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38.3

Mass trapping of the spruce bark beetle *Ips typographus*. Pheromone and trap technology.

Massefangst av granbarkbillen Ips typographus. *Feromon- og felleteknologi*

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Ås 1983

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Abstract

BAKKE, A., SÆTHER, T. & KVAMME, T. 1983. Mass trapping of the spruce bark beetle *Ips typhographus*. Pheromone and trap technology. (Massefangst av granbarkbillen *Ips typographus*. Feromon- og felleteknologi). Medd. Nor. inst. skogforsk. *38* (3): 1—35.

Drainpipe traps baited with synthetic pheromones have been used to control outbreaks of *Ips typographus* in Norway. This paper describes experiments which have been conducted to evaluate the effect of trap models, the dosage and composition of pheromone dispensers and the deployment and mangement of traps. Traps with funnel outside the tube improved the catches and increased the percent of males trapped. Dispensers containing ipsdienol enhanced the response particularly for female beetles. Average catches per trap decreased with increasing number of traps in a group. The presence of decaying beetles in the collecting container of the trap caused reduced catches by 50 %.

Keywords: Bark beetle; *Ips typographus*; pheromone; drainpipe trap; trap deployment; pheromone dispensers.

Utdrag

BAKKE, A., SÆTHER, T. & KVAMME, T. 1983. Mass trapping of the spruce beetle *Ips typographus*. Pheromone and trap technology. (Massefangst av granbarkbillen *Ips typographus*. Feromon- felleteknologi). Medd. Nor. inst. skogforsk. *38* (3): 1—35.

Feller av drensrør forsynt med syntetiske feromoner som lokkestoff er brukt som middel til bekjempelse av granbarkbillen, *Ips typographus* i Norge. Dette arbeidet beskriver forskjellige eksperimenter som er utført for å vurdere effekten av fellemodeller, dosering og sammensetning av feromondispensere og utsetting og stell av fellene. Feller med trakt som fanger opp biller fra utsiden av røret ga de beste fangstene og økt andel av hanner. Dispensere som inneholder ipsdienol forsterket responsen hos billene særlig fra hunnene. Gjennomsnittsfangst pr. felle avtok med økt antall av feller innenfor en gruppe. Når fella hadde råtne biller i fangstbeholderen ble fangstene redusert med ca. 50 %.

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Preface

The field experiments described in this paper were conducted in the forest of Treschow-Fritzøe. This company also provided us with buildings for field stations and other facilities. Borregaard Ind. Ltd. supplied us with semiochemicals and dispensers. Lars Strand assisted with statistical analyses. Øystein Austarå, Broder Bejer, Finn Brække, Erik Christiansen, Hubertus H. Eidmann and Kåre Venn have read the manuscript and given valuable suggestions. Edel Lyngstad and Kirsten Molteberg typed the draft and Richard Worrell corrected the English text. We are grateful to all those who have contributed with their help and assistance. The work was supported by The Agricultural Research Council of Norway.

Ås-NLH, February 1983.

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Contents

1 Introduction

Suppression of bark beetle populations by mass trapping has been used as a control measure in Europe to fight beetle outbreak. Fore more than 200 years trap trees were cut in early spring, left in the forest during the main flight period of the beetles and removed from the forest while the beetles and their brood were still in the bark.

The trap-tree method had become more and more expensive, and has many disadvantages. During the severe bark beetle outbreak in Norway in the 1970's the need for more effective and economic control measures was urgent.

The identification of the aggregation pheromone of *Ips typographus* (BAKKE et al. 1977) presented the possibility of countering the continuing outbreak by manipulating the bark beetles with synthetic analogues of their natural behavior-controlling semiochemicals. For this purpose, pheromone dispensers were developed and used as bait in traps. A control program which included the use of about 600 000 traps started in Norway in 1979 (BAKKE & STRAND 1981) and continued until 1982.

This paper describes field experiments aimed at the development of an effective pipe trap model, the optimum pheromone dosages for the trap and a practical way of managing the trapping system. These experiments were the basis for some of the guidelines worked out during the control program period.

The problems which have been studied are:

1 Trap technology, including the effectiveness of trap models, sex ratios of the captured beetles, temperature conditions inside the trap and effect of trap colour on the catches.
2 Pheromone dispenser technology; including response to traps with different pheromone dosages, and to dispensers containing different compositions of pheromone components, the longevity of dispenser effectiveness throughout the season and the storage tolerance of dispensers.
3 Trap deployment including mean catches per trap when number of traps in a group and distance between the traps varies.
4 Trap management, including the impact of keeping the captured decaying beetles in the collecting container throughout the season.

2 Materials and methods

The experiments were conducted during the years 1979—82 at Lardal (altitude 250—400 m) and Kjose (altitude 30—80 m), Vestfold county in South-Norway. In both areas the populations of *I. typographus* were high, particularly in 1979, 1980 and 1981, when large stands of Norway spruce, *Picea abies* (L.) Karst. were attacked and killed by the beetle. Pure stands of Norway spruce were the dominating forest type at all the experimental sites. All experiments were conducted with traps located more than 20 m from forest edge at felling coups of 2 to 4 years of age.

2.1 Trap technology

2.1.1 Trap models

Three trap models were used in the experiments, all made of polyethylene and consisting of a black ridged, perforated cylindrical drainpipe and a funnel with collecting container. The pheromone bait is placed inside and in the lower part of the pipe. The traps are manufactured by A/S Fjeldhammer Bruk and distributed by Borregaard Ind. Ltd., Sarpsborg, Norway.

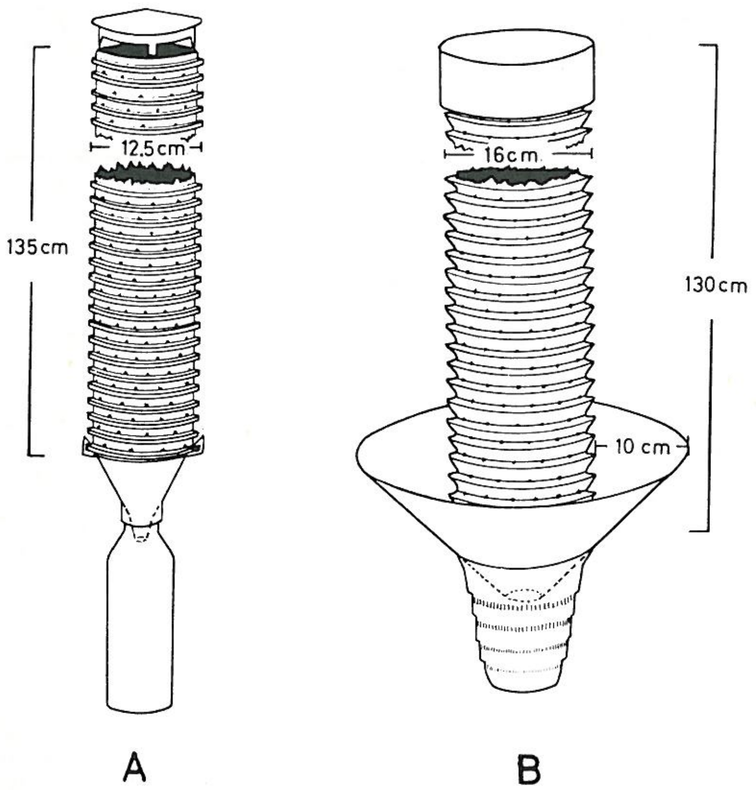

Fig. 1. The pipe-trap models which were used in the experiments. A: The 1979 model. B: The 1980 model.

The 1979 model

The tube (12.5 × 135 cm) is stiff with a fine structured surface. It has approximately 900 holes with diameter 3.5 mm, evenly distributed between the ridges (Fig. 1A). The top end of the tube is covered with a lid, and the lower end has an interior funnel connected to a collecting bottle.

The 1980 model

The tube of this model has thinner walls, a larger diameter (16 × 130 cm) and about 800 holes (Fig. 1 B). There is an exterior funnel at the base, reaching 10 cm out from the tube to collect beetles falling down outside the tube. The collecting container has draining holes to permit rain water to pass through.

The polyethylene material of the container is not hard enough to prevent the captured beetles from enlarging the holes and escaping. The bottom of the container is therefore strengthened by a plate of perforated aluminium (holes 1.5 mm diameter). The collecting containers of traps used in forestry in 1980 and 1981 did not have this aluminium plate and beetles therefore escaped (BAKKE & STRAND 1981). All traps included in the experiments described in this paper had containers with a metal screen or aluminium bottom.

Other trap designs

In one experiment a trap model was used which combined the tube of the 1979 trap and a wide funnel similar to that of the 1980 trap, reaching 10 cm out from the tube. These traps had the same collecting containers as had the 1980 trap model with a metal screen inside.

