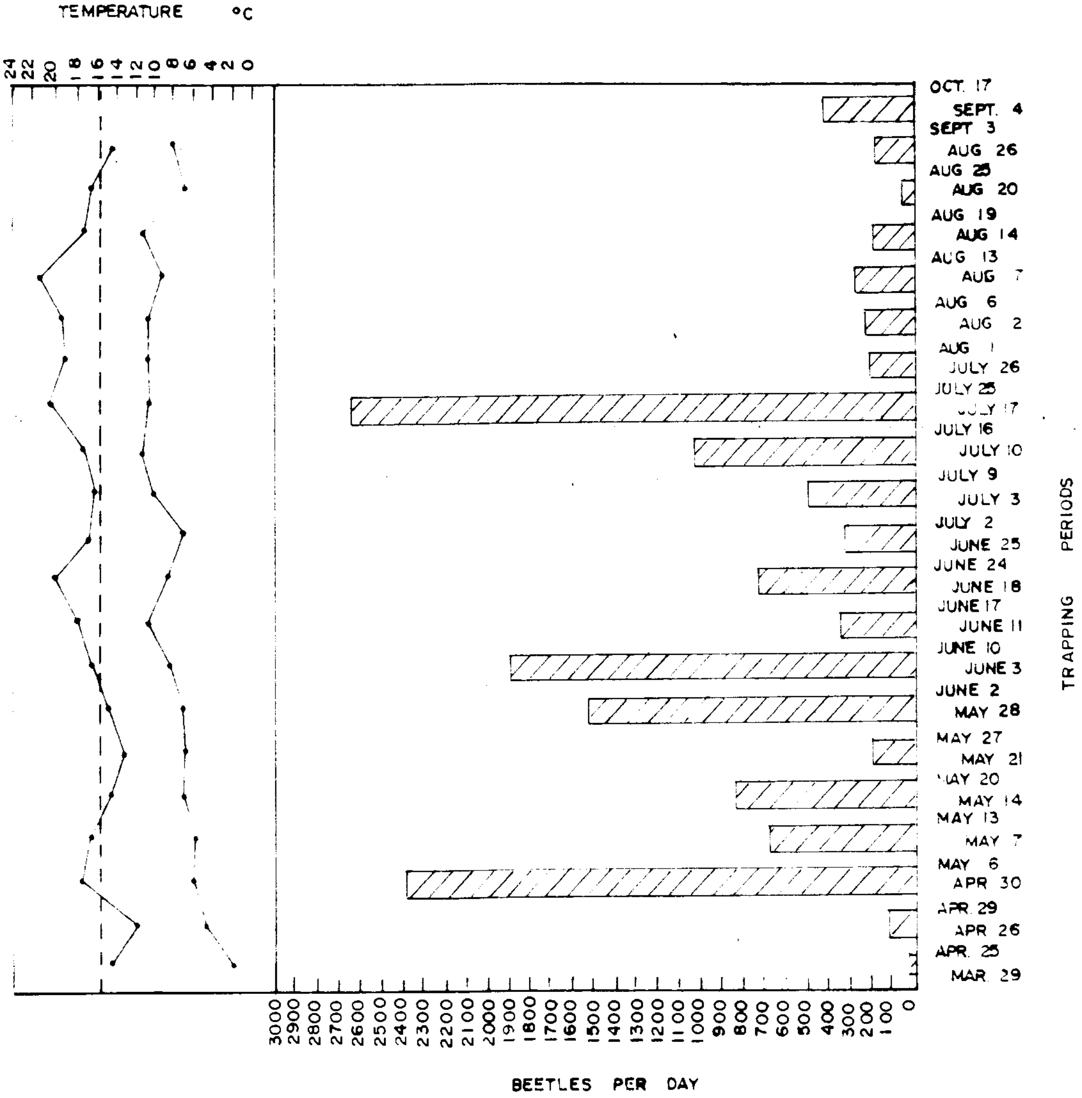
