The influence of time of precommercial thinning on the colonization of Douglas-fir by three species of root-colonizing insects[1]

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In plantations of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in western Oregon, precommercial thinning resulted in significantly increased abundances of insect vectors of black-stain root disease. *Hylastes nigrinus* (Mann.), *Pissodes fasciatus* LeC., and *Steremnius carinatus* (Boh.) were monitored for 2 years (1983 and 1984) in unthinned plots and in plots thinned in September 1982, January 1983, or May 1983. Abundances of these beetle species were significantly higher in thinned plots, relative to unthinned plots. However, the numbers of *H. nigrinus* and *P. fasciatus* caught by unbaited traps in plots thinned in May was reduced relative to plots thinned in September or January. These results suggest that time of thinning can be manipulated to reduce the activity of these vectors in plantations that are mechanically thinned.

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L'eclaircie précommerciale effectuée dans des plantations de sapin Douglas (*Pseudotsuga menziesii* (Mirb.) Franco) dans la partie occidentale de l'Orégon a eu pour effet une augmentation substantielle du nombre d'insectes vecteurs de la maladie du pourridié verticicladielléen. On a examiné durant deux ans (1983 et 1984), à la fois dans des peuplements non éclaircis et dans ceux éclaircis en septembre 1982, janvier 1983 ou mai 1983, l'abondance de *Hylastes nigrinus* (Mann.), *Pissodes fasciatus* LeC. et *Steremnius carinatus* (Boh.). Le nombre de ces insectes était significativement plus élevé dans les places éclaircies que dans celles non éclaircies. Toutefois, le nombre de *H. nigrinus* et de *P. fasciatus* retrouvés dans les pièges à appât des places éclaircies en mai était inférieur à celui trouvé dans les places éclaircies on septembre ou janvier. Ces résultats indiquent qu'on pourrait modifier la saison de l'éclaircie afin de réduire l'activité de ces vecteurs dans les plantations éclaircies systématiquement.

[Traduit par la revue]

Introduction

Black-stain root disease of conifers, caused by the fungus *Verticicladiella wageneri* Kendrick (sexual stage: *Ceratocystis wageneri* Goheen and Cobb) is widely distributed throughout western North America and kills single-leaf pinyon (*Pinus monophyla* Torr. and Frem.), ponderosa (*Pinus ponderosa* Laws.) and lodgepole (*Pinus contorta* Dougl.) pines (Wagener and Mielke 1961), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (Cobb and Platt 1967). *Verticicladiella wageneri* spreads through the soil from diseased trees to adjacent, healthy trees of the same species via the continuous xylem of functional root grafts (Goheen 1976; Hessburg 1984). The fungus can also grow through the soil for short distances of perhaps 1–6 cm (Goheen and Cobb 1978; Hessburg 1984; Hicks et al. 1980) and enter healthy hosts through infection courts on fine roots (Goheen and Cobb 1978; Hessburg 1984).

Established foci of *V. wageneri* are estimated to enlarge at 0.5–6.0 m/year (Byler et al. 1979; Cobb et al. 1982; E. M. Hansen and D. J. Goheen, unpublished). This rate can be explained by fungal growth alone (Hessburg 1984). However, widely separated new foci of black-stain root disease apparently are initiated by insects.

Goheen and Cobb (1978) suggested that the root bark beetle, *Hylastes macer* LeC., initiated new foci of *V. wageneri* in ponderosa pine. In plantations of Douglas-fir in the Pacific Northwest, three beetle species, *Hylastes nigrinus* (Mann.) (Coleoptera: Scolytidae), *Pissodes fasciatus* LeC., and *Steremnius carinatus* (Boh.) (Coleoptera: Curculionidae), are consistently associated with black-stain root disease (Witcosky and Hansen 1985). These insects carry inoculum of *V. wageneri* in the field, transmit the fungus to Douglas-fir under laboratory conditions, and feed or oviposit in susceptible hosts under conditions suitable for transmission of *V. wageneri* (Harrington et al. 1985; Witcosky 1985; Witcosky and Hansen 1985). *Hylastes nigrinus* has been shown to transmit *V. wageneri* to Douglas-fir in the field (Witcosky 1985).

Forest pathologists have expressed growing concern over the reported relationship between intensive forest-management practices and the development of black-stain root disease in the coastal Douglas-fir region of the Pacific Northwest. These reports have associated the development of foci of black-stain root disease with forest disturbances such as road construction (Hansen 1978), tractor logging (Goheen et al. 1983), and precommercial thinning (Goheen and Hansen 1978; Harrington et al. 1983). Therefore, our research was aimed at providing an experimental basis for pest-management strategies in young Douglas-fir plantations in this region, especially those sustaining black-stain root disease. In this paper, we describe the influence of time of precommercial thinning on the immigration and activity of *H. nigrinus*, *P. fasciatus*, and *S. carinatus* within plantations of Douglas-fir.