2.1.2 Comparison of trap models

Experiments to compare the catch of the trap models were made at Kjose in May—June 1982. Groups of three traps, two of the 1979 model and one of the 1980 model, were spread out with distances of minimum 30 m between the trap groups. Within groups the trap distance was 5 m. There were 12 replicates, i.e. groups of traps. The traps were supplied with plastic bag dispensers on 10 May and the catches were collected 18 May and 2 June. The catches of *I. typographus* and *Thanasimus* sp. were recorded.

2.1.3 Catches from inside/outside the trap tube

To analyze the ratio of beetles passing through the holes in the tube and those caught through the outside funnel, a smaller funnel with a collecting bottle was inserted into the lower part of the tube (Fig. 2). The pipe was extended to compensate for the reduction in length due to the arrangement of the inner funnel. There were 5 replicates.

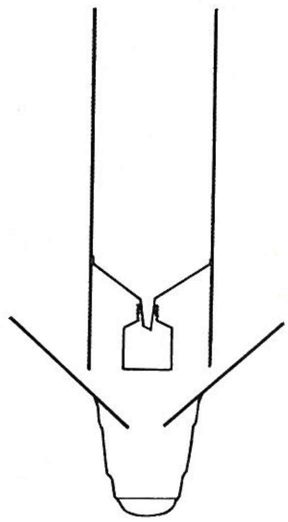

Fig. 2. The trap design for analysing the catches from inside and outside the tube.

Samples of beetles (200) caught through the holes of the tube and from the outside funnel were identified to sex by dissection. So were also samples of beetles captured in the 1979 and 1980 trap model. A total of 4 000 beetles were sexed. The experiments were conducted at Lardal in May 1981.

2.1.4 Temperature records inside the trap tube

The temperature inside tubes of the 1979 trap model was recorded at Lardal during the period 15 May to 30 June 1979, and compared to the outside air temperature. The traps were deployed in an open area and exposed to the sun most of the day. Thermocouples (copper-constatan) recorded the temperature every 15 minutes from the center of the tube and the air temperature from a Linke screen. The temperature conditions were expressed as percentages of the total period with temperatures above certain levels (BAKKE 1968).

2.1.5 Trap tube colours

To determine the effect of different tube colouration on the catches black tubes of the 1979 model were painted with latex paint in different colours (Fig. 5). The experiments were conducted at Lardal as a randomized block layout (5 replicates) with 10 m between traps and minimum 100 m between blocks. The period was 5—19 May 1979 and the catches were collected 3 times after periods of mass flight.

2.2 Pheromone technology

2.2.1 Pheromone components and their relase system

Three components are known from the aggregation pheromone system of *I. typographus* (BAKKE et.al. 1977). In the experiments these have been released from dispensers containing 1400 mg methylbutenol, 70 mg *cis*-verbenol and ipsdienol. In 1979 the ipsdienol content was 10 mg and since 1980 15 mg.

Two different systems for slow release of volatiles were used: laminated structure dispensers and polyethylene bag dispensers.

Laminated structure dispensers

The laminated structure dispenser is made of multiple layers of plastic with a central layer permeated with the pheromone. The outer layer allows the pheromone to pass through at a predetermined, controlled rate. Each dispenser is a 100 cm long and 2.5 cm wide tape. The dispenser is produced by Herculite Products Inc., New York, N.Y., USA. Average daily release rates from one dispenser inside a pipe trap during the second and fourth week of field exposure were: Methylbutenol 30 mg and 12 mg, *cis*-verbenol 1.5 mg and 0,5 mg, ipsdienol 0.2 mg and 0.07 mg (Data Borregaard 1979).

Polyethylene bag dispensers

The polyethylene bag dispenser consists of a transparent plastic bag (50 × 75 mm) containing a cellulose sheet (40 × 60 mm) permeated with the pheromone. The components penetrate the wall at a controlled rate. The dispenser was developed and produced by Celemerck, Ingelheim, West-Germany. The average daily release rates from one dispenser inside a pipe trap during the second and fourth week of field exposure were approximately the same for both periods: Methylbutenol 40 mg, *cis*-verbenol 2 mg, ipsdienol 0.6 mg (Data Borregaard 1979). Both dispensers are marketed by Borregaard Ind. Ltd., Sarpsborg, Norway with the trade name «Ipslure».

2.2.2 Pheromone dosages

Catches in traps with various pheromone dosages were studied at Lardal in 1980 using the 1979 trap model. Traps were baited with laminated plastic-tape dispenser 0.25 m, 0.5 m, 1 m, 2 m or 4 m long and located about 50 m apart on 12 May. The catches were collected 13 times until 30 June. On each occasion the trap positions were interchanged randomly.

2.2.3 Dosages of pheromone components

To evaluate the response to dispensers with various amounts of the three pheromone components, field experiments were conducted at Lardal 14 May—28 Juli 1981. Dispensers were made of plastic bags (80 × 60 mm) and an absorbing sheet (50 × 60 mm) of cellulose and used as baits in 1979 traps. Each component was tested in three doses (1-3-9) keeping the dose of the two other components constant (Figs. 7—9).

Traps were arranged as a randomized block layout (5 replicates) with 10 m between traps and minimum 100 m between blocks. The catches were collected 6 times during the experimental period.

2.2.4 Dispensers with and without ipsdienol

In 1979 plastic bag dispensers and laminated plastic tape dispensers (1500 mg methylbutenol and 70 mg *cis*-verbenol) were field-tested at Lardal with and without addition of 10 mg ipsdienol. Three traps (1979 model) were baited with each of the four formulations on 15 May, 1 June, 15 June and 1 July, and located randomly in lines 20 m apart. The catches were collected after 2 weeks.

A sample of 100 beetles from each of 3 traps with ipsdienol and 3 traps without ipsdienol (plastic bag dispensers) were selected on 15 June and identified to sex.

2.2.5 Attractiveness of the dispensers throughout the season

Experiments were conducted at Lardal in 1979 to study the relative response to dispensers exposed for different periods of time during the summer. Six traps (1979 model) baited with plastic bag dispensers and six traps with plastic tape dispensers were deployed randomly in lines 20 m apart every two weeks from 15 May to 1 July. Catches from the period 1—15 July were compared. Average catches in traps deployed earlier were estimated in percent of catches in traps deployed on 1 July.

2.2.6 Storing capability of dispensers

The attractiveness of dispensers stored for different periods in their packages at -20—-22° C were tested at Lardal 1981. Traps (1979 model) were baited on 14 May with plastic bag dispensers and plastic tape dispensers produced in 1979, 1980 and 1981. They were arranged as a randomized block layout (5 replicates) with 20 m between traps and 100 m between the blocks.

2.3 Trap deployment

2.3.1 Traps in groups — trap distance within groups

To study the mean catches per trap for traps in a group where the traps are spaced at different distances apart, experiments were conducted at Kjose 1981 and at Lardal 1982.

Each group consisted of 6 traps baited with plastic bag dispensers, and located in a triangular pattern, with trap distances of 0.5 m, 1.5 m, 3 m, 6 m and 12 m. The distance between groups exceeded 50 m.

In 1982 eight 3—4 years old felling coups were selected and a group of traps were deployed in each coup on 10 May. The catches were collected three times on 22 May, 9 June and 13 July.

In 1982 the same trap layout was used in a 3—4 years old large felling coup. The trap groups were deployed on 12 May and randomly interchanged 5 times when the catches were collected until 4 June.

2.3.2 Size of trap groups

To determine the catch per trap in groups with different numbers of traps, groups of traps were deployed on felling coups at Kjose 1981 and at Lardal 1982. Trap groups of 1, 3, 6 and 12 traps were located 3 m apart in a triangular pattern and with a minimum distance of 60 m between the groups. In 1981 the traps were deployed on 10 May on 8 different felling coups and baited with laminated plastic tape dispensers. The catches were collected 22 May.

In 1982 traps baited with plastic bag dispensers were deployed on 15 May, one group of each size on 2—3 years old felling coups, minimum distance of 100 m. The trap groups were randomly interchanged 4 times when the catches were collected until 4 June.

2.3.3. Large group of traps in grid system

To determine the ability of traps to capture beetles flying into an area, a grid system of traps was deployed at Lardal in 1979. Ninetyone traps were located 20 m apart in a hexagonal pattern at a 3 years old felling coup, as indicated in Fig. 13. On 23 May before the spring flight had started, the traps were baited with plastic bag dispensers. The catches were collected on 1 and 6 June.

2.4 Trap management

2.4.1 Traps with and without decaying beetles kept in collecting containers

Beetles trapped in the collecting containers will begin decaying after some days and gases will be released during the decomposing process. These

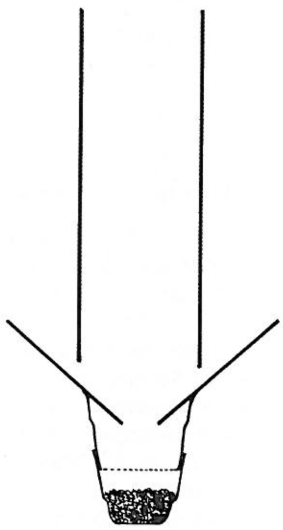

Fig. 3. The trap design for analyzing the influence of keeping decaying beetles in the collecting container.

gases may influence the efficiency of the traps. Experiments were conducted at Lardal and Kjose in 1981 (3 replicates at each location) to determine the catches in traps of the 1979 and the 1980 models with decaying beetles compared to traps which were regularly emptied.