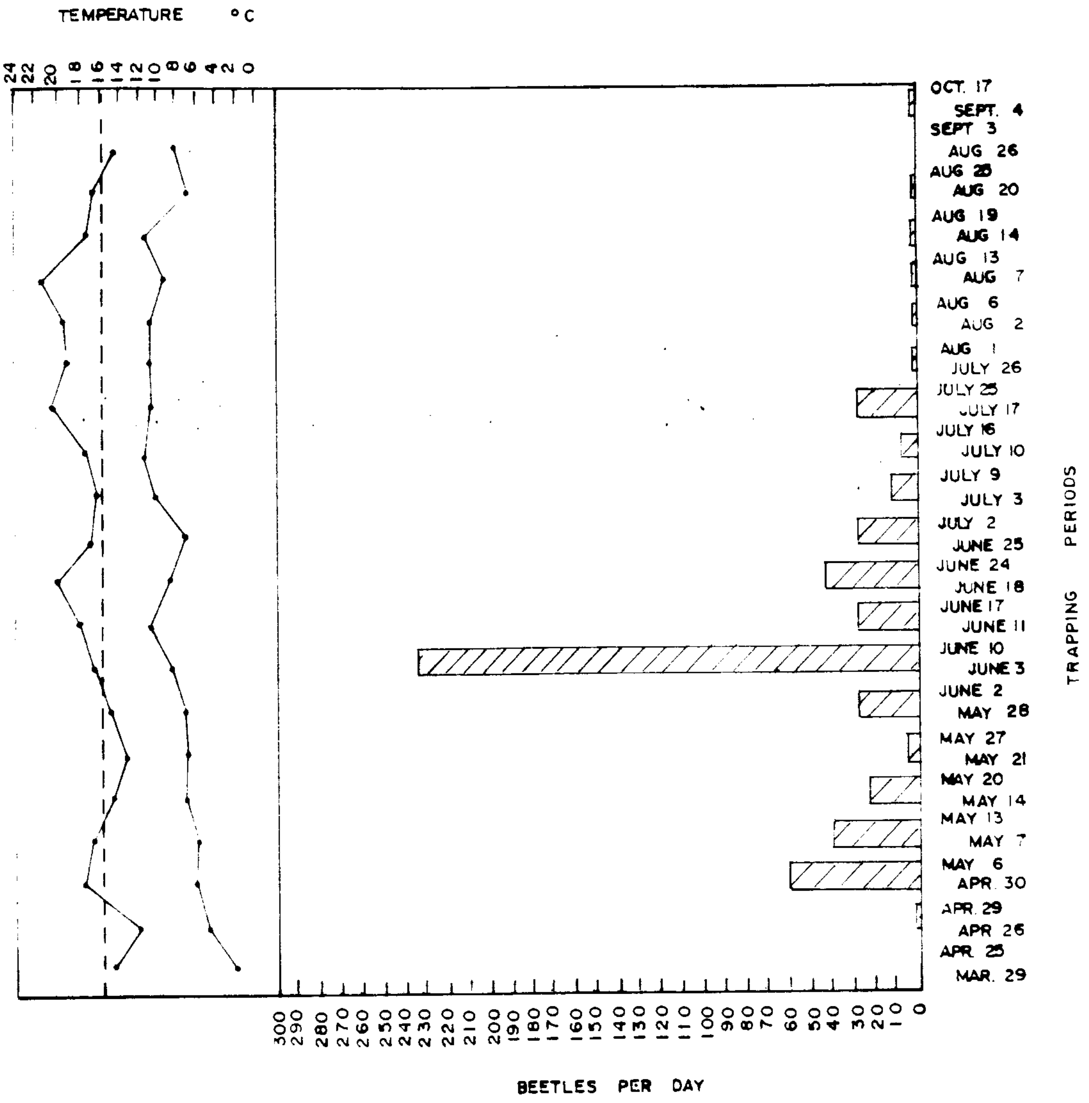

