

The incidence of seedling attack and mortality by *Hylastes ater* (Coleoptera: Scolytidae) in second rotation *Pinus radiata* forests in the Central North Island, New Zealand

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Abstract

The incidence of seedling attack by *Hylastes ater* was assessed in Central North Island second rotation *Pinus radiata* plantings by destructively sampling seedlings in a variety of sites. The results show that *H. ater* attack was the dominant factor contributing to seedling mortality in the first year following planting. Seedling mortality due to *H. ater* was not evenly distributed throughout the forest.

In the majority of sites, seedling mortality was low; however levels of sub-lethal attack were often high. Although the extent to which seedling health may be compromised is not known, this result suggests that seedlings may be able to survive all but the most severe attacks. The incidence of mortality and attack was found to be related to the harvesting history of a site. Seedlings planted in sites harvested during late summer/autumn were identified as being at greatest risk from *H. ater* attack.

Introduction

Hylastes ater (Paykull) is a European bark beetle that was first recorded in New Zealand in 1929. It is now well established in all exotic pine plantations. *H. ater* breeds in stumps, roots and logs of *Pinus* spp (Clark 1932, Milligan 1978). During maturation feeding adults attack and may kill young pine seedlings. Despite initial concerns following its introduction, *H. ater* has not been regarded as a significant pest in New Zealand until recently (Reay 2001).

In New Zealand large areas of mature *P. radiata* forest are harvested all year round. The stumps that result from harvesting activities create a supply of breeding habitat that would not normally exist in the natural forest environment (Örlander *et al.* 1997, Leather *et al.* 1999). This allows *H. ater* populations to persist at epidemic levels for longer periods of time than would be expected

in a natural forest environment. Adults emerge from stumps following larval development and begin maturation feeding on seedlings. *H. ater* attacks the roots and collars of seedlings below the ground (Clark 1932, Crowhurst 1969). It is usually not possible to observe wounding as a result of *H. ater* attack without removing a seedling from the ground (Reay 2001).

Seedling death resulting from bark beetle attack has not been well documented in New Zealand. Elsewhere, seedling mortality resulting from attack by other species of bark beetles and weevils has been reasonably well documented (Du Toit 1975, Tribe 1990, Eidmann 1992, Wilson *et al.* 1996, Leather *et al.* 1999, Örlander & Nilsson 1999, Rieske & Raffa 1999). Patchy mortality of Norway spruce (*Picea abies* L.) seedlings resulting from *Hylastes cunicularius* Er. and *Hylobius abietis* L. attack was reported from Sweden by Lindelöw (1992). Lindelöw (1992) observed that high levels of seedling mortality were uncommon, but also that mortality was often undetected as dead seedlings were seldom found. When they were, the causes of death were often misdiagnosed. *Hylastes angustatus* (Herbst) was reported to kill *Pinus patula* Schiede & Deppe seedlings in South Africa, but there was little quantitative assessment given (Atkinson & Govender 1997). In Britain, *H. abietis* was reported to kill 30-100 % of all *Pinus* seedlings planted in restocking sites and is therefore considered a serious threat to British and European forestry (Leather *et al.* 1999). Corrective treatment of bark beetle attack is not possible once seedling damage is apparent (Atkinson & Govender 1997).

Lindelöw (1992) and Leather *et al.* (1999) attempted to identify the characteristics of sites where seedlings were more susceptible to attack by *H. abietis* and *H. cunicularis*. A wide range of site characteristics were investigated with relatively little success (Lindelöw 1992, Leather *et al.* 1999). If a relationship was established between high levels of attack by *H. ater* and site characteristics, then high-risk sites could be treated prior to planting. Treatment could be management or control-based, depending on the costs and benefits associated with each, and the potential costs of the expected *H. ater* damage.

In New Zealand, *H. ater* does not build up high populations in all areas (Reay 2001). Seedling mortality has been attributed to factors such as drought or poor planting, and *H. ater* was reported to only kill weak or

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stressed seedlings (Milligan 1978). Given overseas experience and the uncertainty surrounding the pest status of *H. ater* in New Zealand it was thought to be important to quantify the amount of mortality of first year plantings that could be attributed to *H. ater* attack. This would clarify whether *H. ater* was a dominant cause of seedling mortality in the early establishment of plantings, or whether other factors (environmental and/or biological) were responsible.

Methods

Second rotation *P. radiata* sites that had been planted during the winters of 1998 and 1999 were selected in the Central North Island Kinleith and Kaingaroa forests. Thirty two sites in 1998 and twenty eight sites in 1999 were chosen to include a variety of harvesting histories and site types. Information on harvesting activities and site factors were provided by forest managers. Sampling was undertaken during late autumn, approximately nine months following planting.

