Forest characteristics affecting the rate of shoot pruning by the pine shoot beetle (*Tomicus piniperda* L.) in *Pinus radiata* D. Don and *P. sylvestris* L. plantations

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Summary

Different variables, such as altitude and presence of defoliators, were studied in Bizkaia (northern Spain) in order to assess the susceptibility of *Pinus radiata* (D. Don) and *P. sylvestris* (L.) stands to *Tomicus piniperda* (L.) (Coleoptera: Scolytidae). Altitudes higher than 400 m, presence of logs, degree of thinning and incidence of fires, all increased the susceptibility of *P. radiata* monocultures to shoot attack by *T. piniperda*. *P. sylvestris* plantations were more affected at altitudes lower than 400 m and by poor forest hygiene. The presence of the processionary moth (*Thaumetopoea pityocampa* Den and Schiff.) had a significant effect on the rate of shoot pruning on the trees; vigorous trees and those with bare leader were more affected by the bark beetle attack if *T. pityocampa* larvae were feeding on their needles, while trees with dominance taken by the side shoots were less attacked when moth larvae were present.

Introduction

Conditions under which trees are grown have an important influence on their resistance to attack by insect pests. Many pest problems are due to alteration of forests and forest soils by man growing tree species on sites to which they are ill-adapted or in kinds of forest stands that are unduly favourable to certain pests (Pesson and Chararas, 1969; Smith, 1976). Damage by forest insects may be linked to certain cultural conditions such as 'site' on which the trees are grown, the stage or rate of growth and the density of trees (Schroeder, 1987; Speight and Wainhouse, 1989). Pesson and Chararas (1969) found that the introduction of an exotic species ill-adapted to the region affected the rapid

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multiplication of scolytids in the stands. However, environmental factors such as lightning strikes, large fire scars or drought can also lead to serious pest problems (Hopping and Mathers, 1945; Christiansen *et al.*, 1987; Cameron and Billings, 1988).

In general, traditional silvicultural practices of planting the right species of tree in the right environment, and managing the forest for vigorous growth followed by timely harvest, have contributed to minimize the risk of insect outbreaks triggered by site or other cultural factors. But the increasingly widespread practice of planting exotic tree species in new ecological settings, not only in Europe and other developed countries but also in tropical regions (Evans, 1982; Savill and Evans, 1986) places greater emphasis on the role that forest practices can play in insect control.

Tomicus piniperda L. (Coleoptera: Scolytidae) is a serious pest of pine in Europe, northern Africa and Asia (Eidmann 1985; Bouhot *et al.*, 1988; Hui, 1991) and in 1992 was first discovered in United States (McCullough and Smitley 1995). High populations of this beetle can reduce tree growth and cause tree mortality (Langstrom and Hellquivst, 1985; Eidmann, 1985; Hui, 1991).

Pinus radiata D. Don, native of California, is a commonly used exotic species in forest plantations in Bizkaia. The object of this study was to determine which of the factors such as pine species (*P. radiata* or *P. sylvestris*), altitude, forest sanitation (e.g. presence of breeding material), presence of fire and other site attributes (e.g. presence of defoliators) affected the attack rates of *T. piniperda* on shoots in forest plantations in northern Spain.

Methods

A total of 61 sites were visited throughout northern Spain, in the counties of Bizkaia and Araba (Basque Country), located on the 42°N parallel. The sites surveyed varied from high attack areas to sites with no attack, and covered a range of altitudes from sea level to 800 m. Each site was first visited with the local forest ranger who described the history of the site (tree age, number of thinnings, fires and tree density). Additional information was recorded at each site: altitude, slope, orientation, soil type, presence of fires, thinning, presence of logs and litter, tree age, tree diameter, stand density and ground vegetation. Altitude was measured using a portable altimeter. At the same time, the slope of the sampled area was noted, varying from flat to a slope of roughly 60°, and categorized as either flat, half slope or steep slope. Site orientation (north, south, east and west) was recorded with a pocket compass. Soil type was classified as either sandy, intermediate or clay. Ground vegetation was recorded as: dense shrubs, open shrubs, dense grass, open grass or bare. The quantity of logs on the forest floor was categorized according to the numbers of logs seen at the time the site was visited. Three categories were used: none, some (meaning a few dead trees) and many logs in the near vicinity (i.e. close to an area where the logs are kept before taking them out of the forest). The amount of brash was categorized as: clear, some and lots of branches around. These two measures give an idea of the level of forest hygiene.