TEMPERATURE °C
24
22
20
18
16
14
12
10
8
6
4
2
0
OCT. 17
SEPT. 4
SEPT 3
AUG 26
AUG 25
AUG 20
AUG 19
AUG 14
AUG 13
AUG 7
AUG 6
AUG 2
AUG 1
JULY 26
JULY 25
JULY 17
JULY 16
JULY 10
JULY 9
JULY 3
JULY 2
JUNE 25
JUNE 24
JUNE 18
JUNE 17
JUNE 11
JUNE 10
JUNE 3
JUNE 2
MAY 28
MAY 27
MAY 21
MAY 20
MAY 14
MAY 13
MAY 7
MAY 6
APR 30
APR 29
APR 26
APR. 25
MAR. 29
TRAPPING PERIODS
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
BEETLES PER DAY

Fig. 12 Comparison of the catch/day of _G. retusus_ with the mean maximum and mean minimum temperature for each trapping period. March 29-October 17, 1980. Beaver Cove dryland sort. Temperatures were not available for the September 4-October 17 period.


TEMPERATURE °C
24
22
20
18
16
14
12
10
8
6
4
2
0
OCT. 17
SEPT. 4
SEPT 3
AUG 26
AUG 25
AUG 20
AUG 19
AUG 14
AUG 13
AUG 7
AUG 6
AUG 2
AUG 1
JULY 26
JULY 25
JULY 17
JULY 16
JULY 10
JULY 9
JULY 3
JULY 2
JUNE 25
JUNE 24
JUNE 18
JUNE 17
JUNE 11
JUNE 10
JUNE 3
JUNE 2
MAY 28
MAY 27
MAY 21
MAY 20
MAY 14
MAY 13
MAY 7
MAY 6
APR. 30
APR. 29
APR. 26
APR. 25
MAR. 29
TRAPPING PERIODS
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
BEETLES PER DAY

Trap number 88, placed on the peninsula across the Kokish River and trap number 26, placed in the southwest corner of the dryland sort, had the highest and fourth highest catches, respectively, of *T. lineatum* (Table VII).

The pattern of trap catches was somewhat similar for *G. sulcatus*. Trap number 4, adjacent to the northeast corner of the dryland sort, and trap number 54 (Fig. 5), adjacent to the southwest corner of the dryland sort, had the highest and second highest total catches, respectively, of *G. sulcatus*. Together with trap numbers 9 and 50 (also in the same areas), they accounted for 4 of the 5 highest total trap catches. Trap number 17 had the fourth highest total catch of *G. sulcatus* (Table VIII).

Trap number 25 (Fig. 5) caught far more *G. retusus* than any other trap, accounting for 47% of the total for all 15 traps baited with *S*-(+)-sulcatol (Table IX).

It is impossible to conclude what might be responsible for the pattern of trap catches since there was no systematic testing of the numerous variables. Certainly the location of overwintering populations, position of brood-producing material at the time of emergence, proximity of competing natural pheromone sources, interference of brush with the traps, and wind direction might be included among those variables having an influence on trap-catching performance.

Table VII. Ranked individual trap catches of *T. lineatum*. March 29-October 17, 1980. Beaver Cove dryland sort. Trap locations shown in Fig. 5.

Trap no.	Total catch	Trap no.	Total catch
88	19,136	85	5,296
1	18,536	68	5,159
6	17,902	46	5,049
26	16,959	53	4,995
57	15,863	77	4,509
64	15,680	65	4,432
63	13,607	31	4,394
62	13,177	76	4,239
41	11,628	38	3,662
48	11,486	67	3,614
60	11,423	66	3,524
58	8,825	51	3,421
59	8,707	70	3,316
81	7,926	16	3,303
3	7,894	28	2,684
74	7,751	21	2,576
43	7,405	8	2,427
11	6,909	75	2,097
73	6,770	79	1,838
13	6,695	33	1,766
23	6,665	36	1,547
69	5,956	61	815
18	5,619		
		Total	327,182

Table VIII. Ranked individual trap catches of G. sulcatus. March 29-October 17, 1980. Beaver Cove dryland sort. Trap locations shown in Fig. 5.

Trap no.	Total catch	Trap no.	Total catch
4	15,143	12	2,900
54	12,177	44	2,865
9	11,332	47	2,771
17	11,245	49	2,645
50	9,189	42	1,689
19	8,338	29	1,444
2	7,506	32	1,216
24	6,517	34	1,012
22	5,894	87	962
82	5,828	80	388
14	3,828	39	309
7	3,628	37	252
27	3,517		
86	2,998		
		Total	125,593

Table IX. Ranked individual trap catches of _G. retusus_. March 29-October 17, 1980. Beaver Cove dryland sort. Trap locations shown in Fig. 5.