The bottom of the collecting containers of the 1979 and 1980 trap models were removed. The container was then fitted with a metal screen bottom and an extra container beneath with approximately 5 000 newly collected beetles (Fig. 3). Traps with and without rotten beetles baited with plastic bag dispensers were located at 3 sites at Lardal and Kjose on 20 May. The catches were collected regularly after periods of beetle flight until 15 July. Samples of 200 beetles were identified to sex from catches from both trap models, with and without rotten beetles.

3 Results

3.1 Comparison of catches from the trap models

The 1980 trap model which has a larger pipe surface compared to the 1979 model and an exterior funnel was designed to collect more beetles, including those that did not enter the holes of the tube, but dropped down after collision with the trap. Further, the trap construction should permit the predatory clerids *Thanasimus formicarius* (L.) and *T. femoralis* (Zett.) to escape. The predators, which are attracted to the pheromones (Bakke & Kvamme 1981), have greater mobility than have the bark beetles. They climb the walls of the collecting container, find the opening between the funnel and the tube, and escape easily.

Table 1 indicates that the 1980 model has got these two advantages compared to the 1979 model. The catches of *I. typographus* have increased by more than 90 % and the catches of *Thanasimus* are significantly reduced.

In traps with exterior funnel approximately ⅔ of the beetles had entered the holes of the pipe, whereas ⅓ was caught by the outer funnel (Table 2). This applies to traps consisting of pipes of both the 1979 and the 1980 model.

The 1980 model caught a higher percentage of male beetles than did the 1979 model (Table 3). The majority of these males came through the outside funnel.

3.2 Temperature inside the trap tube

The temperature in trap tubes exceeded the air temperature (Fig. 4). The differences were largest on sunny days. During the period 15 May to 30 June 1979 no air temperatures above 30° C were recorded but for 6 % of the time (68 hrs.) the tube temperature exceeded this level. Inside the tube the temperature was estimated to have exceeded 25° C for 173 hrs. during the same period compared with only 30 hrs. in the air.

Table 1. Average catches of *Ips typographus* and *Thanasimus* sp. in two trap models

	10 May—18 May		18 May—2 June	
	1980 model	1979 model	1980 model	1979 model
Ips typographus	622	325	534	272
Thanasimus sp.	1.3	3.3	1.1	4.3
No. of *Thanasimus* per thousand *Ips*	2	10	2	16

An analysis of variance indicated that there are significant differences ($P<0.005$) between the catches in the trap models. This applies to *I. typographus* and *Thansimus*, both periods.

Table 2. Average trap catches of *Ips typographus* from inside the tube and from the exterior funnels

Trap model		No. of beetles	Per cent	
			Mean	Range
1979 pipe	Inside	2016	64	58—69
	Outside	1128	36	31—42
1980 pipe	Inside	3064	63	52—71
	Outside	1814	37	29—48

Table 3. Per cent males of *Ips typographus* caught in drainpipe trap models

Trap model		Per cent males	
		Mean	Range
1979		21.0	19—23
1980		30.6[1])	27—34
1980	Inside	27.8	24—32
	Outside	35.4[2])	30—48

[1]) Difference 1979—1980 models significant $P<0.001$.
[2]) Difference inside/outside significant $P<0.005$.
Statistically analysed by arcus sinus-transformation of the percentage figures.

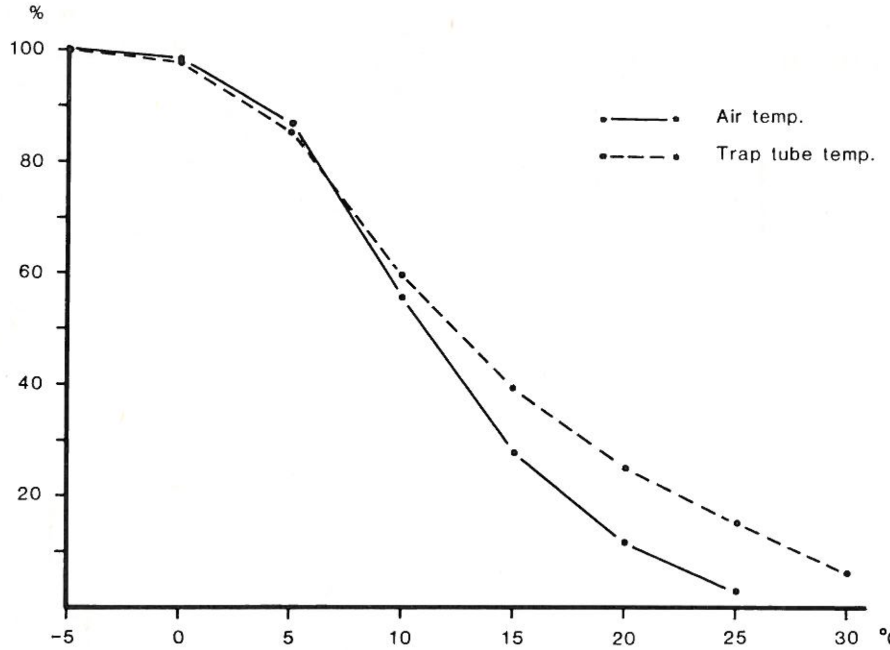

Fig. 4. Percentage of time during the period 15 May to 30 June 1979 with trap tube temperature and air temperature above certain limits.

3.3 Trap tube colours

The colour of the trap tube strongly influenced the catches. The dark colours gave 4—5 times higher catches during the main flight period than did yellow and white (Fig. 5).

3.4 Pheromone dosages

The total trap catches during the period 12 May—30 June increased with increasing length of the dispenser tape (pheromone dosages), up to 2 m (Table 4). The trap with 4 m of tape had smaller total catches.

The catches in the same traps at different times during the experimental period are indicated in Fig. 6. The trap with the lowest pheromone dosage (0.25 m tape) lost its relative attractiveness early in the period, whereas traps with 1 and 2 m of tape stayed attractive throughout the period. The trap with 4 m of tape seemed to be overloaded early in the period, but gained the best attractiveness later.

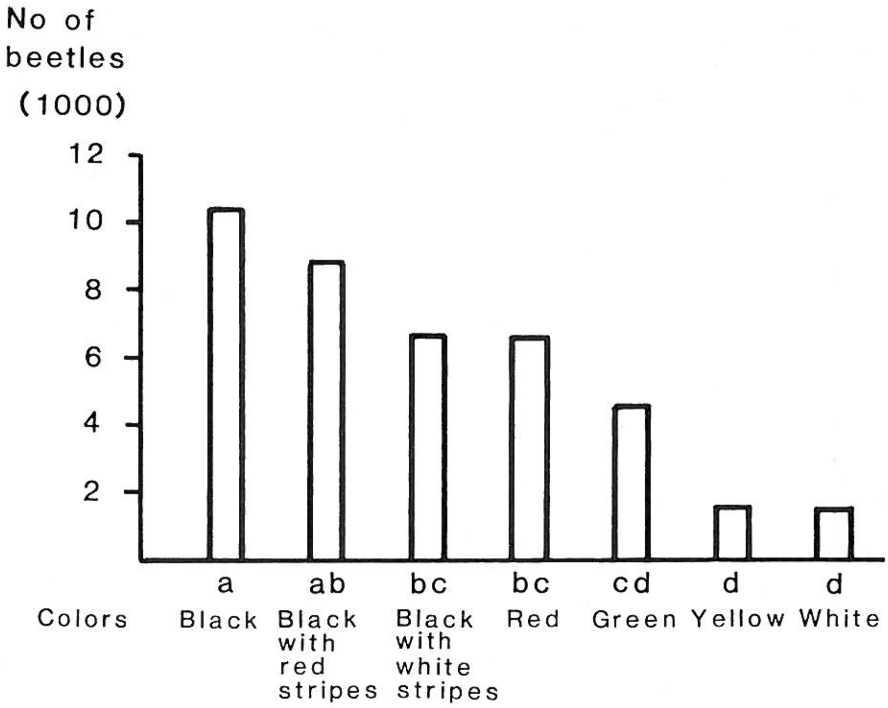

Fig 5. Catches in drain pipe traps painted with different colors.