Sites were sampled by randomly locating a transect in each site. Depending on the spacing of seedlings in each site, the length of each transect was between 300-600m. One hundred seedlings encountered along each transect were recorded as being either dead or alive. All dead seedlings encountered were removed from the soil and examined for evidence of *H. ater* attack. Mortality was only attributed to *H. ater* if feeding damage was considered to be severe (as described below). Every fifth seedling encountered was destructively sampled regardless of condition. At least twenty seedlings were destructively sampled in each site. Each of these was examined for evidence of *H. ater* attack. The severity of attack on seedlings was recorded as follows:

0= No evidence of *H. ater* attack

No evidence of feeding activity was observed on the root collar and the roots of seedlings.

1= Mild *H. ater* attack

Small pits or spots of resin around the root collar or on roots indicated a minor attempt by *H. ater* to feed. In some cases, feeding attempts were not severe enough to initiate a resin response by the seedling. Small "pits" of chewing activity indicated these feeding attempts.

2= Moderate attack by *H. ater*

Moderate attack was recorded when either many feeding wounds (described above) were observed, or when there was evidence of one or two more sustained feeding attempts. For example, when feeding activity resulted in the removal of an area of bark greater than 1cm².

3= Severe attack by *H. ater* (Fig. 1)

Severe attack was recorded if ring barking or multiple feeding wounds covering the root collar and stem of the seedling by *H. ater* were observed.

Differences with respect to seedling mortality and the frequency of attack between sites were investigated using chi-square tests, using the statistical package SAS (PROC FREQ, Version 6.12 for Windows, SAS Institute 1996). Differences with respect to the severity of attack between

sites were investigated using analyses of variance (ANOVA), using the statistical package SAS (PROC GLM, Version 6.12 for Windows, SAS Institute 1996). Pairwise multiple comparisons were conducted using Duncan's multiple range tests to determine the nature of the differences detected by ANOVA.



Fig. 1. *P. radiata* seedling showing evidence of severe attack by *H. ater*.

Results

Mortality resulting from *H. ater* attack

In the 1998 plantings the number of seedlings killed by *H. ater* ranged from 0-30% and was significantly different between sites ($X^2_{(31)} = 300.762$, $P < 0.001$, Fig. 2). Mean seedling mortality due to *H. ater* attack was 4.47% and was greater than mortality due to other causes ($X^2_{(1)} = 32.101$, $P < 0.001$). Mean seedling mortality not attributable to *H. ater* attack was 1.97% and was significantly different between sites ($X^2_{(31)} = 205.684$, $P < 0.001$). In the 1999 plantings the amount of seedling mortality due to *H. ater* attack ranged from 0-13% and was again significantly different between sites ($X^2_{(27)} = 150.179$, $P < 0.001$). Mean mortality attributable to *H. ater* in these plantings was 2.46% and was greater than mortality due to other causes ($X^2_{(1)} = 30.368$, $P < 0.001$). Mean mortality not attributable to *H. ater* attack was 0.64% and differed between sites ($X^2_{(27)} = 53.902$, $P < 0.001$).

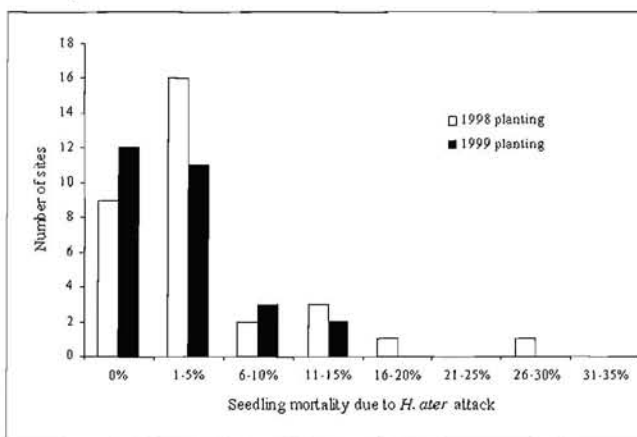


Fig. 2. Amount of seedling mortality due to *H. ater* attack for 32 sites planted during the winter of 1998 and 28 sites planted during the winter of 1999.

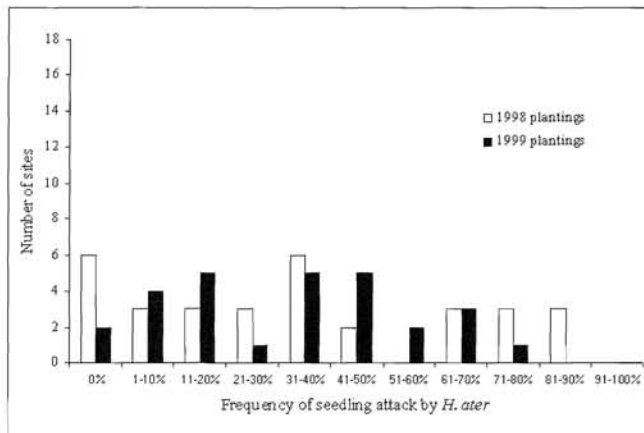


Fig. 3. Frequency of seedling attack by *H. ater* for 32 sites planted during the winter of 1998 and 28 sites planted during the winter of 1999.