Trap no.	Total catch	Trap no.	Total catch
25	1,946	30	127
52	440	84	127
15	385	35	51
20	237	40	46
45	231	83	9
55	226	78	8
5	213	89	8
10	130		
		Total	4,184

3.2.2 Catches in 1981

Trap catches for 1981 totalled 870,947 beetles, 91% greater than in 1980. The patterns of trap catches for 1980 and 1981 are somewhat similar. Direct comparisons cannot be made due to the binary baiting system of 1981 and absence of species identification, but as in 1980, the traps adjacent to the southwest corner of the dryland sort and along the forest margin east and south of the dryland sort had the highest catches. Trap number 18 in the southwest corner of the dryland sort (Fig. 7) caught 12% of the total catch for vane traps (Table X).

In addition to those variables cited above as having a probable influence on the 1980 trapping results, the condition of individual traps varied in 1981 due to dust, brush, captured beetles, and animal damage influencing the sticky nature of the traps. Trap numbers 35, 36, and 37, placed on the peninsula across the Kokish River, caught only 1,342 beetles, 0.15% of the total catch. This area had yielded the single highest trap catch in 1980. All 3 traps suffered repeated animal damage in 1981.

In contrast to 1980 results, lineatin-baited traps placed inside the forest margin did not perform well in 1981. All cylinder traps ranked lower than the poorest vane trap (Table X).

Table X. Ranked individual trap catches of all 3 species. March 20-October 13, 1981. Beaver Cove dryland sort. Trap locations shown in Fig. 7.

Trap no.	Trap type[a]	Total catch	Trap no.	Trap type[a]	Total catch
18	v	101,130	20	v	15,758
9	v	65,328	24	v	13,089
6	v	61,384	16	v	12,135
5	v	59,809	15	v	12,724
17	v	51,214	13	v	11,126
7	v	43,372	29	c	7,938
3	v	40,360	30	c	6,833
8	v	39,243	25	c	5,930
21	v	39,218	26	c	5,019
4	v	37,080	27	c	4,744
11	v	33,721	34	c	4,583
2	v	31,041	28	c	4,122
10	v	21,736	33	c	3,058
12	v	20,041	32	c	2,698
1	v	18,267	31	c	1,426
14	v	18,220	36	c	1,052
23	v	17,037	37	c	290
19	v	16,956	35	c	damaged
22	v	16,494	unknown[b]	v	26,771
			Total		870,947

[a] v = vane trap
c = cylinder trap

[b] 6 vanes were unidentified as to trap location

4. DAMAGE ASSESSMENT AND DEGRADE VALUE

4.1 Materials and Methods

The damage to logs caused by ambrosia beetle attack in 1980 and the division of this damage into that suffered prior to log arrival at the dryland sort (forest damage) and that suffered while the logs remained at the dryland sort (sort damage) was determined in the following manner.

The number of pieces of each species-grade in each of 87 booms examined was estimated by dividing the total volume of the species-grade present in the boom (obtained through company boom information) by the average piece size of the species-grade (obtained through a sample of Ministry of Forests scales). Average dimensions and calculated average volumes for the 8 species-grades are shown in Table XI. Although Douglas-fir peelers were not scaled as a separate sort by Ministry of Forests scalers, Industrial Grading Rules indicated that Douglas-fir peeler 1 must meet the minimum dimensions of Douglas-fir 1 and that Douglas-fir peelers 2, 3, 4 and 5 must meet the minimum dimensions of a Douglas-fir 2 log. Therefore, the average dimensions of a Douglas-fir 1 log have been used for Douglas-fir peeler 1 and the average dimensions of a Douglas-fir 2 log have been used for Douglas-fir peelers 2, 3, 4 and 5.

The pieces of each species-grade present in an examined boom

Table XI. Average dimensions and calculated volume for each species-grade. April 30-June 16, 1980. Beaver Cove dryland sort.