Table 4. Trap catches of *Ips typographus* in response to various dosage of pheromone dispensers. Trapping period 12 May—30 June 1980

Length of dispenser tape (m) (Hercon)	No. of beetles	Per cent
1/4	1503	11
1/2	1691	12
1	3184	23
2	4254	31
4	3105	23

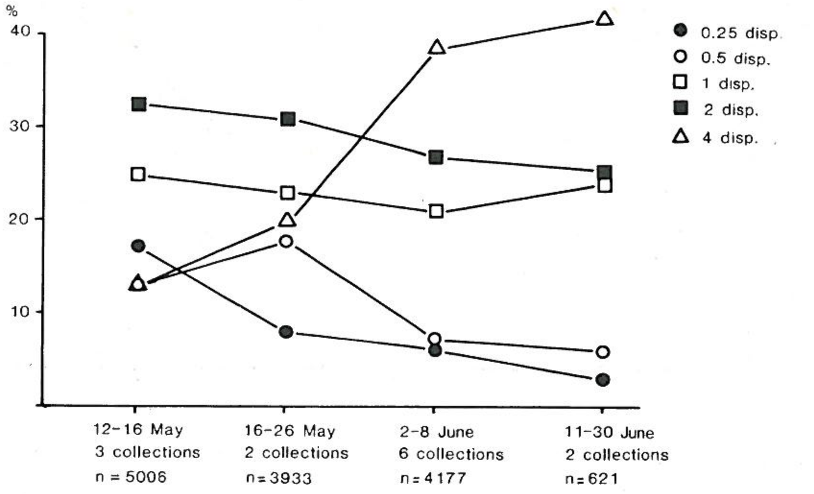

Fig. 6. Trap catches during May and June in response to different pheromone dosages. Plastic tape dispensers (1 dispenser = 1 m) were used as bait. The catches are estimated as per cent of total catches in the period.

3.5 Dosage of pheromone components in the dispensers

The dosage of pheromone components inside the plastic bag of the dispenser did not influence the attractiveness of the dispenser during the first week of exposure (Figs. 7, 8, 9). After a few weeks, however, the attractiveness of the dispensers containing the lowest dosage decreased. This was most obvious for dispensers containing the lowest dosage of methylbutenol (Fig. 7), where the response was almost zero after the 4 June. During July the dispensers with the highest dosages of methylbutenol and *cis*-verbenol had the highest relative catches (Figs. 7 and 8), whereas the response to dispensers with different dosage of ipsdienol seemed to be more uniform (Fig. 9).

The results indicate that a certain and sufficient dosage of the pheromone components penetrates the plastic film, as long as some of the components are still present inside the dispenser bag. When either methylbutenol or *cis*-verbenol were totally evaporated, the dispensers lost the attractiveness. Because ipsdienol is a less important part of the pheromone of *I. typographus*, this trend is not so obvious in the experiments with ipsdienol (Fig. 9).

3.6 Dispensers with and without ispdienol

Traps baited with ipsdienol in addition to methylbutenol and *cis*-verbenol had higher catches than traps without ipsdienol (Table 5). The average catches in response to bag dispensers were 61 % higher when ipsdienol was added. The increase in catches was only 20 % for tape dispensers. The per cent of females was somewhat higher in catches from traps where ipsdienol is a part of the pheromone bait (Table 6).

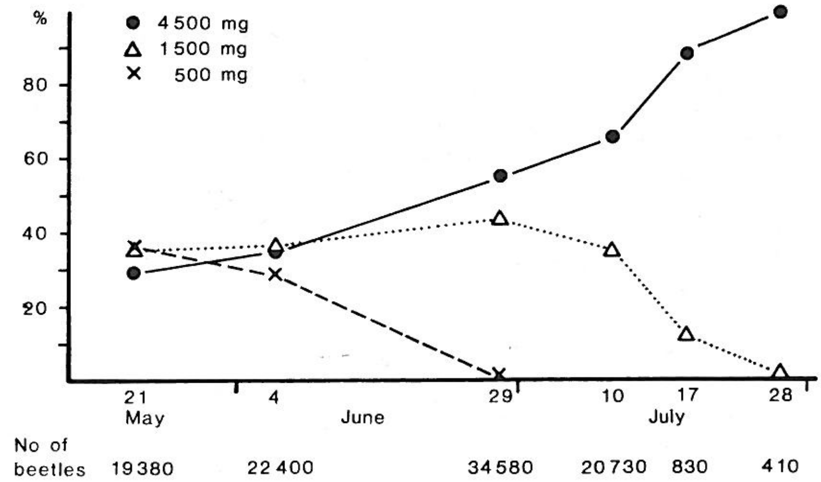

Fig. 7. Relative trap catches in response to bag dispensers with different dosages of methylbutenol. Dosages of *cis*-verbenol 70 mg and ipsdienol 15 mg.

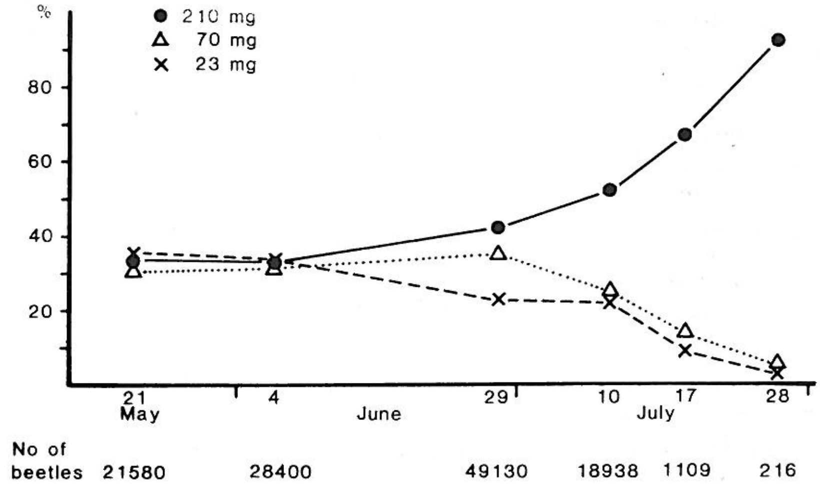

Fig. 8. Relative trap catches in response to bag dispensers with different dosages of *cis*-verbenol. Dosages of methylbutenol 1500 mg and ipsdienol 15 mg.

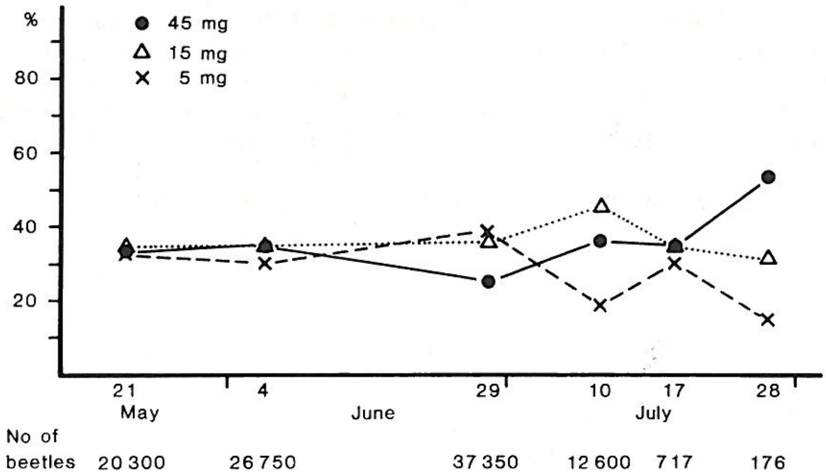

Fig. 9. Relative trap catches in response to bag dispensers with different dosages of ipsdienol. Dosages of methylbutenol 1500 mg and *cis*-verbenol 70 mg.

Table 5. Average catches of *Ips typographus* to dispensers with and without ipsdienol

Dispenser formulation		Catches	Per cent higher catches with ipsdienol
Plastic bag (Celamerck)	with ipsdienol	723	61
	without ipsdienol	449	
Plastic tape (Hercon)	with ipsdienol	588	20
	without ipsdienol	489	

An analysis of variance indicated that the difference between catches is significant ($p<0.005$) for plastic bag dispensers, but not for tape dispensers.

Table 6. Per cent females in trap catches when dispenser does or does not have ipsidienol as part of the pheromone mixture (sample size, 100 beetles)

Dispenser	Sample no.			Total
	1	2	3	
With ipsdienol	77	71	72	73.3
Without ipsdienol	73	66	67	68.7

3.7 Effectiveness of the dispensers throughout the season

The dispensers were designed to give slow and controlled release of pheromones which permeate through a layer of polymeric film. The experiments showed that both dispensers were still releaseing pheromones after 6 weeks of exposure in the 1979 trap. The effect, however, diminshed gradually. After 6—8 weeks catches in traps with tape dispenser had dropped by 65 % (Fig. 10), whereas the corresponding figure for bag dispensers was 41 %.

