

USING PHEROMONES IN THE MANAGEMENT OF BARK BEETLE OUTBREAKS

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INTRODUCTION

Identification of aggregation pheromones and field experiments using synthetic components have given scientists a better understanding of the behavior of many bark beetles. They have also yielded more effective weapons with which to control outbreaks of aggressive pest species. Synthetic pheromone components are commercially available for control of many species (Borden 1985) and are used in forestry practice in several areas of the world (Vité and Francke 1985). The pheromone may be used as part of an integrated pest management program: for mass trapping, for monitoring of beetle populations, and for inhibition/disruption of beetle infestation.

During the last 10 years we acquired valuable knowledge about the potential of pheromones for practical use. This paper summarizes some of the experience we have gained in our work with the spruce bark beetle, *Ips typographus*.

THE PHEROMONE SYSTEM OF *IPS TYPOGRAPHUS*

The spruce bark beetle, *I. typographus*, is one of the most aggressive and serious pests of Norway spruce in Eurasia. There are two main reasons for their capacity to attack and kill healthy trees. First, they carry a pathogenic blue-stain fungi that invades the sapwood of the tree, induces water stress, and renders the tree susceptible to colonization by the beetles (Horntvedt et al. 1983). Second, they have developed an effective chemical signal system by which to coordinate the attack and to aggregate in masses on selected trees (Bakke et al. 1977, Schlyter et al. 1987).

When the male beetle initiates the boring in the bark of trees, he produces a pheromone which attracts female beetles and other males. The two major components of the aggregation pheromone are (S) chaos-verbenol and 2-methyl-3-buten-2-ol. Ipsdienol, common in many *Ips* species, is also present, but seems to play only a minor role. Two components occur when the females have entered the gallery. These are ipsenol and verbenone, which inhibit response to the aggregation pheromone and act as an antiaggregation pheromone (Bakke 1981).

MASS TRAPPING

Mass trapping of bark beetles to suppress the population is a control measure that has been employed in Europe for more than 200 years. Until 1979 the trap used was a mature fresh tree which was felled in spring and left in the forest during the main flight period of the beetle. When the trunk had been colonized by the beetles it was removed from the forest while they were still breeding in the

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bark. After development of the synthetic pheromone and a trapping technology, the trap tree was replaced by the pheromone-baited trap (Bakke et al. 1983, Vité and Francke 1985).

The Epidemic in Scandinavia in 1970-80

Parts of southern Norway and Sweden suffered from an extensive beetle outbreak in the 1970s. In Norway, trees equivalent to 5 million cubic meters of timber were attacked and killed in an area of 140,000 km², which is equal to the area of East Germany.

Extensive windthrow and severe summer drought combined to cause the outbreaks (Worrell 1983, Bakke 1983). At the same time, many forest areas contained an abundance of overmature trees susceptible to beetle attack.

Methods of the Control Program

The pheromone of *I. typographus* was identified in a research program conducted to search for methods to control the outbreak. Syntheses for commercial production of the pheromone were developed, and a method was devised by which to use the pheromones as bait in traps. A simple trap was designed to replace the trap trees (Bakke et al. 1983).

In 1979, 600,000 drainpipe traps (Fig. 1) were produced and distributed in the outbreak area in Norway. Guidelines were developed for location of the traps. During 1979, 1980, and 1981 several billion beetles were trapped (Table 1).

It must be emphasized that the use of traps alone was not recommended. Traps must be included in an integrated management program. In Norway several measures, both short-term and long-term, were undertaken during the outbreak period. Government funds were available for support of road construction in areas containing overmature stands and for logging in steep terrains. A forest practices law was amended to prohibit storage of unbarked logs in the forest during summer and to require cleanup after storm damage and logging. Besides the mass trapping, felling and removal of beetle-infested trees comprised the main short-term measure. Trapping was not recommended for saving old stands with extensive beetle infestation or stands severely weakened by drought. Only clear-felling was recommended for such stands (Nou 1979).