The survey was carried out between March and April, when previous studies (Amezaga, in press) had shown that spring maturation feeding by *T. piniperda* should have been finished. However, there is always a possibility of a phenological effect due to altitude or other environmental factors. Within each site an area of 100 × 100 m was chosen and 30 trees were randomly selected (numbered and selected by a random draw) and the following information was gathered from each tree: leader condition or state of the main shoot, canopy form, crown density, presence of processionary caterpillar (*Thaumetopoea pityocampa*) (Lepidoptera: Thaumetopoeidae) nests, attack density and tree diameter. The first three variables were evaluated following the method of Innes (1990). Crown density was recorded using scores which represented the amount of light passing through the crown. However a high score does not necessarily mean that a tree has lost foliage. Rather, it indicates that it does not have as much foliage as a completely dense tree. The reduction in crown density was assessed in 5 per cent classes and photographic standards, similar to those from Innes (1990), were used. The presence of nests of the processionary caterpillar was recorded by counting the number of nests in the tree, and noting their damage (amount of defoliation of the canopy of the tree) as none, light, moderate or heavy. Damage caused by *T. piniperda* was measured by examining the upper whorls of the crown of the trees, where Langstrom (1980) found the higher proportion of affected shoots, with a pair of binoculars and making a visual estimate of the percentage of shoots at the top of the tree that had been attacked. The evaluation was always done by the same person (assuming that any random or systematic error remained the same for all trees) and it was done by looking at the number of drooping, brownish shoots and the number of shoots that had the top part missing, pruned by the beetles. This method was previously assessed making the recordings on 15 trees and cutting them down in order to do a direct sampling. The tree girth was measured using a tape measure at breast height.

Data analysis

Data analysis was carried out using GLIM (Generalized Linear Model) with the percentage of shoots at the top of the tree attacked by *T. piniperda* as the dependent variable. Percentages were transformed using an angular transformation. There was insufficient replication within sites to obtain meaningful interaction effects in most cases, and so the only interaction effects studied were those involving *T. pityocampa*. The different variables were reviewed by step-wise removal from the maximal model in order to determine to the simplest model (the so called minimal adequate model, see Crawley, 1993).

Terms were retained in the model if, following their deletion, there was a significant increase in residual deviance. Insignificant terms were left out of the model.

Results

Out of the 61 sites visited, five were *P. pinaster* plantations. However, due to the small number they were used only for the analysis of the effect of the processionary moth on the pine shoot beetle attack on shoots.

Pinus radiata

Out of the 61 sites visited, 37 were *Pinus radiata* plantations. The analysis (Table 1) showed a significant increase in *T. piniperda* attack due to a history of recent fires (passing through them and adjacent areas, two years previous to this study, in 1990) and the presence of logs on the forest floor (Figure 1a). Altitude also had a significant effect, with attacks increasing at altitudes higher than 400 m. Thinning, however, had a negative effect on the severity of attack (Figure 1a). Soil type, orientation and brash seemed to have no effect on level of attack suffered by *P. radiata* (Table 1).

Table 1: Table of the ANOVA carried out on angularly transformed dependent variable (percentage of shoot attacked at the top of the tree) at *P. radiata* sites in order to find the Minimal Adequate Model, showing the significant variables with a $P<0.05$. During model simplification, some of the levels of the factors were aggregated showing only the significant levels. The degrees of freedom do not add up to 36 because insignificant model terms have been omitted

Treatment	SS	d.f.	MS	*F*
Fire	0.9835	1	0.9835	34.83
Log	0.1424	1	0.1424	5.045
Altitude	0.5724	1	0.5724	20.27
Thinning	0.1476	1	0.1476	5.229
Error	0.2541	9	0.02824	
Total	2.7870	36		

However, if the effect of altitude was studied on its own, and if the sites over 500 m, which were mixed stand areas, were left aside, altitude was seen to be related to attack density such that:

$$y = 0.16 + 0.001\,x$$
$$\text{s.e.} \quad 0.08 \quad 0.0002$$

where x=alt (m) and y=ang (% of attack), $r^2=0.36$, $n=34$ and $P<0.001$. Further, if the three *P. radiata* sites above 500 m, which were mixed stands, were added to the sample, the quadratic term was significant, which means that there was a significant non-linearity with altitude.

