Comparison of Protection Methods of Pine Stacks against *Tomicus piniperda*

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Three most promising protection methods of pine pulp wood stacks against the attacks of *Tomicus piniperda* were compared. The methods were the covering of stacks by fibreglass-strengthened paper or twofold achrylene netting, removing the upper parts of stacks, and enhanced planning of the placement of the timber store using ARC/INFO GIS-software. *T. piniperda* was observed to strongly prefer the upper parts of the stacks: 90 % of the beetles occurred within 0.5 meters of the top of the stacks. Covering of the stacks decreased the attack density of *T. piniperda*, and the protection effect of covering was 80 %. Due to long transport distances and fragmentation of forest landscape the relocation of timber store was found to be an unsuitable method in the practical level. Also, taking into account the costs of the method, removing of the upper parts of stacks was considered to be the optimal solution.

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1 Introduction

Modern timber harvesting methods and the fresh timber required by the forest industry have led to round-the-year forest cuttings. Consequently, wood stacks have been stored along forest roads also during summer. Many insect pests, especially bark beetles, breed in these stacks and disperse in the surrounding forests causing losses in quality or growth of living trees or even death of trees.

A Finnish law on the prevention of forest insect and fungi damage (Laki metsän...263/91) came into force on July 1, 1991 and the corresponding decree (Asetus metsän...1046/91) was set on August 1, 1991. According to these laws, it is not allowed to store fresh unbarked timber so that storing causes insect damage to the surrounding forests. Therefore, timber must be either removed from cutting areas or temporary timber stores by the dates mentioned in the law, or protected by other means. These include irrigation, chemical protection, right location of the timber stacks, covering of the timber stacks, debarking or removing the uppermost parts of the stacks. More detailed information about the methods are described in the decision of the Ministry of Agriculture and Forestry (Maa- ja metsätalousministeriön päätös...1397/91), but it has no exact definition about the uppermost parts of stacks.

The aim of the present study was to investigate the usability of the three potentially most promising protection methods in practical forest protection, partly by utilizing a geographical information system (GIS). The selected methods were: 1) covering of stacks 2) removing the uppermost parts of stacks, and 3) enhanced planning of the placement of the stacks using a GIS. The study was restricted to pine pulp wood stacks and the common pine shoot beetle, *Tomicus piniperda* L. (Coleoptera, Scolytidae), breeding in these stacks.

2 Material and Methods

2.1 Covering of Stacks

The experiment was carried out in the communes of Juupajoki and Längelmäki in southern Finland in 1992. Four sample stacks in different places (four replicates) were selected, and they consisted of about 5 m long pine pulp wood bolts.

All sample stacks were divided into three parts of approximately equal size (treatments). The length of the parts varied from 4.7 m to 16.4 m and the volumes from 30 to 160 m^3, respectively. The first part was covered with fibreglass-strengthened paper, the second one by twofold achrylene netting, and the third one was left uncovered (control). The paper and achrylene covers extended downwards one meter on both sides of the stacks. The cover was fastened with paper staples to the sides of the stacks. In addition, pine bolts were used as weight on top of the stacks.

Sample bolts from the stacks were chosen from 4 to 6 vertical lines using 0.5–1 m buffers between the treatments. Sample bolts were selected from these lines at levels of 0.0, 0.2, 0.5, 1.0, 1.5 and 2.0 m from the top of the stacks (levels A–F, Fig. 1).

Marked sample bolts were checked from July 1 to August 15, 1992. The sample stacks were unloaded by using a truck's hydraulic knuckle boom loader. The sample bolts were debarked by a barking spud. After debarking, mother galleries of *T. piniperda* were counted and possible bark damage which may have reduced the usable phloem area of *T. piniperda*, were estimated from each sample bolt. Because *T. piniperda* breeds only under thick bark, only the sample bolt sections in which the bark thickness were bigger than or equal to 3 mm, were considered as suitable breeding material for *T. piniperda* (Annila and Petäistö 1978, Saarenmaa 1983, Långström 1984). Finally, the attack densities were calculated by dividing the number of mother galleries by the phloem area (m^2) suitable for *T. piniperda*.