Species-grade		No. of sample logs	Mean dimensions[a] Length (m)	Top radius (cm)	Butt radius (cm)	vol.[b] (m^3)
Western hemlock	1	7	12.43(0.57)	0.41(0.05)	0.45(0.05)	7.24
	2	32	11.92(1.27)	0.34(0.04)	0.39(0.04)	5.01
	3	49	9.23(3.10)	0.17(0.09)	0.21(0.10)	1.06
	4	39	6.40(2.94)	0.16(0.08)	0.20(0.10)	0.66
Douglas-fir	1	1	10.80	0.50	0.58	9.95
	2	42	13.19(3.91)	0.23(0.09)	0.29(0.10)	2.84
	3	39	10.03(4.12)	0.15(0.05)	0.20(0.06)	0.98
	4	32	4.86(2.02)	0.21(0.17)	0.24(0.17)	0.78

[a] standard deviations given in parentheses

[b] volume calculated from mean dimensions

were then divided into exposed or submerged portions by the visual estimation that 40% of the pieces of a Douglas-fir boom and 35% of the pieces of a western hemlock boom were above water and exposed.

Total damage (forest plus sort damage) on the exposed portion of a boom was estimated as close to the removal date as possible. A minimum sample of 50 randomly chosen logs from each boom was examined for external signs of ambrosia beetle attack (boring dust and pinholes). The attack level (proportion of sample logs with signs of attack) was then used to estimate the number of attacked pieces of each species-grade in the exposed portion of a boom.

Total damage on the submerged portion of a boom was estimated by examining a total of 839 logs for external signs of ambrosia beetle attack as they arrived by train at the dryland sort. All western hemlock logs visible on the rail cars arriving within each of 7 periods, each approximately one week long, constituted a sample. Similarly, Douglas-fir logs constituted another set of samples. The attack level of the sample examined during the assembly period of a boom was used to estimate the number of attacked pieces of each species-grade in the submerged portion. The assembly period was estimated by the known date of completion from company boom information and company production records for the period of the study.

It was impossible to sample the submerged portion of a boom for sort damage due to the constraints imposed by the operation of the dryland sort. Sort damage was calculated only on the exposed portion of a boom and was equal to the number of attacked pieces in the exposed portion of the boom (calculated as above) minus the number of pieces which were attacked prior to their arrival by train at the dryland sort. The number of pieces attacked prior to arrival was estimated by the proportion of logs attacked prior to arrival (same as damage on the submerged portion, explained above) and the number of pieces of each species-grade present in the exposed portion. Forest damage was then calculated as total damage minus sort damage.

Volumes of wood degraded as a result of beetle attack were calculated using the number of attacked pieces of each species-grade, the average dimensions of each species-grade and the depth of ambrosia beetle galleries. McLean (1985) reported gallery depths of 3.0 and 4.0 cm for *T. lineatum* in Douglas-fir and western hemlock, respectively, and 3.0 and 8.0 cm for *G. sulcatus* in Douglas-fir and western hemlock, respectively. Gallery depth for *G. retusus* was assumed to be equal to that of *G. sulcatus*. Based on results of mass trapping during the summer of 1980 the attacking population was estimated to be comprised of 72% *T. lineatum* and 28% *Gnathotrichus* spp.

The calculated volume of degraded wood within a log of a given species-grade was not allowed to exceed the volume of clear wood estimated by Dobie (1975) for sawlogs and Furniss (1982) for peelers. Value lost due to ambrosia beetle degrade was calculated at \$46/m^3 of degraded volume for sawlogs (McLean 1985) and \$232/m^3 of degraded volume for peelers (Furniss 1982).

4.2 Results and Discussion

Although attack was heavy on logs arriving at the dryland sort, the attack levels approximately doubled due to infestations by ambrosia beetles during the formation of the booms (Table XII).

A total of 61,839 western hemlock logs, 6,320 Douglas-fir sawlogs, and 8,004 Douglas-fir peelers were in the booms sampled. Sampling indicated that 15,543 (25.1%) of the western hemlock logs, 1,204 (19.1%) of the Douglas-fir sawlogs, and 1,541 (19.3%) of the Douglas-fir peelers were attacked. Sort damage accounted for 51.6% of the western hemlock attack, 65.9% of the Douglas-fir sawlog attack and 69.2% of the Douglas-fir peeler attack (Table XIII).

A total of 105 380 m^3 was within sampled booms. Within the 20 315 m^3 of attacked western hemlock logs 1 436 m^3 (7.1%) was degraded volume, constituting a total loss to degrade of \$66,050. Within the 2 040 m^3 of attacked Douglas-fir sawlogs 160 m^3 (7.8%) was degraded volume for a total loss of \$7,354. Within the 1 434 m^3 of attacked Douglas-fir peeler logs 88 m^3 (6.1%) was degraded volume for a total loss of \$20,384. Total loss to degrade

Table XII. Comparison of attack levels on sampled logs arriving by train and leaving in booms. April 30-June 16, 1980. Beaver Cove dryland sort.