Supporting such interpretation, a partial correlation analysis that controlled for the potential

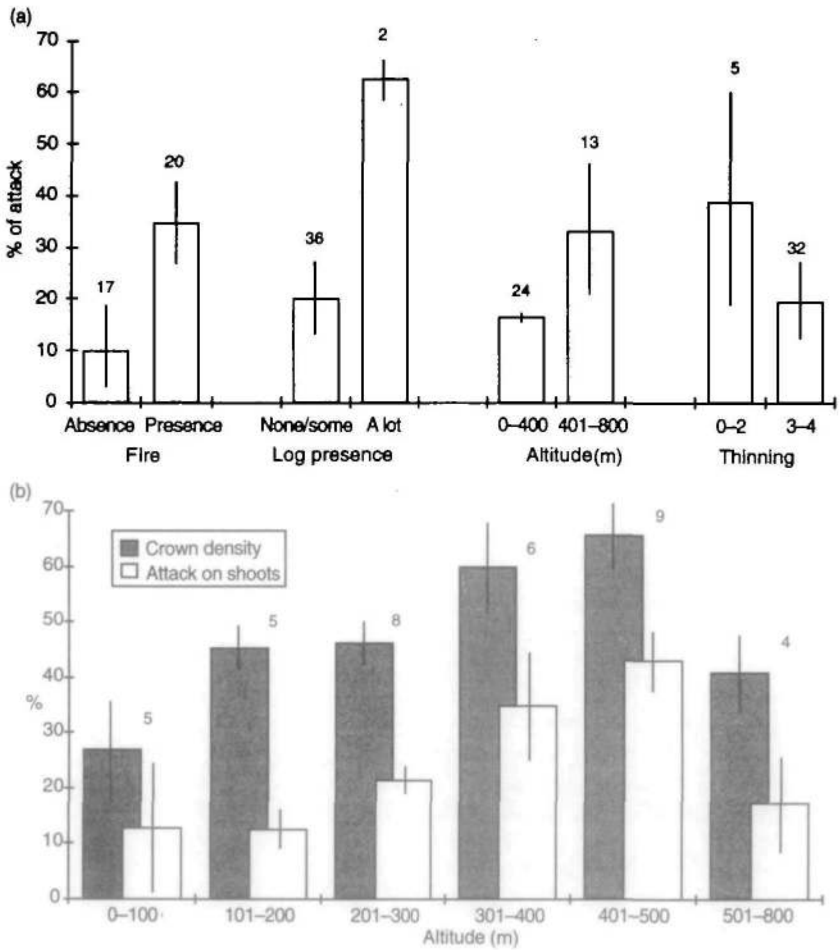

Figure 1. (a) The four different factors that had a significant effect on the attack of *T. piniperda* on the shoots of *P. radiata* using only the categories which were shown to be significant in the model after aggregating them: fire measured with presence and absence of fires; log presence, using only the two categories significant in the model (logs effect recorded as 'none/some', which means none or a few dead trees lying in the surrounding areas, and 'a lot', which means the site being close to an area where the logs are kept before removal from the forest); altitude aggregated in two categories (up to 400 m and over 400 m); thinning aggregated in two categories (up to two thinnings and more than two). Confidence intervals for the means are indicated (95% of confidence interval for the attack mean after back-transformation, n = number of trees).
(b) Percentage of attack and crown density values for each category of altitude for *P. radiata* plantations. Crown density was measured as scores of the amount of light passing through the canopy, so as altitude increases the canopy was thinner and more light passed through it. Standard errors of the mean are indicated (n = number of sites).

confounding effects of altitude, showed a significant correlation between attack and crown density (measured as scores of amount of light passing through the crown, $r_{partial}=0.86$, $P<0.001$, $n=37$), whereas there was no dependence of attack on altitude when crown density was eliminated ($r_{partial}=-0.12$, $P=0.48$, $n=37$). Therefore, it was concluded that the correlation of attack with crown density was not affected by altitude (Figure 1b).