The Trap Catches

Average catches per trap varied widely between areas and years. In 1980, 10,000-12,000 beetles were the average catches per trap in districts with extensive beetle damage. Traps located at clearcuts from recent winter had the highest catches. During 1979-81 several billion beetles were trapped (Table 1).

More than 99 percent of the insects caught in the traps were beetles of the genus *I. typographus*, but a few percent of those caught in certain localities were *I. duplicatus* which respond to ipsdienol. The clerids, *Thanasimus formicarius* and *T. femoralis*, are attracted by the pheromone (Bakke and Kvamme 1981) and were caught in some number even when the trap had been constructed to prevent them from entering through the holes. The average number of clerids per trap was 1.6 per thousand *Ips* in 1979 and 1.4 in 1980. A new trap model (1980 model) giving *Thanasimus* possibilities of escape retained only 0.5 clerids per thousand *Ips*.

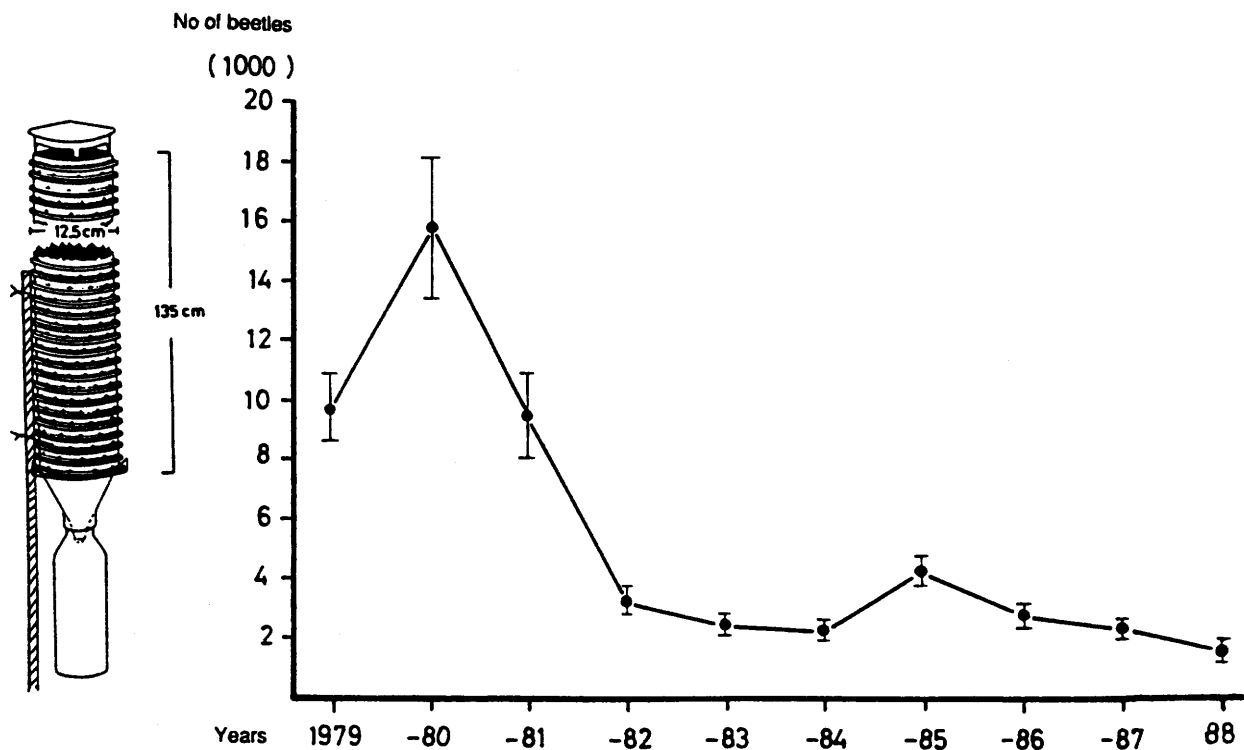


Figure 1. Average catches of *Ips typographus* per trap on fresh clearcuts in districts of southeast Norway during 1979 to 1988. The drainpipe trap is to the left.