	No. logs sampled		No. logs attacked		Percent of logs attacked[a]	
Species	Train	Boom	Train	Boom	Train	Boom
Western hemlock	696	4,012	184	1,820	26.4	45.4
Douglas-fir	143	1,081	30	455	21.0	42.9

[a] Significant differences occurred between logs arriving (Train) and leaving (Boom) the dryland sort for each species, χ^2 test, $p < .001$.

Table XIII. Comparison of forest damage and sort damage for each species-grade. April 30-June 16, 1980. Beaver Cove dryland sort.

Species-Grade		Vol. sampled (m3)	Mean vol./log (m3)	Volume attacked (m3)			% of total		Volume (m3) degraded			Value of degrade loss ($)			% of total degrade	
				Total	Forest	Sort	Forest	Sort	Total	Forest	Sort	Total	Forest	Sort	Forest	Sort
Western	1	4 030	7.24	1 006	485	521	48.2	51.8	165	79	86	7,600	3,659	3,941	48.1	51.9
hemlock	2	15 202	5.01	3 928	1 979	1 949	50.4	49.6	541	273	268	24,893	12,543	12,350	50.4	49.6
	3	60 447	1.06	15 190	7 365	7 825	48.5	51.5	729	354	376	33,539	16,262	17,277	48.5	51.5
	4	807	0.65	191	74	117	38.6	61.4	<1	<1	<1	18	7	11	38.9	61.1
Total		80 486		20 315	9 903	10 412	48.4	51.6	1 436	706	730	66,050	32,472	33,578	49.2	50.8
Douglas-	1	249	9.95	50	20	30	40.0	60.0	6	2	4	270	78	192	28.9	71.1
fir	2	6 766	2.84	1 261	474	787	37.6	62.4	131	49	82	6,034	2,273	3,761	37.6	62.3
	3	10 756	0.98	687	227	460	33.1	66.9	21	7	14	949	314	635	33.1	66.9
	4	81	0.78	42	9	34	20.4	79.6	2	1	2	102	20	82	19.6	80.4
Total		17 853		2 040	729	1 311	34.1	65.9	160	58	102	7,354	2,683	4,671	36.5	63.5
Douglas-	1	351	9.95	70	20	50	28.6	71.4	9	3	6	2,128	752	1,376	35.3	64.7
fir	2	565	2.84	136	88	48	64.6	35.4	8	5	3	1,837	1,203	634	65.5	34.5
peeler	3	1 656	2.84	344	162	182	47.0	53.0	20	9	10	4,596	2,167	2,429	47.1	52.9
	4	676	2.84	140	24	116	17.2	82.8	8	1	7	1,878	327	1,551	17.4	82.6
	5	4 066	2.84	744	190	556	25.5	75.4	43	11	32	9,945	2,533	7,412	25.5	74.5
Total		7 314		1 434	482	952	30.8	69.2	88'	30	58	20,384	6,982	13,402	34.3	65.7
TOTAL, ALL SPECIES-GRADES																
		105 653		23 789	11 114	12 675	46.7	53.3	1 684	794	890	93,788	42,137	51,651	44.9	55.1

(all species-grades) was $93,788.

Sort damage accounted for 50.8% of the total degrade value loss in western hemlock, 63.5% in Douglas-fir sawlogs and 65.7% in Douglas-fir peelers. Losses by species-grade are summarized in Table XIII.

During the 7 weeks of the study, an average total loss of \$0.89/m^3 processed was suffered, \$0.40/m^3 prior to arrival at the dryland sort and \$0.49/m^3 at the dryland sort.

In addition to the 87 booms assessed for attack and reported above, 21 booms left the sort without being examined. Forest damage on these booms caused an additional loss of $17,722.

A comparison of potential savings that could have been achieved by protecting different species-grades while at the dryland sort is given in Table XIV. Elimination of all sort damage during the study would have increased product value by $51,651. Although this might have been an unrealistic goal, protecting certain high value booms by water misting (Richmond and Nijholt 1972), and reducing the beetle population at the dryland sort through a pheromone-based mass trapping program (Lindgren and Borden 1983) could have resulted in substantial savings.