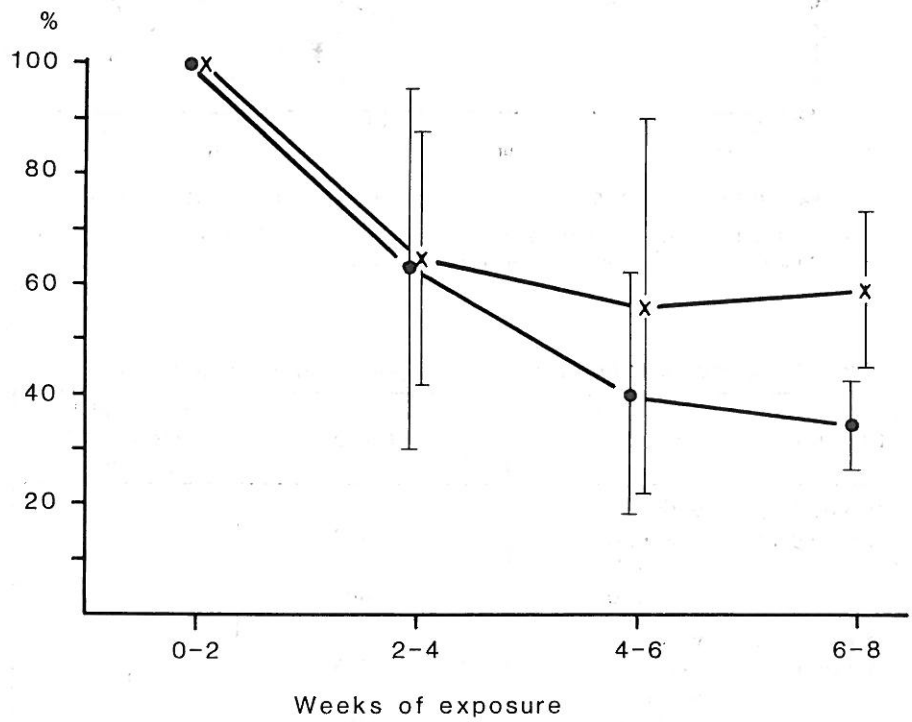

Fig. 10. Relative average catches in the period 1—15 July in response to dispensers exposed inside the trap (1979 model) for different periods. Standard deviations are given in per cent of average catches from traps baited 1 July.
x = plastic bag dispenser. n = 8244
o = laminated plastic tape dispensers. n = 5148

3.8 Response to dispensers stored for different times

Dispensers of either type stored in their packages in freezers for 1 and 2 years had kept their attractiveness compared to newly produced (less than 5 months old) dispensers (Table 7). There was no significant difference between the average catches through the season or the total catches.

Table 7. Mean catches of *I. typographus* in response to dispensers of different ages. Lardal 1981

Dispenser type	Year of production	Date of collection								Total catch
		May 26	June 4	June 18	June 29	July 6	July 13	July 20	July 28	
Polyethylene	1979	1410	710	290	1980	147	1010	38	34	5619
bag	1980	1160	554	276	1710	122	945	38	34	4839
(Celamerck)	1981	1160	700	330	1850	153	820	44	28	5085
Laminated	1979	1380	540	258	1400	62	549	17	12	4218
plastic tapes	1980	1380	500	196	1240	65	539	16	10	3946
(Hercon)	1981	1290	460	178	1270	71	558	20	14	3861

No significant difference between years in either dispenser type (Duncan's multiple range test.)

3.9 Traps in groups — trap distances

When traps were deployed in groups of 6 and the distance between the traps were 0.5, 1.5, 3, 6 or 12 m, no significant differences were found in average trap catches between the groups. These are results obtained in experiments where the groups were permanently located through the season (Fig. 11A) and where the groups were interchanged (Fig. 11B).

3.10 Size of trap groups

The average catches per trap decreased with increasing number of traps in the group (Fig. 12). Trap catches are strongly influenced by several environmental factors and hence considerable variations occur.

The catches from 91 traps deployed in a hexagonal pattern (Fig. 13) indicate a distrinct reduction in catches towards the center of the group: Calculation of the average trap catches in each concentric zone indicates that 72 % of the responding beetles were caught in the three outer zones of the group (Fig. 14). This trend is about the same in catches from the two consecutive trapping periods (Table 8).

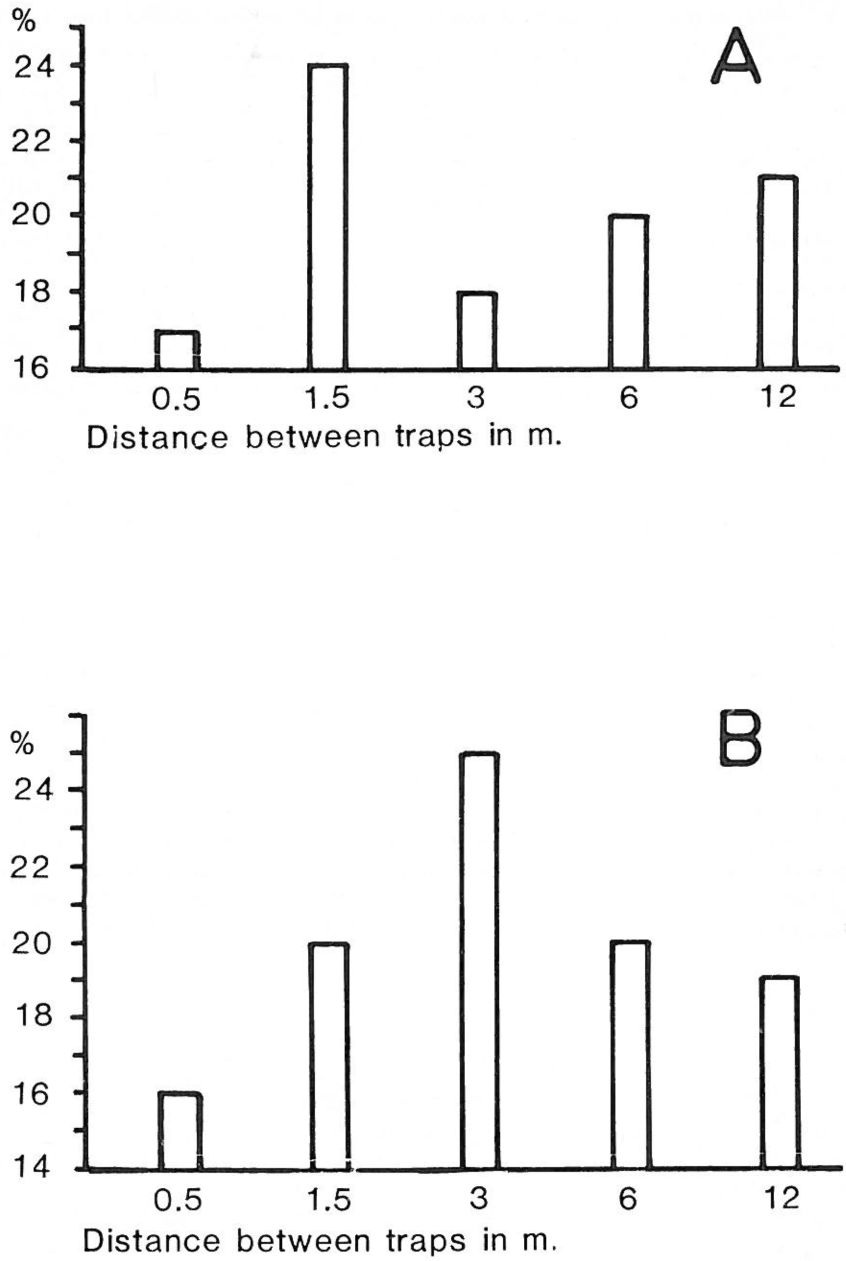

Fig. 11. Average catches per trap in groups of 6 traps with different within-group distance.
A: Means of 8 replicates, permanently located. n = 18 449
B: Means of 5 replicates, interchanged. n = 43 392

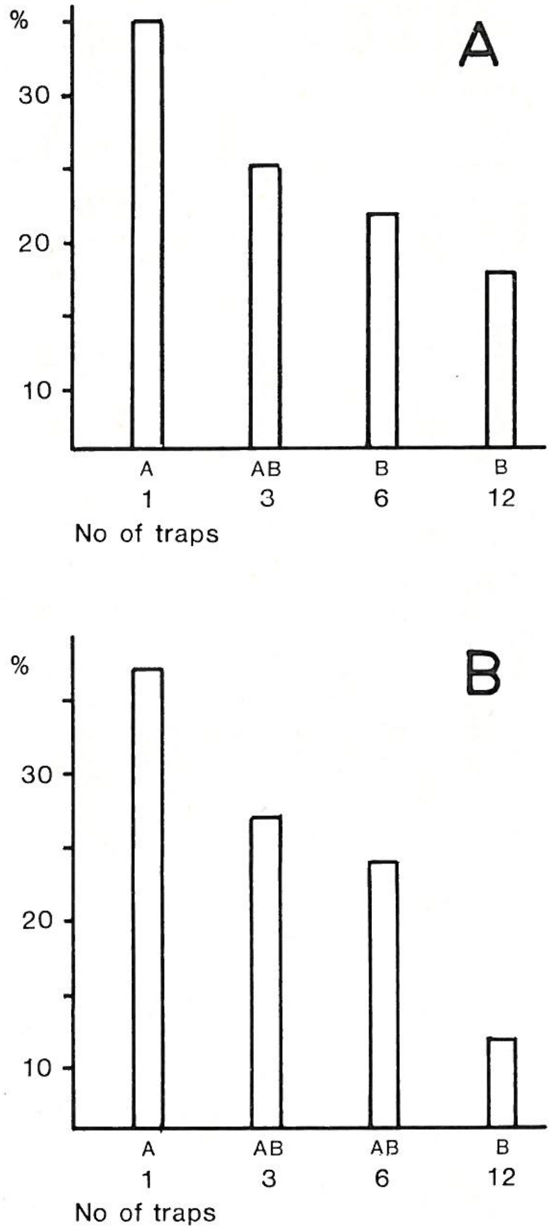

Fig. 12. Average catches per trap in trap groups with different trap numbers.
A: Means of 8 replicates, permanently located. n = 254 800
B: Means of 4 replicates, interchanged. n = 26 811
Means with the same letter are not significantly different. Duncan's multiple range test.