Socio-Economic Aspects

A control campaign involving 80-100,000 private forest owners and people employed in forestry, covering the whole spruce area of South Norway and operating on government funds would have to confront problems in the areas of technology, economics, administration, and information dissemination.

Technological Problems

Trapping technology is, of course, an important part of a mass trapping program. The trap model must catch effectively, and pheromone release and composition must be optimal for the trap model. In addition, trap location and trap spacing must be evaluated, and traps must be inexpensive and easy to manage. Later studies (Bakke et al. 1983) have shown that we had good luck with the selection of our trap model, even though it had some weaknesses. Design of the dispenser and composition of the pheromone components had also been successfully estimated (Schlyter et al. 1987).

Economics

During the period from 1978 to 1982 the control program was supported by government funds totaling 90 million Norwegian Kroner, equivalent to 13 million 1988 U.S. dollars. Input from private forest owners came to at least that amount. The government paid 2/3 of the trap costs and about 1.5 U.S. dollars per pheromone dispenser to the producers who had donated them to the project. A rough estimate of the total trapping cost incurred is 6 million U.S. dollars.

Table 1. Number of traps and estimated number of beetles caught in southern Norway in the years 1979-81

Year	Number of traps	Estimated number of trapped beetles
1979	600,000	2,900,000,000
1980	590,000	4,500,000,000
1981	530,000	2,100,000,000

Administration

The Civil Forest Administration was involved in the campaign in the counties and in every municipality. Committees were appointed on every administrative level. The local committee, headed by the district forest officer, coordinated the measures taken; decided on the number of traps each forest owner should deploy, and organized the search for infested trees, often by means of airplanes. The district officer also administered the government grant supporting the measures and provided the information to the local newspapers, television, and radio.

Information

Information about the control program was directed to the general public as well as the forest owners. Information was disseminated by means of leaflets, meetings and conferences, and newspaper articles. The drainpipe trap was used as the symbol of the program and had a great impact on public awareness. Seeing the thousands of beetles trapped in their forest, most forest owners in particular became aware of the hazard of retaining overmature trees.

The general public had to be informed about the pipe traps they would encounter on their hikes in the forest. The function of the traps was explained in newspaper advertising campaigns and on radio and television. The information reached nearly everyone. The beetles even got their own pop song, "Bark-beetle Boogie," which placed on "top of the hits" in Norway for several weeks.

The Decline of the Epidemic

The epidemic began to decline after 1980, and in 1982 it was difficult to find trees killed by the beetle. The decline may have been caused by several factors, probably by a combination of factors (Bakke 1983). Cool and wet summer weather may have restored the resistance of the trees and limited the flight activity of the beetle. Though it is difficult to prove, we believe that the mass trapping campaign also had a significant impact on the beetle population.

For a couple of reasons, the program is not easy to evaluate scientifically. We can estimate the number of trapped beetles, but we are unable to determine the size of the natural population. It is evident from several studies that the beetle disperses over large distances. Traps may be able to attract and catch most of the beetles within a certain area, but new beetles will quickly move in from surrounding areas to fill the vacated space. Actually to reduce the overall population, a larger area must be covered by a trapping program. Our experience further indicates that the most promising results are obtained with a low-density beetle population and in forests which are not too weak.

Today programs using pheromone-baited traps to maintain a low population of *I. typographus* are established in several countries in Central Europe, among them the German Federal Republic, Poland, and Czechoslovakia (Zumr 1987). There, too, traps have replaced trap trees.

MONITORING

Aggressive bark beetles are a threat to the forest only when the population is above a certain threshold. The flying population must be high enough to overcome the resistance of a healthy tree. Knowledge of the population level is therefore of great importance, particularly when external conditions, such as long-lasting drought or stormfelling, favor population increase. Traps baited with pheromones may be useful in monitoring populations and in assessing the risk for damage caused by bark beetle.

Research data for development of a monitoring system for *I. typographus* have been gathered in Scandinavia in recent years. Different sites for deploying pheromone-baited traps have been studied and evaluated. The trapping period required to obtain a good estimate has also been studied (Bakke 1985).