The frequency of seedling attack by *H. ater*

Attacks on seedlings by *H. ater* ranged from 0-90% for the 1998 plantings and 0-75% for the 1999 plantings (Fig. 3), and varied significantly between sites ($X^2_{(31)} = 222.466$, $P < 0.001$; $X^2_{(27)} = 116.568$, $P < 0.001$ respectively). While seedling mortality due to *H. ater* attack was usually low, there was a moderate incidence of feeding activity in most sites. For approximately 25% of all sites in both years, the frequency of attack was greater than 50% (Fig. 3).

The relationship between seedling attack by *H. ater* and the harvesting history of sites

To examine the influence of the harvesting history on seedling attack by *H. ater*, sites were placed into four categories based on when harvesting activities occurred. The time of harvesting for three sites planted in 1998 was not known (these sites were not included in these analyses). Periods of harvesting were grouped into two-monthly intervals as follows:

- 1= Harvested during the period: 1 February to 31 March
- 2= Harvested during the period: 1 December to 31 January
- 3= Harvested during the period: 1 October to 30 November
- 4= Harvested during the period: Prior to 1 October

There was a significant difference in the frequency of attack which was associated with the time of harvesting for seedlings planted during the winter of 1998 ($X^2_{(3)} = 113.980$, $P < 0.001$) and 1999 ($X^2_{(3)} = 67.103$, $P < 0.001$). Seedlings planted in sites harvested during the period from 1 February to 31 March 1998 were attacked with greatest frequency (Table 1). The incidence of attack by *H. ater* decreased with increasing time between harvesting and planting (Table 1). The mean severity of attack by *H. ater* also differed between harvesting periods for seedlings planted in 1998 ($F_{(3,575)} = 57.18$, $P < 0.001$) and 1999 ($F_{(3,556)} = 18.90$, $P < 0.001$). Sites harvested during the February and March period in 1998 and 1999 were attacked with greatest severity. Mean severity of seedling attack by *H. ater* decreased with increasing time between the harvesting period and planting (Table 1).

Table 1. The mean frequency and severity of seedling attack by *H. ater* for sites harvested at different times (sites planted during winter 1998 and 1999).

Harvesting period	Mean frequency of attack (%)	Mean severity of attack	Number of sites sampled (20 seedlings/site)
1 February to 31 March 98	65	1.36a	9
1 December 1997 to 31 January 1998	35	0.55b	4
1 October to 30 November 1997	29	0.50b	4
Prior to 1 October 1997	15	0.22c	12
1 February to 31 March 1999	65	1.27a	3
1 December 1998 to 31 January 1999	45	0.90b	12
1 October to 30 November 1998	22	0.47c	8
Prior to October 1998	13	0.23c	5

Means with the same letter are not significantly differ ($\alpha=0.05$).

Table 2. Mean frequency of seedlings attacked by *H. ater* in sites harvested at different times (sites planted during winter 1998 and 1999).

Harvesting period	No attack	Mild attack	Moderate attack	Severe attack
1 February to 31 March 98	35%	17%	24.5%	23.5%
1 December 1997 to 31 January 1998	65%	20%	10%	5%
1 October to 30 November 1997	71%	13%	11%	5%
Prior to 1 October 1997	85%	10.5%	2%	2.5%
1 February to 31 March 1999	35%	27%	15%	23%
1 December 1998 to 31 January 1999	55%	14%	17%	14%
1 October to 30 November 1998	78%	5.5%	7.5%	9%
Prior to October 1998	87%	6%	4%	3%

A summary of the frequency and severity of seedling attack by *H. ater* in sites harvested at different times (Table 2) shows that seedlings planted in sites harvested during the February to March period were more likely to be attacked, and that these seedlings were also attacked with greatest severity.

Discussion

Seedling mortality over 90% due to *H. ater* attack has been reported (Boomsma & Adams 1943). Neumann (1987) reported that all seedlings in a 3.2 hectare area in Victoria, Australia were killed by *H. ater*. Ciesla (1988) reported seedling mortality due to *H. ater* attack as high as 70% in Chile. High levels of mortality due to *H. ater* attack were not observed during this study. For this study, the observed seedling mortality resulting from *H. ater* attack was low with the exception of a small number of sites where mortality ranged from 18% to 30%.