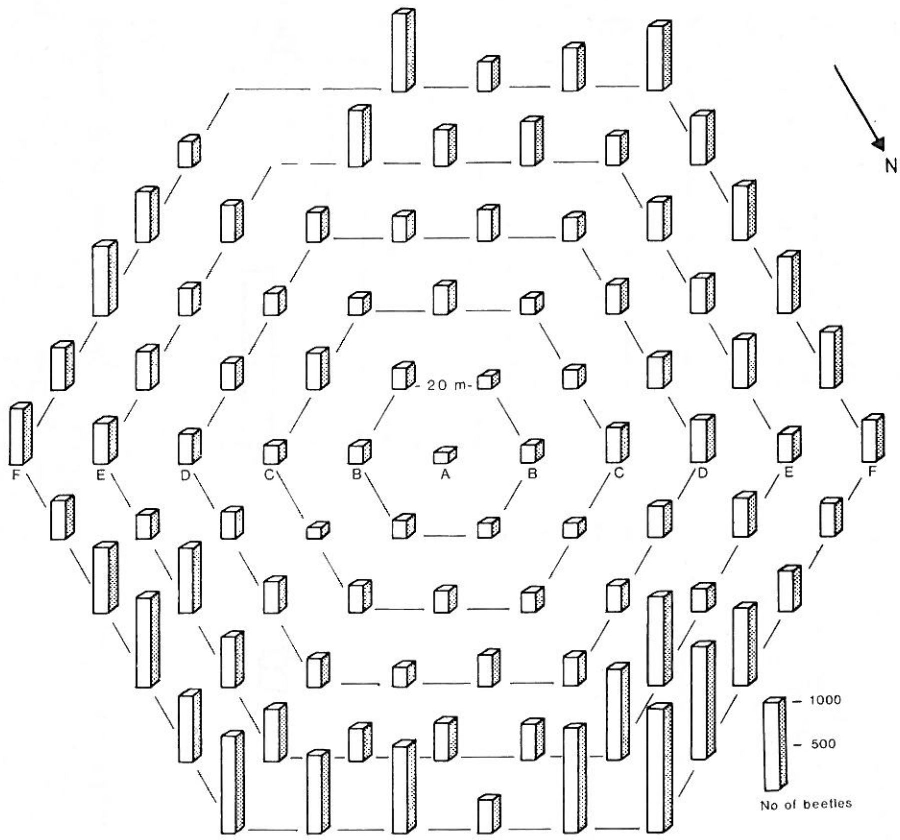

Fig. 13. Catches from traps deployed in a hexagonal pattern.

Table 8. Average trap catches of *I. typographus* in traps from different zones of a hexagonal trap group (Fig. 13)

Trapping period		Zone and (trap no.)					
		A (1)	B (6)	C (12)	D (18)	E (23)	F (28)
23 May—1 June	No. of beetles per trap	191	292	392	484	735	1095
	Per cent	6	9	12	15	23	35
1—6 June	No. of beetles per trap	74	118	133	166	255	340
	Per cent	7	11	12	15	24	31

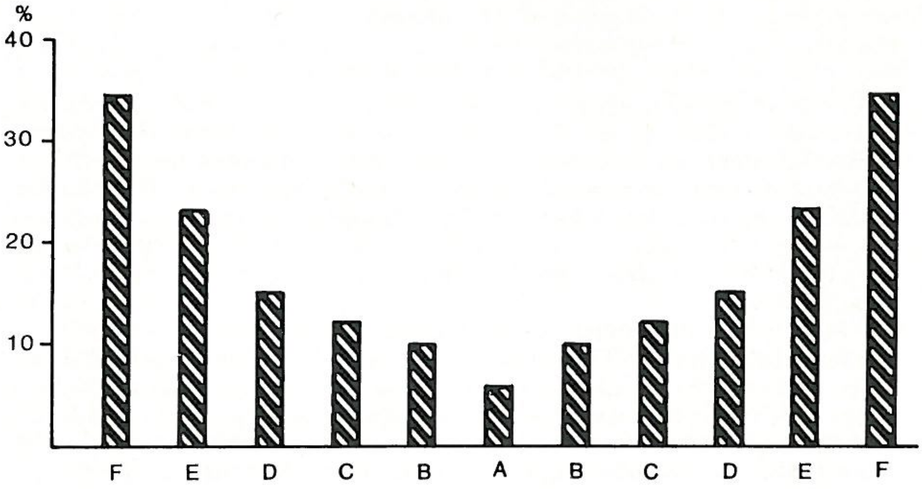

Fig. 14. Relative average catches in traps from different concentric zones (A—F) of the trap group showed in Fig. 13. n = 83 666.

3.11 Traps with and without decaying beetles

Traps where the captured beetles remained in the collecting containers throughout the season caught less beetles than traps which were emptied regularly (Table 9). The catch reduction was largest for the 1979 model, but was also significant for the 1980 model.

There were no significant differences in sex ratio of beetles caught in the traps with and without decomposing beetles.

Table 9. Per cent reduction in catches of *Ips typographus* in drain pipe traps with decaying beetles, compared to traps where the catches were removed regularly. Means of 6 replicates and range.
Lardal and Kjose, 1981

Trap model	Trapping periods			Total
	20 May— 10 June	10 June— 22 June	1 July— 15 July	
1979	27 19—37	51 42—73	52 18—86	44 28—59
1980	29 9—56	21 10—34	42 4—72	30 11—51

The difference between the catches in traps with and without decaying beetles are significant for both trap models ($P<0.005$).

4 Discussion

4.1 The trap models

Traps of different design have been developed to utilize the aggregation pheromone of bark beetles (BAKKE & RIEGE 1982). Flight barrier traps give somewhat higher catches than traps made from perforated cylinders (KLIMETZEK & VITE 1978; KÖNIG et al. 1981; VAUPEL et al. 1981). Barrier traps are, however, less selective than pipe traps, and many predators and other none-target insects are trapped in addition to the bark beetles. The pipe trap has also other advantages: It is inexpensive and easy to handle in practical forestry.

Pipe traps with exterior funnel yielded higher catches than did traps without such a funnel. This confirms the results of REGNANDER & SOLBRECK (1981) who found that traps without funnels caught about 50 % of those with funnels. However, in the experiments by Regnander & Solbreck the Norwegian 1980 model was less efficient than the 1979 model without funnel. This is not in accordance with the results of this study. The reason for this may be that the collecting containers of the 1980 model tested in Sweden were of the soft polyethylene material which permitted many beetles to bore through them and escape. Escape of beetles from these containers were commonly observed in Norway in 1980. The containers have therefore later been replaced by containers made from a harder material and supplied with a perforated aluminium plate at the bottom.

The exterior funnel caught about ⅓ of the total (Table 2), whereas REGNANDER & SOLBRECK (1981) got equal numbers of beetles from ouside and inside the tube. These differences may be due to the larger diameter (40 cm) of the funnel used by Regnander & Solbreck compared to the funnel of the traps used in this experiment (36 cm — 1980 model, 32 cm — 1979 model).

4.2 The sex ratio of captured beetles

The sex ratio of *I. typographus* caught in pipe traps (Table 3) is biased in favour of females (BOTTERWEG 1982). In the 1980 model, which had the highest ratio of males, only 30.6 % were males.

Polygamous bark beetles usually have a sex ratio of 1:1 prior to emergence from the brood tree. This is also true for *I. typographus* (ANNILA 1969). Among beetles emerging during fall ANNILA (1971) found only 44 % males whereas the sex ratio of beetles caught in flight barrier traps during spring had dropped to an average of 40 % males. In brood galleries after the initiation of attack he found only 32.5 % males. The same shift in sex ratio has been observed in *I. typographus* in Japan (KOIZUMI & YAMAGUCHI 1967) and other *Ips* species (THOMAS 1961; CAMERON & BORDEN 1967).

The response to pheromones seems to be greatest in the sex that does not initiate the gallery. Laboratory experiments with *Ips paraconfusus* Lanier indicated that females responded more than males to naturally produced attractants. WOOD & BUSHING (1963) found that the proportion of males exhibiting a positive response was approximately two-thirds or less than that of the females, and BORDEN (1967) showed in May—June a response from *ca.* 75 % of females, but only from *ca.* 35 % of the males. In *Dendroctonus frontalis* Zimmermann, where the females initiate the boring, the opposite sex (males) responds significantly greater to attractants in laboratory tests (MCHARTY et al. 1980) and in the field (MOSER & BROWNE 1978; ROBERTS et al. 1982).