In this study the protection effect was first evaluated by taking into account the levels remaining properly under the cover (levels A–D). A total number of 244 sample bolts were gathered from these levels. In covered stacks the attack of *T. piniperda* may be more heavily concentrated on the lower parts of stacks. Therefore the protection effect was also estimated in levels A–F, giving a total number of 348 bolts.

The data were condensed to 12 average values of attack densities (four sample stacks each having three treatments) and the analysis of variance was based on these. Nonparametric Friedman's two-way analysis for block designs was obtained, and the stacks were considered to be the blocking factor.

Saarenmaa (1983) has described the production of *T. piniperda* by using the following model:

$$P = 15.64A - 0.02071A^2 \tag{1}$$

where P is the production of *T. piniperda* per bark m^2 and A the attack density/m^2 (mother gallery density/m^2). This model was used to transform the observed attack densities into estimated production of *T. piniperda*.

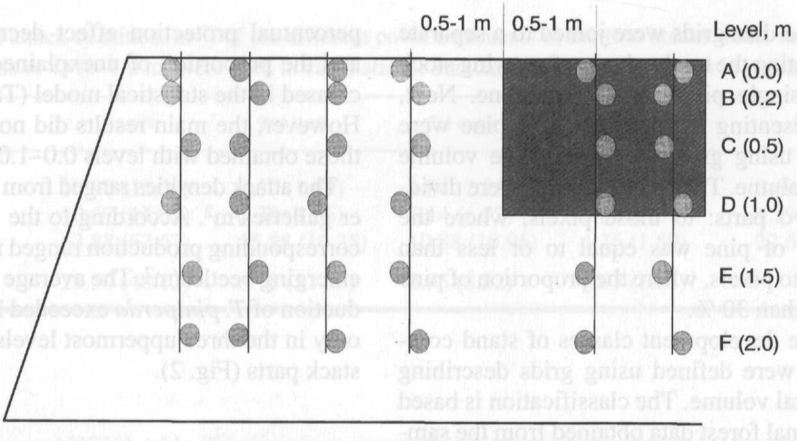

Fig. 1. Schematic illustration of a stack, in which the sample bolts were taken from six levels (A–F, 0–2 meters, respectively) from the top. The shaded area illustrates part of the covered treatment.

2.2 Removing the Upper Parts of Stacks

To evaluate the thickness of the layer which was thick enough to be removed, the control treatments of the four sample stacks were examined. The sample bolts were chosen from levels A–F, i.e. down to 2 m from the top of the stacks, giving a total number of 110 logs. The percentual shares of attack densities in different levels were used to estimate the protection effect of the method.

2.3 Relocation of the Timber Store

According to law 263/91 timber stores must be located so that they do not become a risk to the surrounding forests. Thus, the distance from the store to a stand, where the stand is of the same tree species as that in the store and the volume proportion of that species in the stand is bigger than 30 %, must fulfill the conditions mentioned in Table 1 (Maa- ja metsätalousministeriön päätös...1397/91). These distances were used as criteria when defining suitable relocation places in the commune of Längelmäki. There were altogether 51 stacks in the commune which were fresh enough to require protection. The material was analysed using ARC/INFO GIS-software.

Stack, road and stand information were first represented as separate coverages: the stacks were represented as points, the roads as arcs and the stands as polygons. The road coverage was obtained by digitizing the main roads of the study area and the forest roads having stacks by the road. The stand coverage was obtained from the National Forests Inventory's analysis of remotely sensed imagery taken by the Landsat 5 Thematic Mapper on 21.6.1990. The pixel size of acquired material was 25 m × 25 m.

The satellite data were manipulated by an ARC/INFO GRID-module designed to handle raster data. In the material, different stand variables were expressed as separate thematic layers (grids). For this study, grids describing the volume of pine, spruce, birch and other tree species as well as grid describing stand age were used.