For several reasons, the estimates of ambrosia beetle damage in

Table XIV. Comparison of potential savings to be realized by preventing sort damage on different species-grades. April 30-June 16, 1980. Beaver Cove dryland sort.

Species-grade		Volume arriving (m3)	Value of degrade loss, sort damage ($)	Potential saving ratio $/m3
Western	1	4 030	3,941	0.98
hemlock	2	15 202	12,350	0.81
	3	60,447	17,277	0.29
	4	807	11	0.01
Total		80 486	33,578	0.42
Douglas-	1	249	192	0.77
fir	2	6 766	3,761	0.56
	3	10 756	635	0.06
	4	81	82	1.01
Total		17 852	4 671	0.26
Douglas-	1	351	1,376	3.92
fir	2	565	634	1.12
peeler	3	1 656	2,429	1.47
	4	676	1,551	2.29
	5	4 066	7,412	1.82
Total		7 314	13,402	1.83

this study can be considered conservative. These include:

1) The inability to examine the underside of logs, a preferred site of attack (Dyer 1963; McLean and Borden 1977; Lindgren et al. 1982), means that logs reported as unattacked may in fact have had hidden attacks;

2) Many booms were checked a number of days prior to their being towed away; additional attacks during the interim may have added to the losses;

3) Sort damage was calculated as though it occurred only on the exposed portion of a boom. While this is probably very accurate for a common sort, such as "Hemlock Standard", because bundles of these logs were completed and moved to the water quickly where the submerged portion was protected, logs in a less common sort such as "Fir Chip 'n Saw" might have remained unprotected on the sorting grounds for a day. This additional sort damage, while probably small, would add to the total loss and to the proportion of loss caused by sort damage; and

4) Only Douglas-fir and western hemlock were included in the study; other species, e.g., Pacific silver fir, _Abies_ _amabilis_ (Dougl.) Forbes, and Sitka spruce, _Picea_ _sitchensis_ (Bong.) Carr., were also attacked heavily.

5. CONCLUSIONS AND RECOMMENDATIONS

It is evident that significant damage due to ambrosia beetle attack is occurring within the Beaver Cove dryland sort. In addition, beetle attack occurring outside of the dryland sort accounted for almost half of the economic losses while simultaneously replenishing the overwintering population of _T. lineatum_ around the dryland sort and supplying an attacking population of _Gnathotrichus_ spp. For this reason any serious attempt to reduce losses to ambrosia beetles should address those factors which allow beetle attack to occur in the forest.

Despite catching a very large number of beetles in 1980, calculations show that only 5.3% of the maximum or 10.7% of the minimum estimated population of _T. lineatum_ was captured (Tables III, IV). If it is assumed that in 1981 the attacking population was not significantly different, and that 72% of captured beetles were again _T. lineatum_, then serious efforts at mass trapping in 1981 succeeded in capturing only 10.2% of the maximum or 20.4% of the minimum estimated _T. lineatum_ population (Tables III, X). Population reduction is not likely to occur with trapping successes of this magnitude and efforts should be made to improve trapping efficiency.

Estimates in 1980 indicated that stratum 1 contained an overwintering population of _T. lineatum_ approximately 31 times larger than the Kokish Peninsula stratum (stratum 3) (Table III). Yet traps placed between stratum 1 and the dryland sort, and within the stratum captured only 10 times as many _T. lineatum_ as trap 88 on the Kokish Peninsula. If the catches of traps 33, 36, 38 and 41, positioned between the dryland sort and the peninsula are added to trap 88, then the catch comparison drops to 5 times (Table VII). While there may be several reasons for this difference in trapping efficiency, a very probable factor is the number and proximity of competing pheromone sources. As beetles elude the ring of traps placed around the dryland sort, competing pheromone sources will be initiated and the effectiveness of baited traps will decrease. When the traps and point of origin of attacking beetles are far from the dryland sort, as in the case of trap 88, the effect of competing pheromone sources within the dryland sort is less important and a trap can maintain its level of efficiency.