A recently completed Scandinavian collaboration (Weslien et al. 1989) indicates that pheromone-baited traps as well as selected trees baited with pheromones have potential use in assessing the risk for damage caused by *I. typographus*.

The threat of damage to spruce forests in Central Europe as a result of air pollution, intensifies the need to monitor populations of other bark beetles as well (Vité 1984). Germany is using a system which combines monitoring with mass trapping to suppress beetle populations. In Norway, a monitoring system has continued since the great outbreak in the late 1970s. The mean catches per drainpipe traps during the years 1979-88 are given in Fig. 1.

INHIBITION

Pheromone components acting as inhibitors, lowering the attraction to the aggregation pheromone, are known in several bark beetle species. Best known is the MCH from *I. dendroctonus*, which has been applied to windblown trees to prevent beetles from infesting the trunk (Furniss et al. 1977). In addition, pine oil, a by-product derived from pulp mills, shows a semiochemical effect in bark beetle when sprayed on the bark surface of logs and trees (Nijholt 1980).

In *I. typographus* two pheromone components produced from the beetle have shown antiaggregative effect: ipsenol and verbenone. They are also known to inhibit attraction in other bark beetles (Bakke 1981). Combination of the two components produced the best inhibition effect when used together with the aggregation pheromone as bait in traps.

Logs are stored for short or longer periods in the forest, often because in Scandinavia the snow-melting period in spring makes it difficult to use trucks in the forest. To prevent the logs from being infested by bark beetle and used for reproduction, the logs are often sprayed with insecticides. In Norway a field experiment was conducted during a 3-year period to determine whether any of the semiochemicals, when used in controlled release formulation on logs, are able to influence the colonization process of *I. typographus* (Bakke 1987, Schlyter et al. 1989).

All experiments showed that treatments with a combination of verbenone and ipsenol released from laminated structure dispensers significantly reduced the attack density of *I. typographus*, whereas turpentine treatment had no effect on the rate of beetle infestation.

As applied in these experiments, with a rather high dosage of pheromones, antiaggregative semiochemicals may reduce beetle infestation in logs, but do not prevent logs from being attacked. As a consequence of reduction in population density, moreover, the survival rate of the brood may increase due to a more sufficient supply of food for the larvae. This would be very significant because overpopulation is a primary factor in mortality. On the other hand, the ipsenol acts as a kairomone (Bakke and Kvamme 1981) and may attract a larger number of the predator *Thanasimus*, which may eliminate a larger portion of the beetle and its brood.

In my opinion, the pheromone will be an important part of the integrated management of several forest pests in the future.

SUMMARY

Bark beetle pheromone may be used in integrated pest management for mass trapping, monitoring of beetle population, and inhibition/disruption of beetle infestation. This paper reviews our experience in using both the aggregation pheromone and the antiaggregation pheromone for controlling *I. typographus* in Norway. Drainpipe traps baited with synthetic aggregation pheromone components were used for mass trapping as part of an integrated control program during an epidemic. In 1980, 4,500,000,000 beetles were trapped in 590,000 traps distributed in spruce forests in Norway. A monitoring program was developed using traps deployed on recent winter clearcuts. Application of antiaggregation pheromones to spruce logs stored in the forest during summer significantly reduced the attack density of spruce beetles, but the effect was not sufficiently great to make widespread implementation economically feasible.