Pinus sylvestris

Out of the 61 sites visited, 19 were *P. sylvestris* plantations. The data showed that only altitude and presence of logs had a significant impact on the attack of *T. piniperda* on *P. sylvestris* shoots (Table 2). At low altitude (300 m) this pine species was more susceptible to attack than at higher altitudes (400 m upwards) in contrast to *P. radiata* (above) (Figure 2a). The presence of logs, especially just before the swarming period of *T. piniperda*, provided breeding material, thus increasing the beetle population which then resulted in more attacks on the shoots (Figure 2a).

Table 2: Table of the ANOVA carried out on the *P. sylvestris* sites in order to find the Simplest Model, showing all the factors which explained a significant part of the variance in the model with a $P<0.05$. During model simplification, the levels of altitude (m) were aggregated from three categories (301–400, 401–500, 501–700) to two (300–400, 401–700). The degrees of freedom do not add up to 18 because insignificant model terms have been omitted for the table

Treatment	SS	d.f.	MS	*F*
Altitude	0.1313	1	0.1313	8.056
Logs	0.0763	1	0.0763	4.685
Error	0.1793	11	0.0163	
Total	0.4396	18		

Orientation and soil type did not have any effect on the degree of damage measured. However, this could be due to the small size of the sample which may not have represented sufficient variation in all the parameters. *P. sylvestris* plantations are not as common as those of *P. radiata*, because the former species is usually planted at altitudes above 300 m. Besides, lately *P. pinaster* is replacing *P. sylvestris* because it grows faster.

Processionary caterpillar effect on the pine shoot beetle attack on shoots

For this analysis, all 61 sites were considered. Despite assessing four levels (none, light, moderate and heavy) for the caterpillar presence in the trees, only two levels were used in the model (presence and absence). There was a significant interaction between the presence or absence of the caterpillar in the crown of the trees and the attack rate on the shoots (Table 3). The effect of the presence of the caterpillar was significantly correlated with attack of *T. piniperda* on the shoots when the main shoot of the trees was in category 6 (bare) or 8 (good) (Figure 2b). The category 6 trees had, without the attack of the caterpillar, the highest attack rate by the beetle, the presence of the caterpillar in this category reducing the attack rate on them. The same effect was found on trees in category 7, having the opposite effect on trees in category 8.

Table 3: Table of the ANOVA performed on the angularly transformed data of the attack of *T. piniperda* in studied trees. The table shows the significant effect of the state of the main shoot (M) and the presence of the processionary caterpillar in the trees (Pr) on the attack of the pine shoot beetle on the shoots. Categories of the main shoot: 1-shorter than current, 2-missing, 3-bent or twisted, 4-double, 5-broken, 6-bare, 7-side shoots taken up dominance, 8-good and 9-tree dead

Treatment	SS	d.f.	MS	*F*
M	101.7	8	12.71	118.78***
Pr	0.93	1	0.93	8.69*
M × Pr	5.53	6	0.92	8.61***
Error	194.02	1810	0.10	
Total	302.21	1825		

*$P<0.05$, ***$P<0.001$.

In order to see which category of trees was the least attacked by *T. piniperda* in the absence of the caterpillar, a *t* test was carried out between the least attacked categories, (2) and (8). Trees belonging to the category (8) were significantly less attacked than those of category (2). Thus, vigorous trees were the least attacked by *T. piniperda*. However, as it has been said above, the presence of the caterpillar increased significantly the beetle attack on them (Figure 2b).

Categories (1=shorter than current), (3=bent or twisted), (4=doubled) and (7=side shoots dominant) did not show a significant difference with or without the presence of the caterpillar and in categories (2=missing) and (5=broken)