Table 1. The minimum distances to be used in the proper location of timber stacks according to the decision of Ministry of Agriculture and Forestry (1397/91)

Size of store	Seed tree or shelterwood stand or young stand	Other stand
< 100 m³	200 m	100 m
> 100 m³	400 m	200 m

The volume data grids were joined to a separate grid presenting the total volume of growing stock on every single pixel in the commune. Next, grids representing the proportion of pine were calculated using grids describing pine volume and total volume. The resulting grids were divided into two parts: to those pixels, where the proportion of pine was equal to or less than 30 %, and to pixels, where the proportion of pine was more than 30 %.

Next, the development classes of stand compartments were defined using grids describing age and total volume. The classification is based on communal forest data obtained from the sample plots of the National Forest Inventory.

Finally, a grid representing 'danger classes' was acquired by combining the grids describing the proportion of pine and development classes in an appropriate way. Grid 'danger classes' was converted from raster format to vector coverage and polygons having an area less than 0.3 ha were eliminated. The danger classes in the final print are represented using colour codes (see Fig. 3).

To find possible storing places, stack, road and danger class coverages were overlaid. From the resulting coverage the nearest approvable storing place for each stack was examined by the forest road in question.

3 Results

3.1 Protection Effect of Covering Stacks

As compared with the uncovered, paper and achrylene covers reduced significantly the attack density of *T. piniperda* when sample bolts from levels 0.0–1.0 m (A–D) were taken into account (Tables 2 and 3). The average attack density in the cover treatments was more than 80 % lower than in uncovered stack parts. Differencies between cover materials were not statistically significant according to Tukey's test (alpha = 0.05). The differencies between stacks were statistically significant, since sample stack 1 had higher attack densities than other stacks.

When sample bolts from levels 0.0–2.0 m (A–F) were taken into account, the average attack densities of stacks and treatments as well as the percentual protection effect decreased slightly and the proportion of unexplained variation increased in the statistical model (Tables 4 and 5). However, the main results did not change from those obtained with levels 0.0–1.0 m.

The attack densities ranged from 0 to 274 mother galleries/m^2. According to the model (1), the corresponding production ranged from 0 to 2731 emerging beetles/m^2. The average estimated production of *T. piniperda* exceeded 200 beetles/m^2 only in the three uppermost levels of uncovered stack parts (Fig. 2).

3.2 Protection Effect of Removing the Upper Parts of Stacks

Considerable differences in attack densities were observed between the sample stacks also in the uncovered treatments. No sample bolts could be taken from 2.0 m level (F) from stack 1 raising the average attack density of this stack slightly. The average attack densities/m^2 at the levels of 0.0, 0.2, 0.5, 1.0, 1.5 and 2.0 were 42.8, 27.3, 15.9, 4.1, 4.2, and 1.4, respectively. Thus, 90 % of the beetle attacks were concentrated in the three uppermost levels.

3.3 Proper Relocation of Timber Store

It was very difficult to find temporary timber store places as prescribed by the law. Thus, in the commune of Längelmäki only 12 of 51 stacks could have been relocated in a desirable way. These four possible storing sites are indicated by black dots in Fig. 3. The distances of transports, which would have had performed as extended short distance hauls, would have varied from 150 m to 3400 m. The average distance was 1560 m.

4 Discussion

4.1 Covering of Stacks

Protection results in studies dealing with the covering of timber stacks have showed some variation. Although in Sweden, results were promis-

Table 2. Mean attack densities (m^{-2}) of the different cover treatments in the four stacks when sample logs from levels A–D (0–1.0 m) were used in calculations. Standard deviations are given in parentheses.

	1st stack	2nd stack	3rd stack	4th stack	Mean
Paper	10.97 (12.09)	1.30 (1.69)	1.84 (2.25)	0.79 (2.13)	3.60 (7.23)
Achrylene	10.67 (14.05)	1.38 (1.66)	5.14 (6.72)	0.99 (1.31)	4.29 (8.06)
Uncovered	63.88 (67.67)	15.88 (16.35)	10.88 (10.96)	1.16 (1.59)	22.67 (40.86)
Mean	29.50 (48.12)	6.11 (11.59)	5.95 (8.32)	0.97 (1.68)	

Table 3. Two-way ANOVA table (Friedman's nonparametric analysis for blocked design) of attack densities calculated from levels A–D. Stack is used as the blocking factor.