Apart from the oldfactory response, behavioural traits could also explain parts of the low catches of males. The pipe trap models which require that the beetles enter the holes of the pipe to be trapped may be less sutiable for the sex which is behaviourally adapted to drill the holes themselves. The proportion of males is highest in the catches from the exterior funnel, and consequently higher in the 1980 model than in the 1979 model (Table 3).

Samples of 200 beetles from both trap models (1980 and 1979) were collected weekly at Ås in 1980, from 4 May to 21 July and identified to sex (unpublished data). The proportion of males varied throughout the season from 52 % in early spring to only 10 % in late May, and then increasing to 32 % later in the summer. The proportions of males were always at a level of 5—10 % higher in the trap model with exterior funnel compared to the trap without this funnel.

This means that pipe traps should have an exterior funnel in order to catch a maximum of the responding males.

4.3 Tube colour and temperature

Trap tubes with dark colours gave higher catches than did the light tubes (Fig. 5). This may be an indirect effect of temperature differences inside the tube, where the pheromone dispenser is located. Exposure to sunlight cause increase in temperature inside the tube (Fig. 4) (VAUPEL et al. 1981), which will positively influence the release rate of pheromone components. Dark tubes will absorb the most solar heat and will have the highest temperature. An increase by for instance 10° C inside the trap will strongly increase the release rate from the dispenser.

Another reason for the higher catches in traps with dark tubes may be that beetles easier will recognize a dark object more easily when they are flying in an open area (SHEPHERD 1966). There is no support for a theory of colour vision in *I. typographus*.

4.4 Pheromone dosages and dispenser compositions

The release rates of the plastic tape dispensers are supposed to be highest during the first warm day of exposure and then only decrease slowly until all components have evaporated (ZEOLI et al. 1982). The release rates from 1 m and 2 m long tape dispensers seemed to yield a fairly stable catch throughout the experimental period. A higher dosage (4 m) gave no higher catches during the first 6 weeks, but catches remained higher later in the season. Field tests in W. Germany with plastic bag dispensers (Typolure I) containing methylbutenol and *cis*-verbenol gave similar results, i.e. only a

10—30 % increase in the catches when the pheromone dosage was doubled, (KLIMETZEK et al. 1979). This means that the dispenser units which have been choosen seem to have a suitable release rate for the trap model.

The plastic bag dispenser used to study the effect of various dosages of pheromone components is a reservoir system with a rate-controlling membrane (ZEOLI et al. 1982). A steady state wil be established with the release rate being constant and independent of time as long as the air within the bag is maintained saturated with the pheromone components. The effect of this system is clearly demonstrated in this experiment. The attractiveness of the dispensers dropped drastically when one of the two main components had evaporated.

Methylbutenol and *cis*-verbenol are the main aggregation pheromone components of *I. typographus* (BAKKE et al. 1977; KRAWIELITZKI et al. 1977). Ipsdienol is produced by the male beetle (VITÉ et al. 1972) after the nuptial chamber is excavated and females have entered the gallery (BAKKE 1976).

The spruce bark beetle responds in masses to pheromone dispensers without ipsdienol (KLIMETZEK 1978; KLIMETZEK et al. 1979). It has been uncertain whether or not ipsdienol is a necessary component of the aggregation pheromone of *I. typographus.* The data from this experiment are confirmed by results from W. Germany that addition of ipsdienol to the mixture of methylbutenol and *cis*-verbenol enhances the catches in pipe traps (SAUERWIEIN & VITÉ 1978). The experimental data also indicate that an increased response of femals is the reason for some of the higher catches, but hardly for all of them.

During the mass trapping program in Norway 1979—82 (BAKKE 1982) ipsdienol has been included in the pheromone mixture used as bait in the pipe traps.

4.5 Duration of dispenser effectiveness

The main flight period of *I. typographus* in Norway is during May/June (BAKKE et al. 1977). Later in the season flight may also occur, but often on a minor scale.

The results given in Fig. 10 are confirmed also by experience from the mass trapping program. Traps baited in early May caught beetles even in mid-July (BAKKE & STRAND 1981, Fig. 2). The period of dispenser attractiveness, however, depends on weather conditions and location of traps. Long periods with direct solar radiotion on the trap tube will increase the temperature of the dispensers, which then will be emptied sooner. After 4 years of trapping experiments a general conclusion is that traps located on open areas have to be rebaited in late June or early July to be effective during late summer. This is true particularly when May and June are warm and sunny. In Germany DIMITRI (1981) recommends renewal of the bait in the middle of the summer to catch the second generation of *I. typographus.*

The experiment indicates that the plastic bag dispenser stays effective for at least 8 weeks and keeps its effectiveness at a higher level than does the tape dispenser. This is in accordance with the release system of the two dispenser types. The bag dispenser releases pheromones at an approximately constant rate as long as the concentration of pheromones in the air within the bag remains constant. When the pheromone reservoir is emptied, the attractiveness drops more immediately. The tape dispenser formulation retains its attractiveness for a longer period, but the release rate drops gradually (see Fig. 6).

4.6 Trap catches — trap deployment

Trapping experiments with western pine beetle, *Dendroctonus brevicornis* LeConte indicated that more beetles were flying in the vicinity of a source of attract than would be caught in a single small trap located at the source (TILDEN et al. 1979). Similar observations have been made in trapping studies with *I. typographus.* This has lead to effort to improve the trap model, but also to test different patterns of trap deployment.

It is obvious that one single trap catches more beetles than does each of several traps located in a group when the distance between the traps is short (Fig. 12). However, more traps in a group increase the total catch of the group.

It is more difficult to estimate the distance between traps in a group that gives the best catches per trap. Within the range of 0.5 to 12 m there were no significant differences in our experiments (Fig. 11). This corresponds to the results obtained by AUSTARÅ & STRAND (1979) from an area with a very high beetle population. SAUERWEIN (1981), however, caught less beetles per trap with a distance of 45 m between them.

Traps deployed in a grid pattern, 20 m apart, caught most beetles per trap in the perifery and the number decreased towards the centre (Fig. 14). But this experiment also demonstrates that more than 60 % of the responding beetles were able to penetrate through a single barrier of traps located 20 m apart.

The question of optimal spacing of traps is related to that of the effective distance from which a pheromone trap is able to attract beetles. Data available indicates that most beetles respond from distances of less than 10—20 m from the pheromone source (SAUERWEIN 1981). This question of distance can hardly be answered with exact figures because several factors influence the result. The spread and direction of air movement strongly influence the dispersal of pheromone components (FARES et al. 1980) and turbulence conditions may cause high concentrations of pheromones at greater distances from the source (SIVERTSEN 1980) and stimulate beetles to fly against the wind towards the source.

4.7 Effects of decaying beetles in the collecting container

Bark beetles are able to produce inhibitors or anti-aggregants which reduce the effect of the aggreating pheromones (RUDINSKY 1968; RENWICK & VITÉ 1969; PAYNE & al. 1978). These components are often further oxidization products of aggregating pheremone components (VITÉ & FRANCKE 1976). When added to the aggregation pheremone of *I. typograp-*

hus ipsenol and verbenone reduce the catches in pheromone traps (BAKKE 1981).

The reduction of catches due to decaying beetles may therefore be caused by gases containing verbenone, ipsenol or components with similar effects, which are released during the decompisition process.

In the 1979 model the collecting flask has air connection only to the inside of the trap tube. The only passage for gases released from the decomposing beetles is through the holes of the tube. The gases will thus be mixed with the pheremones from the dispenser. Volatile components from the decomposed beetles may then interfere with the pheromone and reduce its attractiveness. The 1980 model has some holes in the collecting container and a passage between the funnel and the tube. This gives some air circulation and probably somewhat better drainage of the gases from the decomposed beetles.

Summary

Suppression of bark beetle populations by mass trapping was part of a program for the control of *Ips typographus* outbreaks in Norway during the 1970's. This paper describes experiments on trap technology, pheromone dispenser technology and trap management which were developed during this control program.

Two trap models were used in most experiments, both made of ca. 130 cm long drain-pipes with approximately 900 holes, large enough to let *I. typographus* pass through. One model (tube diameter 12.5 cm) has a bottle serving as the collecting container (1979 trap model). The other model (tube diameter 16 cm) has a funnel at the base reaching 10 cm out from the tube to collect beetles falling down along the tube, and a perforated collecting container (1980 trap model).

Two types of pheromone dispenser containing the aggregation pheromone of *I. typographus,* methylbutenol, *cis*-verbenol and ipsdienol were used as a bait in the traps. One is a laminated structure dispenser made of a multiple layer of plastic with a central layer permeated with the pheromone. The other is a polyethylene bag dispenser consisting of a transparent plastic bag holding a cellulose sheet permeated with the pheromone components. Both dispensers are marketed by Borregaard Ind. Ltd., Sarpsborg, Norway with the trade name «Ipslure». Additional plastic bag dispensers were made to study the response to different dosages of the pheromone components.