There was no evidence that the *H. ater* attack in this study was the sole cause of seedling mortality. While it was reasonable to assume that severe attack by *H. ater* was the cause of seedling mortality, other factors may have been involved. These include site, environmental or seedling characteristics. It has been suggested that *H. ater* may only attack weak seedlings and does not kill healthy trees (Milligan 1978). However, these results show that *H. ater* attack was likely to be the predominant cause of seedling mortality in the first year following planting. The mortality of undamaged seedlings was minimal compared to the mortality of seedlings that showed evidence of severe attack by *H. ater*. This indicates that the majority of seedlings would likely have survived in the absence of severe *H. ater* attack. If *H. ater* only attacks weak or less resistant seedlings, it is unlikely that such high levels of sub-lethal attack in apparently healthy growing seedlings would have been observed.

Seedling death resulting from *H. ater* attack has been reported from New Zealand and overseas. However, these reports have not recorded the extent of sub-lethal attacks (Clark 1932, Boomsma & Adams 1943, Crowhurst 1969, Neumann 1987, Ciesla 1988). Problems associated with seedling attack by *H. ater* may be more complex than just seedling mortality. Sub-lethal *H. ater* attack may be as significant to the forestry industry in terms of loss of value, as the attack by *H. ater* that results in seedling death. Reay *et al.* (in press) showed that incidence of sapstain fungi in seedlings increased with increasing severity of sub-lethal *H. ater* attack. Given the substantial amount of sub-lethal attack in many sites, this should be of concern to the forest industry. Sub-lethal attack by *H. ater* may also influence seedling growth and make seedlings more susceptible to invasion by pathogens (Reay *et al.* in press).

An important component of this study was to determine if any factors were related to high mortality and attack. If predisposing factors were identified, it would be possible to identify high-risk sites prior to planting and to make management decisions accordingly. Leather *et al.* (1999) discuss attempts to identify site factors that predispose seedlings to attack by *H. abietis*. Studies have investigated factors that affect *H. abietis*

brood production and development rate, the effects of planting technique and weevil-seedling interactions (Leather *et al.* 1999). Despite the large amount of research that has been directed at this problem, high-resolution predictive models have not been satisfactory. However, models which operate at lower levels of resolution, have been more successful when used to forecast 'at risk' areas (Leather *et al.* 1999).

This study indicates that the time of year that sites are harvested is an important factor in determining whether seedlings are likely to be attacked by *H. ater*. The results show that seedlings planted in sites which were harvested during February and March, and planted the following winter, were at the greatest risk from *H. ater* attack. The relationship between harvesting history and the likelihood of attack by *H. ater* may be related to the flight activity and life history of *H. ater*, and competition for brood sites by other bark beetles. Observations by Reay and Walsh (2001) indicated that *Hylurgus ligniperda* (Fabricius), another common introduced bark beetle, was the dominant species in stumps for most of the summer period. The majority of sites harvested during the period from October to February were colonised predominantly by *H. ligniperda*. However, there is no evidence that overwintering *H. ligniperda* larval populations are a threat to seedlings in New Zealand (Bain 1977, Reay 2001). Although there was *H. ater* activity during this period, *H. ater* adults colonised sites in low numbers. The main period of *H. ater* flight activity was during autumn (March to April) (Reay & Walsh 2001). During this period *H. ater* was the dominant species colonising recently harvested sites.

Seedling attacks result from the maturation feeding of emerging *H. ater* adults. For this to occur, seedlings have to be planted in sites prior to the emergence of beetles. Currently, operational practice is to plant seedlings during the winter months. The only sites where reasonable numbers of *H. ater* larvae were present in stumps at the time of planting were those that were colonised by *H. ater* during late summer/autumn. Larval development was not completed before winter and *H. ater* over-wintered as larvae. Development of these larvae was completed during the following spring and summer months. Emerging beetles were able to begin maturation feeding on seedlings that were planted during winter while larvae were developing in the surrounding stumps.

Larval feeding and adult emergence prior to the planting of seedlings rapidly degraded stumps colonised early in the summer period (Reay 2001). The stumps were then unsuitable for re-colonisation by breeding adults (while there may occasionally have been an opportunity for a second generation to breed in stumps, emerging populations were likely to be minimal). Beetles emerged from these stumps during summer and autumn. Therefore, seedlings were planted in these sites after *H. ater* populations had emerged.

Seedlings were not damaged by *H. ater* when planted in sites which had remained fallow for extended periods. This demonstrates the efficacy of this cultural technique of damage reduction. Emerging adults appear unable to detect seedlings unless they emerged among them (Reay 2001). Unlike *H. abietis* (Leather *et al.* 1999), there is

no evidence of host searching and dispersal by *H. ater* into newly planted areas from populations in other sites, so the prediction of high-risk areas is not as complicated for *H. ater* in New Zealand as it is for bark beetles in other areas.

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