Source	df	SS	MS	F	P
Stack	3	6104.26	2034.75	8.01	0.0001
Treatment	2	19008.86	9504.43	37.42	0.0001
Error	238	60445.14	253.97		
Total	243	85558.26			

Table 4. Mean attack densities (m^{-2}) of the different cover treatments in the four stacks when all sample logs (levels A–F) were used in calculations. Standard deviations are given in parentheses.

	1st stack	2nd stack	3rd stack	4th stack	Mean
Paper	9.17 (10.56)	1.75 (2.50)	2.23 (2.60)	0.60 (1.78)	3.41 (6.36)
Achrylene	10.09 (12.59)	2.23 (3.16)	4.22 (5.79)	1.05 (1.31)	4.11 (7.24)
Uncovered	55.50 (64.05)	12.00 (15.16)	7.92 (10.28)	1.10 (1.50)	17.75 (36.33)
Mean	23.84 (42.23)	5.10 (9.85)	4.76 (7.26)	0.91 (1.54)	

Table 5. Two-way ANOVA table (Friedman's nonparametric analysis for blocked design) of attack densities calculated from levels A–F. Stack is used as the blocking factor.

Source	df	SS	MS	F	P
Stack	3	23040.98	7680.33	12.93	0.0001
Treatment	2	33476.67	16738.33	28.18	0.0001
Error	342	203136.83	593.96		
Total	347	259654.48			

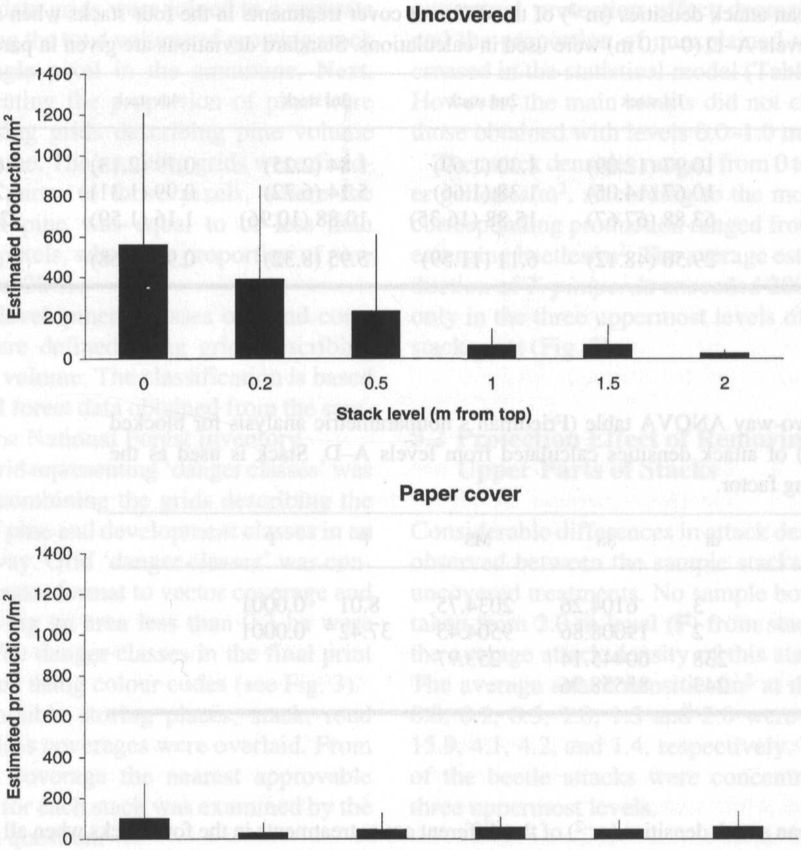

Fig. 2. The average estimated production of *T. piniperda* in different levels (A–F) and treatments. Vertical lines indicate standard deviation.