Competing pheromone sources are a greater problem in efforts to trap *Gnathotrichus* spp. where it is not possible to place an intercepting ring of traps between uninfested logs and infested logs containing emerging beetles. Although estimates of the attacking population of *G. sulcatus* and *G. retusus* were not made, it can be strongly suggested on the basis of the probable effect of competing pheromone sources that the trapping efficiency for these 2 species was poorer than for *T. lineatum*.

These facts of economic losses occurring outside the dryland sort, the repopulation of resident *T. lineatum* and supplying of attacking *Gnathotrichus* spp. through forest attack, the relatively poor overall results of mass trapping attempts, and a probable reason for poor and variable mass trapping efforts, are the factors which when taken together support the implementation of a multi-faceted beetle management program [or an integrated pest management (IPM) program]. Such a program might consist of 4 components:

1) Inventory management. This should include not only management of inventory within the dryland sort but also inventory of felled timber in the field. Inventory management within the dryland sort should be aimed at keeping stockpiled logs to a minimum during beetle flight times. This will reduce the potential number of attacking Gnathotrichus spp. that can emerge from infested, stockpiled logs. It will also reduce the amount of uninfested material that can be degraded while beetles are attacking. Finally, during the emergence of T. lineatum from infested material (usually during July/August) it will reduce or eliminate any increase to the resident overwintering T. lineatum population.

Inventory management in the field should be aimed at reducing the amount of felled material during beetle flight times. In particular, material felled from October to March should no longer be present in the field during the T. lineatum flight since this material is the most attractive to T. lineatum (Chapman 1961; Christiansen and Saether 1968; Annila 1975). This will not only reduce the $0.40/m^3 lost due to ambrosia beetle attack, but will also reduce the increase to the resident T. lineatum population in the dryland sort.

2) Product protection. Water misting has been proven to offer effective protection of logs from ambrosia beetle attack (Richmond

and Nijholt 1972; Nijholt 1978b). Product protection will serve not only to reduce product degrade by preventing attack but will probably increase the efficiency of pheromone trapping by reducing the number of competing pheromone sources. While it is not practical to protect all logs within the dryland sort, economic savings can be maximized by protecting the highest value logs. Protection of the 7 314 m^3 of fir peeler logs may have saved $13,402 in product degrade during a seven week period alone (Table XIV). Cost estimates in 1980 for a misting system to protect 2 x 130 m of boomed logs and 2 x 150 m of wind-rowed logs indicated that a capital expenditure of $9,750 and an annual maintainance cost of $5,318 were necessary. Thus such a system would be cost effective soon after implementation.

3) Alteration of overwintering habitat. The best trapping efficiency in 1980 was observed when the distance between traps and competing pheromone sources from the dryland sort was greatest. Kinghorn and Chapman (1959) reported that _T. lineatum_ may travel into the forest searching for an overwintering site until a sufficiently high degree of shade is encountered. Thinning of the stands around the dryland sort would result in beetles travelling farther from the dryland sort in search of an overwintering site and allow trapping to be done within the thinned forest at a greater distance from the dryland sort. Further habitat management may be possible by conducting a light fall burn to remove part of the duff layer and to destroy overwintering _T. lineatum_. Care would need to be exercised so that stress to Douglas-fir trees did not give rise

to an infestation of Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins.

4) Mass trapping. Pheromone-based trapping should be continued to reduce ambrosia beetle attacks. While pheromone trapping in 1980 and 1981 may not have been successful in intercepting a large portion of the *T. lineatum* (or *Gnathotrichus* spp.) population, trapping can be made more efficient by simultaneously utilizing a form of product protection and by alteration of the overwintering habitat. Several additional traps may also be placed within the dryland sort to capture attacking *Gnathotrichus* spp.; most should be baited for *G. sulcatus*. Additional lineatin-baited traps should be placed on the Kokish Peninsula. As Shore and McLean (1983) have shown that the binary trapping systems employed in 1981 are less efficient than traps baited for single species, these systems should not be continued. Finally, utilization of multiple funnel traps (Lindgren 1983) might allow more traps to be deployed in critical locations while simultaneously decreasing problems of trap maintenance and catch assessment. This proposed integrated program will serve to reduce attack and losses suffered outside the dryland sort, reduce attack and losses within the dryland sort, and reduce the resident population of *T. lineatum*.

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