Groups of traps were deployed during the seasons of 1979—82 at 2—4 years old felling coups at Lardal and Kjose, the county of Vestfold in South-Norway.

The results were as follows:

1. The trap model with larger pipe surface and exterior funnel (1980 model) caught about 90 % more beetles than did the 1979 trap model, and

a higher percentage of male beetles. The catches of predator beetles of the genus *Thanasimus* in the 1980 model was only 2 per thousand of *Ips*, compared to 13 per thousand in the 1979 model.

2. The exterior funnel caught about ⅓ of the total catch of the trap and a significantly higher percentage of male beetles.
3. The temperature in trap tubes exceeded the air temperature. During the period 15 May to 30 June 1979 the tube temperature in a 1979 trap was estimated to have exceeded 25° C for 173 hrs. compared to only 30 hrs. in the air.
4. Trap tubes with dark colours had 4—5 times higher catches compared with traps with tubes painted in light colors. Higher temperatures inside the tubes during sunexposure and thereby increased release of pheromones are supposed to cause the higher catches.
5. Traps loaded with one and two dispensers had the highest total catches during the spring and early summer, compared to traps with lower and higher pheremone dosages. Traps with four dispensers seemed to be overloaded early in the experimental period, but gained the best attractiveness later.
6. Plastic bag dispensers containing different dosages of the various pheromone components had about the same inititial attractiveness. When all the methylbutenol or *cis*-verbenol were evaporated, the dispensers lost their attratctiveness.
7. Traps baited with dispensers containing ipsdienol in addition to methylbutenol and *cis*-verbenol, yield 60 % higher catches than traps with dispensers without ipsdienol. The female sex ratio was higher when ipsdienol was present in the dispenser.
8. Analyses of the attractiveness of the dispensers throughout the season indicated that both dispenser types still released pheromones after 6 weeks inside the trap. The effect diminished gradually; and after 6—8 weeks traps with plastic tape dispensers had dropped by 65 % of newly baited traps, whereas the corresponding figure for bag dispensers was 41 %.
9. There were no significant difference in attractiveness between dispensers of either types stored frozen in their packages for 1 and 2 years compared to recently produced dispensers.
10. When traps were deployed in groups of 6 and the distance between the traps within the groups were 0.5, 1.5, 3, 6 or 12 m, no significant differences were found in average trap catches between the groups.
11. Average catches per trap decreased significantly with increasing number of traps in the group. When 91 traps were deployed in a group with 20 m distance between the traps, the catches decreased towards the centre of the group.
12. Traps where the captured beetles remained in the collecting containers throughout the season, had their catches reduced by approximately 50 % compared with traps which were emptied regularly. The reduction was highest for the 1979 trap model, but was also significant for the 1980 model.

Massefangst av granbarkbillen *Ips typographus*. Feromon- og felleteknologi

Fangst av biller ved hjelp av feromoner og rørfeller var et av de mottiltak som ble nyttet under kampen mot granbarkbillen i Norge i 1970-årene (BAKKE & STRAND 1981). Dette arbeidet omhandler feltundersøkelser som er utført for å finne frem til effektiv bruk av feromondispensere, utvikle en effektiv fellemodell og utarbeide retningslinjer for hvordan fellene bør brukes.

Eksperimentene er for det meste utført i Treschow-Fritzøes skogeiendommer i Lardal og Kjose i Vestfold i årene 1979—82.

To fellemodeller ble brukt i de fleste eksperimentene, begge laget av et ca. 130 cm langt drensrør av polyethylen med ca. 900 huller, store nok til at granbarkbillen kan slippe gjennom. Rørene er montert vertikalt festet til en staur. Den ene modellen (rørdiameter 12,5 cm) har en flaske i nedre del for å samle opp biller som blir fanget (1979-modell) (fig. 1A). Den andre (rørdiameter 16 cm) har en trakt nederst som rekker 10 cm ut fra røret på alle sider (fig. 1B). Hensikten med trakten er at også biller som faller ned langs utsiden av røret skal fanges opp (1980-modell).

To typer av feromondispensere ble brukt som lokkestoff i fellene. Begge inneholdt feromonkomponentene til granbarkbillen; methylbutenol (1400 mg), *cis*-verbenol (70 mg) og ipsdienol (10 mg i 1979 — siden 1980 15 mg). Den ene dispenseren er et laminert bånd av plastlag hvor det midtre laget er mettet med feromonkomponentene (Herculite Products Inc., New York, N.Y., U.S.A.). Den andre er en polyethylen pose med et stykke absorberende cellulose som er mettet med feromonkomponentene (Celamerck, Ingelheim, West-Germany). Feromonet diffunderer i begge typene gjennom plastiklagene. Begge dispenserne blir markedsført av Borregaard Ind. Ltd., Sarpsborg, Norge, under handelsnavnet «Ipslure». Plastikpose-dispensere av samme utførelse ble også laget og tilsatt forskjellige doser av feromonkomponenter for å studere effekten av ulik dosering.

Fellene ble plassert på hogstflater som var 2—4 år gamle, minst 20 m fra skogkant, og i forskjellige gruppestørrelser og med innbyrdes avstander som vi fant hensiktsmessig ut fra de forskjellige problemstillingene.

Følgende resultater ble oppnådd:

1. Fellemodellen med den største røroverflate og utvendig trakt (1980-modellen) fanget ca. 90 % flere biller enn 1979-modellen (tabell 1), og fangstene inneholdt en større prosentdel av hanner (tabell 3). Bare 2 ‰ av maurbiller, *Thanasimus*, som lever av barkbiller og lokkes av feromonene, ble fanget i 1980-modeller, sammenlignet med 13 ‰ i 1979-fella (tabell 1).
2. I feller med utvendig trakt blir ca. ⅓ av billene fanget ved hjelp av denne trakten (tabell 2) og andelen av hanner blant disse billene er større enn blant de som fanges gjennom hullene i røret (tabell 3).
3. Temperaturen i fellerøret vil være høyere enn i luften rundt (fig. 4). I perioden 15. mai til 30. juni 1979 ble temperaturen i sentrum av et rør beregnet til å ha vært høyere enn 25° C i 173 timer, sammenlignet med bare 30 timer i luften utenfor.

4. Feller med mørke rør hadde 4—5 ganger så store fangster som lyse rør (fig. 5). Høyere temperaturer inne i rørene p.g.a. solbestråling og sterkere absorbsjon på mørke flater, og dermed økt fordamping av feromoner fra dispenserne, er en naturlig forklaring på forskjellen i fangst.
5. Feller som var ladet med 1 og 2 dispensere hadde den høyeste totale fangst gjennom sesongen (tabell 4). Feller med 4 dispensere hadde lavere fangster tidlig i forsøksperioden, men ga de beste resultatene senere (fig. 6).
6. Dispensere av plastikposer som inneholdt forskjellige doser av de tre feromonkomponentene ga de samme fellefangstene de første ukene, men senere avtok effekten for de dispenserne som hadde lavest doser av methylbutenol og *cis*-verbenol (fig. 7, 8, 9).
7. Dispensere som inneholder feromonkomponenten ipsdienol i tillegg til methylbutenol og *cis*-verbenol gav 60 % høyere fangster enn dispensere uten ipsdienol. Prosenten av hunner var også høyere i fangstene når ipsdienol var med i dispenseren (tabell 6).
8. Begge dispensertypene hadde lokkeeffekt etter 6 uker. De var da brukt i 1979-feller siden 15. mai. Effekten avtok gradvis. Etter 6—8 uker var fangsten i feller med plastikbånd-dispensere redusert med 65 % sammenlignet med nyladede feller, mens det tilsvarende tallet for pose-dispensere var 41 % (fig. 10).
9. Dispensere av begge typer som var lagret ved ca. -20° C i 1 og 2 år hadde beholdt sin lokkevirkning sammenlignet med nyproduserte dispensere (tabell 7).
10. Når feller ble plassert i grupper på 6 og avstanden mellom fellene innenfor gruppen var 0,5 - 1,5 - 3 - 6 eller 12 m kunne det ikke påvises signifikante forskjeller i fangstene (fig. 11).
11. Middelfangsten pr. felle avtok med økende antall feller i fellegruppen (fig. 12). I forsøket var det 3 m mellom fellene innenfor gruppen. På en hogstflate ble 91 feller plassert med 20 m avstand i et heksagonalt mønster (fig. 13). Fellene ble tømt to ganger. Fangsten avtok tydelig fra periferien mot sentrum (fig. 14). Tendensen var den samme begge svermeperiodene (tabell 8).
12. Feller hvor billefangsten fikk ligge i oppsamlingsbeholderen gjennom sesongen hadde ca. 50 % lavere fangster enn feller hvor fangsten ble regelmessig tømt. Reduksjonen var størst i 1979-feller, men signifikant også i 1980-fella (tabell 9).

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