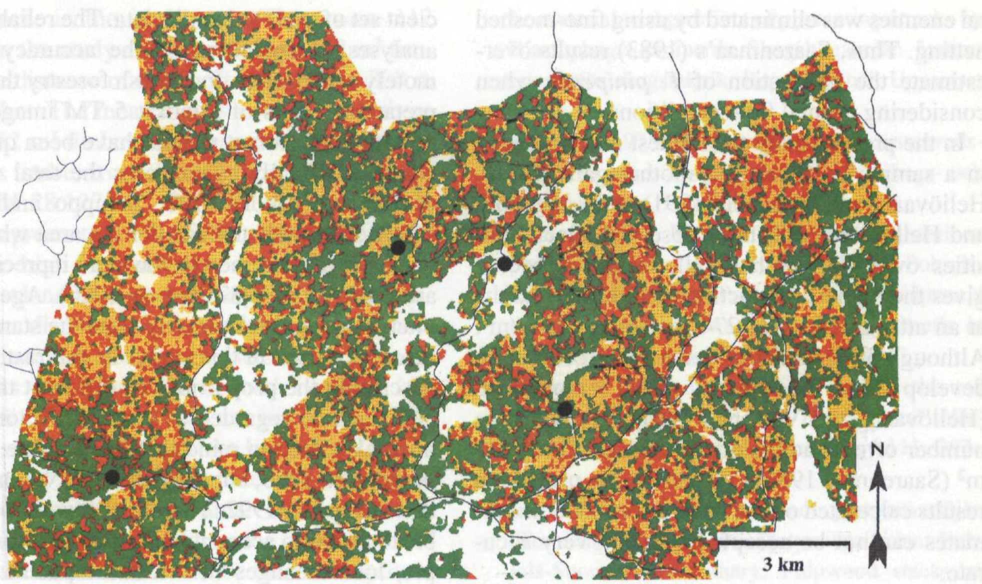

Fig. 3. A part of the commune of Längelmäki with danger classes. The distances from the stacks to a compartment coded red must be at least 200 (or 400) meters and to a orange compartment 100 (or 200) meters. The green areas describe areas where storing is allowed (see Table 1). White areas are lakes and open fields. Existing stacks are indicated by black boxes. The four possible storing sites are shown by black dots.

ing when spruce stacks were covered with plastic against the attacks of *Ips typographus* L. (Regnander 1975), the protection effect against *T. piniperda* has been less satisfactory. According to Dehlén and Nilsson (1976) *T. piniperda* only moves to the lower parts of stacks when the upper parts are covered with plastic. In southern Finland the achrylene netting gave quite poor a result: the protection effect was on the average 61 % even if the cover was twofold (unpublished). Very promising results were obtained with plastic covering (protection effect > 90 %) by Heikkilä (1978) in northern Finland and Juutinen (1978) in southern Finland.

The differences between the studies can partly be explained by climatic factors. In climatically favourable regions *T. piniperda* is able to breed also in the colder lower parts of stacks (Dehlén and Nilsson 1976, Ehnström 1975, Långström et al. 1984). However, in colder regions *T. piniperda* does not have enough time to develop into new adults (Juutinen 1978, Långström et al. 1984, Saarenmaa 1985a,b). In the present study the protection effect calculated from attack density was over 80 %. Thus, covering timber stacks so that the cover comes down one meter on both sides of a stack can be considered to give satisfactory protection in Finland.

Estimates of the influence of attack density on the production of *T. piniperda* have been made by Annila and Petäistö (1978), Långström (1984), Saarenmaa (1983) and Salonen (1973). The studies of Annila and Petäistö (1978) and Långström (1984) were made using windthrown trees, where root connections are partially in place. Saarenmaa (1983) and Salonen (1973) used fresh 2 m long bolts as breeding material. The production results of all these studies agree with each other. However, according to Salonen (1973) at an attack density of 301–400 mother galleries/m^2 the number of new adults decreases more radically as compared to that stated by Saarenmaa (1983). This can be partly explained by the fact that in Saarenmaa's (1983) study the influence of natural enemies was eliminated by using fine-meshed netting. Thus, Saarenmaa's (1983) results overestimate the production of *T. piniperda* when considering normal field conditions.