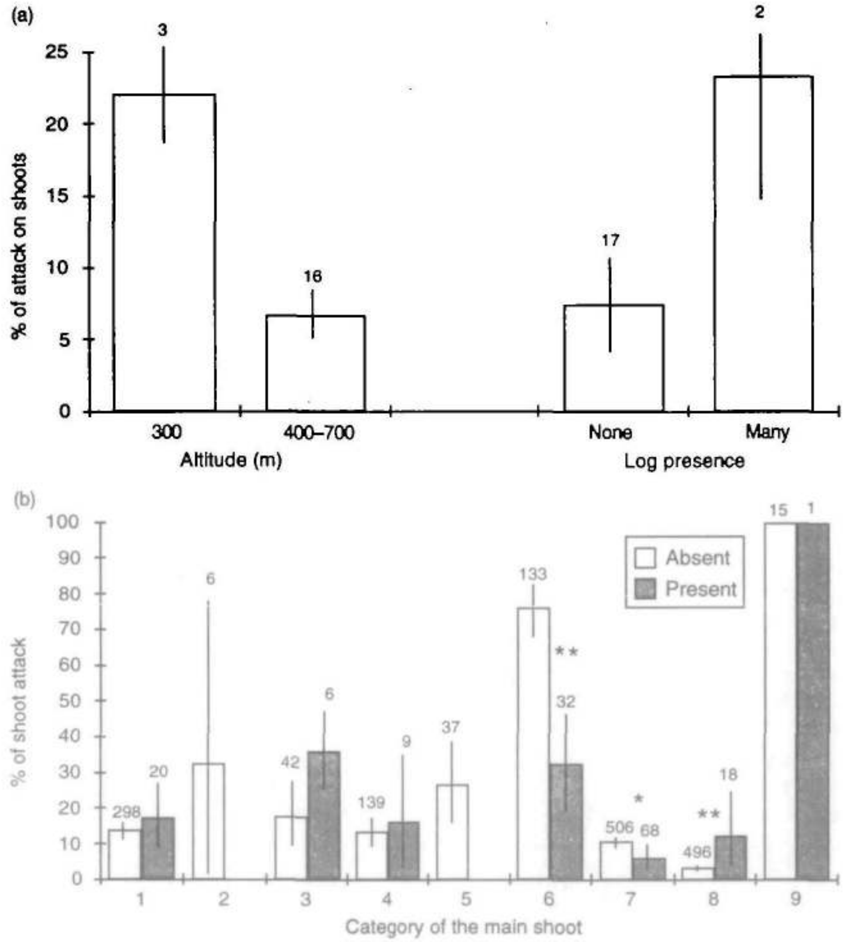

Figure 2. (a) Altitude and log effect on the attack of *T. piniperda* on the shoots of *P. sylvestris* using only the categories which were significant in the model after aggregating them: altitude aggregated in two categories, 300 m and from 400 to 700 m, and the category of log aggregated in two categories, 'none' and 'many' when the site was close to an area where logs were kept before removed from the forest. Confidence intervals for the means are indicated (95% of confidence interval for the attack mean after back-transformation, n = number of trees).
(b) The effect of the condition of the main shoot and the presence or absence of the processionary caterpillar on the probability of attack on the shoots by *T. piniperda*. Categories of the main shoot: 1–shorter than current, 2–missing, 3–bent or twisted, 4–double, 5–broken, 6–bare, 7–side shoots taken up dominance, 8–good and 9–tree dead. A t test was carried out in each category with and without the presence of the caterpillar in the trees. Confidence intervals for the mean are indicated (95% of confidence interval for the attack mean after back transformation, n = number of trees, $^*P<0.05$ and $^{***} = P<0.001$).

there were no trees attacked by the processionary caterpillar. Category (9) included the dead trees. They were trees attacked in the shoot and in the trunk by *T. piniperda*, so the attack value was considered 100 per cent.

Discussion

Pinus radiata

The main reason for increased levels of *T. piniperda* attack in the top shoots, is the rise of the beetle population locally. Abundance of logs, thinning and fire increase the beetle density by providing susceptible breeding material. Thinning dates and avoidance of logs or any material suitable for breeding (cutting stumps close to the ground) in the forests is an important way of keeping forest pests under control, not only by reducing the availability of breeding sites but also by enhancing the resistance of remaining trees to insect attack through thinning (Waring and Pitman, 1983; Savill and Evans, 1986; Anhold and Jenkins, 1987). However, if thinnings is not carried out at the right dates (Andersson and Lekander, 1966) or performed properly (Nebeker and Hodges, 1983), this can result in severe damage to the site, reduced growth rates of residual trees and increased susceptibility to pest attacks.

Fire has also been found to be an important agent for the increase of pest attacks (Langor and Raske, 1989), because it increases the availability of breeding sites not only for the period straight after the fire (partially burned logs and fallen trunks) but also for years after. Sometimes, trees that seem not to be affected directly by the fire are weakened to the point that they are attacked subsequently by the pests (Baylis *et al.*, 1986; Bogdanova, 1986; Speight and Wainhouse, 1989).