LITERATURE CITED

- BAKKE, A. 1981. Inhibition of the response in *Ips typographus* to aggregation pheromone: field evaluation of verbenone and ipsenol. *Z. ang. Ent.* 92: 172-177.
- BAKKE, A. 1983. Host tree and bark beetle interaction during a mass outbreak of *Ips typographus* in Norway. *Z. ang. Ent.* 96: 118-125.
- BAKKE, A. 1985. Deploying pheromone-baited traps for monitoring *Ips typographus* populations. *Z. ang. Ent.* 99: 33-39.
- BAKKE, A. 1987. Repression of *Ips typographus* infestation in stored logs by semiochemicals. *Scand. J. For. Res.* 2: 179-185.
- BAKKE, A. and KVAMME, T. 1981. Kairomone response in *Thanasimus* predators to pheromone components of *Ips typographus*. *J. Chem. Ecol.* 7: 305-312.
- BAKKE, A., FRØYEN, P., and SKATTEBØL, L. 1977. Field response to a new pheromonal compound isolated from *Ips typographus*. *Naturwissenschaften* 64: 98.
- BAKKE, A., SÆTHER, T., and KVAMME, T. 1983. Mass trapping of the spruce bark beetle *Ips typographus*: pheromone and trap technology. *Medd. Nor. Inst. Skogforsk.* 38(3): 1-35.
- BORDEN, J.H. 1985. Aggregation pheromones, p. 257-285. In Kerkut, G.A. and Gilbert, L.I., eds. *Behavior*. vol. 9. *Comprehensive Insect Biochemistry and Pharmacology*. Pergamon Press, Oxford.

- FURNISS, M.M., YOUNG, J.W., MCGREGOR, M.D., LIVINGSTON, R.L., and HAMEL, D.R. 1977. Effectiveness of controlled-release formulations of MCH for preventing Douglas-fir beetle (Coleoptera: Scolytidae) infestation in felled trees. *Can. Ent.* 109: 1063-1069.
- HORNTVEDT, R., CHRISTIANSEN, E., SOLHEIM, H., and WANG, S. 1983. Artificial inoculation with *Ips typographus*--associated blue-stain fungi can kill healthy Norway spruce trees. *Medd. Nor. Inst. Skogforsk.* 38(4): 1-20.
- NIJHOLT, W.W. 1980. Pine oil and oleic acid reduce attack on logs by ambrosia beetles (Coleoptera: Scolytidae). *Can. Ent.* 112: 199-204.
- NOU. 1979. Granbarkbillen. Granbarkbille--og grantørkesituasjonen i Sør-Norge: The spruce bark beetle. The bark beetle--and the drought situation in South Norway. Norges offentlige utredninger. vol. 22. Universitetsforlaget, Oslo, Bergen, and Trømso. 71 p. (In Norwegian.)
- SCHLYTER, F., LÖFQVIST, J., and BYERS, A. 1987. Behavioral sequence in the attraction of the bark beetle *Ips typographus* to pheromone sources. *Physiol. Entomol.* 12: 185-196.
- SCHLYTER, F., BYERS, J.A., LÖFQVIST, J., LEUFVÉN, A., and BIRGERSSON, G. 1989. Reduction of attack density of the bark beetles *Ips typographus* and *Tomicus piniperda* on host bark by verbenone inhibition of attraction to pheromone and host kairomone, p. 53-68. In Payne, T.L. and Saarenmaa, H. eds. *Integrated Control of Scolytid Bark Beetles*. VA Polytech. Inst. State Univ. 355 p.
- VITÉ, J.P. 1984. Erfahrungen und Erkenntnisse zur akuten Gefährdung des mitteleuropäischen Fichtenwaldes durch Käferbefall. *Allg. Forst Zeitschr.* 39: 249-252.
- VITÉ, J.P. and FRANCKE, W. 1985. Waldschutz gegen Borkenkäfer: Vom Fangbaum zur Falle. *Chem. unserer Zeit* 19: 11-21.
- WESLIEN, J., ANNILA, E., BAKKE, A., BEJER, B., EIDMANN, H.H., NARVESTAD, K., NIKULA, A., and RAVN, H.P. 1989. Estimating risks for spruce bark beetle (*Ips typographus* L.) damage using pheromone-baited traps and trees. *Scand. J. For. Res.* 4: 87-98.
- WORRELL, R. 1983. Damage by the spruce bark beetle in South Norway 1970-80: A survey, and factors affecting its occurrence. *Medd. Nor. Inst. Skogforsk.* 38: 1-34.
- ZUMR, V. 1987. Reduction of mass outbreak in spruce bark beetle *Ips typographus* (L.) (Coleoptera: Scolytidae), by pheromone traps. *Lesnictvi* 33(1): 49-64. (In Czech with Russian and English summary.)