In the present study the highest attack density in a sample bolt was 275 mother galleries/m^2. Heliövaara and Väisänen (1991) and Långström and Hellqvist (1988) have observed attack densities over 400 mother galleries/m^2. Model 1 gives the highest production of 2731 new adults at an attack density of 274 mother galleries/m^2. Although 3000 adults/m^2 have been recorded to develop in exceptional field conditions (Heliövaara and Väisänen 1991), normally the number of new adults do not exceed 1700 ind./m^2 (Saarenmaa 1983). Therefore, the protection results calculated on the basis of production estimates can not be accepted as being very accurate.

4.2 Removing the Upper Parts of Stacks

According to Långström et al. (1984) piling small timber stacks on bigger ones remarkably reduces the production of *T. piniperda* per cubic metre of timber. Our present results strenghten the assumption about the preference of *T. piniperda* for attacking the upper parts of uncovered stacks. Removing a layer 0.5 m thick from the top of stacks as a protection method will provide satisfactory protection result, especially if the timber is driven to paper mills immediately. However, this treatment has the embedded cost of two visits required by a transport vehicle. Due to the limited running capacity of paper mills and the periods of frost damaged roads, timber must be transported first to logging terminals. Because logging terminals are often closer to the final processing places, the costs of transporting stacks from field to logging terminals are not purely extra costs.

4.3 Relocation of Timberstore

It is probable that in the future entomological problems will be solved more frequently by using remotely sensed data (Liebhold et al. 1993). Geographical information systems offer an efficient set of tools to handle data. The reliability of analyses is dependent on the accuracy of remotely sensed data. In Finnish forestry the interpretation results of Landsat 5 TM imagery applied to large forest regions have been quite accurate, especially as concerns the total volume of forests (Tokola 1990, Tomppo and Katila 1993). However, the smaller the area where the results are determined to, the more inprecise they are (Poso et al. 1987, Tokola 1990). Age can be interpreted most accurately from the stand characteristics used in this study. In contrast, results describing the proportions of different tree species must be regarded as less satisfactory. One must also keep in mind that the satellite images were taken 1990, but the field observations were done in spring 1992. Therefore, it was not possible to take into account in the analysis, for example, local changes in the development classes due to timber cuttings.

4.4 Costs of the Protection Methods

In practice, to choose the right protection method one must also take into account the protection effect as well as the expenses of the method. When covering stacks, the total costs are composed of the covering materials, the expenses involved with driving from stack to stack and the covering work. In addition, when unloading the stack, the cover should be taken off if the cover is to be reused. Typically the cover will tear quite easily because of wind, and therefore the same cover cannot be used year after year. If the cover contains even small pieces of plastic, the cover must be taken off carefully to avoid plastic getting into the paper production process. Assuming that the price of paper is FIM 1.85/m^2 and that of achrylene FIM 2.50/m^2, and that the driving costs FIM 1.48/km and working hour FIM 33.75, the costs for covering of a stack are FIM 334 for paper and FIM 152 for achrylene. Total expenses for covering all the stacks in the study area are FIM 25 000 for paper and FIM 51 000 for twofold achrylene. These figures represent 2.4 % and 5.0 % of the monetary value of the stacks.

As compared with covering, the total costs of transportation of the upper parts of the stacks were lower in the study area. There were 112 stacks in the study area containing 2462 m^3 timber. The distance of transport varied from 800 m to 20.4 km. The mean load was 44 m^3, and there was 1652 m^3 timber to be transported. To transport this timber from the upper part of the stacks cost FIM 28 127 i.e., FIM 251 per stack. This figure represents 6.4 % of the value of the stack.

Due to high fragmentation degree of the Finnish forest landscape and consequently long transportation distances, it is difficult to find new legal relocation sites for the stacks. To relocate 12 stacks cost FIM 2370 in total, i.e. FIM 198 per stack. However, it was not possible to relocate 39 stacks according to the law, which makes this method unsuitable in practical forestry at least in the present study area. This leads us to the conclusion that removing the upper parts of stacks can be considered to be the most optimal protection alternative.

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