The effect of altitude on the attack of *T. piniperda* on *P. radiata* could be explained by the fact that *P. radiata*, being an exotic species, does not grow well above 400 m, as noted by the crown density values which were significantly correlated with percentage of attack and decreased with altitude. Crown density is one of the most used indices of tree condition in forest health surveys (Innes, 1990). Aubert (1947) described one of the causes increasing populations of *Ips typographus* to be the plantating of artificial stands of spruce out of its optimum range. However, looking at Figure 1b, it can be seen that, above 500 m, the attack seemed to decrease and the crown density improved. The biological explanation could be that those sites at higher altitudes were typically smaller plantations (1–2 ha) of *P. radiata* surrounded by, and in some cases mixed with, other species of trees such as *P. pinaster* or *Picea sitchensis*, factors which are known to give more resistance to pest attacks (Eidmann, 1985; Klimetzek, 1990) and, thus, are stands less susceptible to *T. piniperda* attack. This could be the cause of the decline rather than altitude *per se*.

Pinus sylvestris

In northern Spain *P. sylvestris* is usually planted at higher altitudes than *P. radiata* (above 400 m) because it does not grow well at lower altitudes and is more susceptible to insect attack. For example, Schroeder (1987) found that low vigour Scots pine trees were more attractive to *T. piniperda* than higher vigour ones. This could explain the high attack at 300 m and the decrease of damage with increasing altitude. However, the presence of logs in the vicinity has an important effect on the attacks for both tree species. Thus, even if the trees are growing at high altitudes and could be less susceptible to attack, the presence of logs may serve as a breeding site and, thus, may contribute to increased attack on the trees.

*Processionary caterpillar (*Thaumetopoea pityocampa*) effect on* Tomicus piniperda *rate of attack on shoots*

The presence of the processionary caterpillar in the tree canopy apparently affected the number of attacks of the beetle in the tree shoots. According to the results, trees with processionary caterpillars present seemed to have a higher level of damage by the beetle than those without the caterpillar. However, when the trees were divided into categories according to the state of the main shoot, the response was rather different. It seemed that vigorous trees, which could be too strong for pine shoot beetle to attack were more vulnerable to the beetle when the caterpillar was present. Conversely, it could be that *T. piniperda* is capable of attacking vigorous trees and, then, the processionary caterpillar can attack the weakened tree, subsequently. The processionary caterpillar is considered a primary pest, and caterpillars can defoliate trees, regardless of their vigour (Cobos-Suarez and Ruiz-Urrestarazu, 1990). The female moth prefers dominant trees for oviposition (Demolin, 1969). *T. piniperda* is sometimes considered a primary pest when it attacks the pine shoots, so more research needs to be carried out in order to understand the sequence of attack. Nevertheless, trees that have been attacked by *Thaumetopoea pityocampa* are usually more susceptible to the attack of secondary pests, especially on the trunks, and that phenomenon was observed at sites visited in the present study. In general, the weakening of defoliated plants may favour the presence of wood feeders (Langor and Raske, 1989).

The main damage caused by the caterpillar usually occurs between September and March (Cobos-Suarez and Ruiz-Urrestarazu, 1990). The pine shoot beetle usually attacks the shoot between May and September. So, it could be that both species stress the trees and make the attacks easier for each other.

Conclusions

Although *P. radiata* has been planted at a wide range of altitudes (0–800 m), tree condition (crown density) and the rate of shoot attack by *Tomicus piniperda* observed in this study suggests that the tree species should not be planted at altitudes higher than 400 m, especially in large plantations. However, the effect of altitude might be diminished by planting *P. radiata* in small, mixed plantations, but more research needs to be done on this point. On the other hand, *P. sylvestris* should be planted at altitudes higher than 400 m. *P. radiata*, like *P. sylvestris*, is a good breeding material for the beetle as indicated by the presence of logs in the vicinity of the plantations increasing the attack rate on the shoots. Forests should be monitored for the presence of other pests such as the processionary moth, which might increase the susceptibility of *P. radiata* to *T. piniperda* the beetle attack on the crowns. However, further research needs to be done in order to understand more of this relationship.

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