Materials and methods

This study was conducted in the eastern portion of the Coast Range of southern Oregon, where black-stain root disease is widely distri-

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TABLE 1. Mean (±SE) number of *Hylastes nigrinus* and *Pissodes fasciatus* caught per trap on sticky traps and *Steremnius carinatus* caught per trap in pitfall traps at biweekly intervals during 1983 and 1984 in precommercially thinned and unthinned 2-ha plots in two 12-year-old plantations of Douglas-fir

Species, year	Interspersed control	Sept. 1982 thinning	Jan. 1983 thinning	May 1983 thinning
H. nigrinus				
1983	0.04±0.08*a*	2.8±1.4*b*	5.1±5.4*b*	0.90±0.77*a*
1984	0.1±0.1*a*	2.0±0.7*b*	1.0±1.1*ab*	1.3±1.3*b*
P. fasciatus				
1983	0±0*a*	0.20±0.14*b*	0.20±0.16*b*	0.06±0.06*a*
1984	0±0*a*	0.11±0.18*a*	0±0*a*	0.11±0.17*a*
S. carinatus				
1983	0.16±0.06*a*	0.51±0.23*b*	0.53±0.18*b*	0.57±0.20*b*
1984	0.23±0.13*a*	0.35±0.16*b*	0.49±0.18*bc*	0.68±0.18*c*

NOTE: Values within rows followed by a different letter(s) are significantly different at $\alpha = 0.05$ (Kruskal–Wallis test for all paired comparisons, $n = 8$ plots per treatment in 1983, $n = 4$ plots per treatment in 1984).

buted. Two 12-year-old, 50-ha plantations (BURD (tp. 27S, rge. 8W) and No. 5340 (tp. 27S, rge. 7W) were selected for study. Each plantation was stocked with 2000–4000 stems/ha and was sustaining some mortality as a result of *V. wageneri*. In each plantation, four blocks were established, each consisting of four 2-ha plots. The plots in each block were randomly allocated to four treatments: precommercial thinning in September 1982, January 1983, or May 1983, and unthinned. Thus, there were four replicates of each treatment per plantation. Four additional unthinned plots within the BURD plantation, located at a distance >30 m from the experimental blocks and surrounded by unthinned plantation, served as an external check to account for the influence of thinning on insect activity in the interspersed control plots. Stand density in the thinned plots was reduced to approximately 900–1000 stems/ha by felling excess trees with a chainsaw.

We monitored insect activity and immigration into each plot of the BURD and No. 5340 plantations in 1983, but only the plots of the BURD plantation were monitored in 1984. We used a series of unbaited pitfall traps to capture *S. carinatus* and vertical sticky traps to capture flying *H. nigrinus* and *P. fasciatus*. The pitfall traps were placed across the middle of each plot along two parallel transects, 5 m apart, from edge to edge. Each transect had five pitfall traps spaced within 5 m of both edges of the plot and at distances of 1/4, 1/2, and 3/4 of the plot's width. Two sticky screen traps were placed in each plot: one 5 m from one edge and another at midplot in each plot, between the pitfall trap transects.

Each unbaited pitfall trap consisted of a plastic container (15.7 cm diameter, 19 cm height) buried to the soil surface and fitted with an aluminum funnel. Within this container was a second plastic container (12.2 cm diameter, 8 cm height) containing undiluted antifreeze (ethylene glycol) or water with detergent. Fresh antifreeze was added at the beginning of trapping in March and again in July each year. The opening was covered by a 20 cm × 20 cm plywood board elevated about 3 cm off the ground with nails. In the NO. 5340 plantation, coyotes removed pitfall traps and disrupted trapping from 2 July through 13 August 1983 (Julian dates 181–223) until the preservative was changed to water with detergent. Thereafter, fresh water–detergent solution was added at the beginning of each 2-week sample period in these traps.

The sticky traps consisted of two 1/4-m^2 hardware cloth screens (2 mesh/cm) coated with Stikem Special® (Seabright Enterprises, Emoryville, CA) and stapled to opposite sides of a 80 cm long, 5 cm × 5 cm stake driven into the ground. The Stikem Special® on the screens was renewed at 4- to 6-week intervals throughout the trapping period. Samples were collected simultaneously from the pitfall and sticky traps at 14-day intervals beginning before first flight in the spring and continuing through August.

During September 1983, populations of immature and adult insects were removed from under the bark of roots and stumps of trees cut during precommercial thinning. At randomly selected points in each thinned plot in the BURD plantation, two stumps within 5 m of the edge and two stumps near the center of each plot were randomly selected and excavated. All insects, except eggs, were collected from under the bark and the number of egg galleries made by *H. nigrinus* counted. Crop trees were similarly sampled in all plots and were examined non-destructively for wounds or insects. Individuals of *H. nigrinus*, *S. carinatus*, and *P. fasciatus* were tallied.

During 1984, we placed 1-mm mesh screen emergence cages covering 1 m^2 over randomly selected stumps in the twelve thinned plots in the BURD plantation to capture emerging *H. nigrinus*. Four traps were placed within 10 m of the edge of each plot in groups of two traps. Emerging insects were collected daily from 28 March through 1 July 1984 (Julian dates, 088–183).

To detect seasonal trends in beetle abundance among treatments, we employed the Friedman test (Lehmann 1975) to detect significant differences in mean number of beetles captured per trap among treatments over the entire year and at 14-day sample intervals for the 1983 data alone. Means were compared at the $\alpha = 0.05$ level using the Kruskal–Wallis test (Hodges and Lehmann 1962; Lehmann 1975).

Results

We detected an increase in abundance of insect vectors of *V. wageneri* following precommercial thinning. More *H. nigrinus*, *P. fasciatus*, and *S. carinatus* were caught in pitfall and sticky traps in thinned plots during 1983 and 1984 than in unthinned, control plots, regardless of time of thinning (Table 1). Fewer *H. nigrinus* and *P. fasciatus* were caught in the plots thinned in May relative to plots thinned the previous September or January.

Examination of the biweekly collections indicated that during the peak flight period more *H. nigrinus* were caught in September and January treatments than in the May treatment. However, means were not significantly different at other times when captures were low (Fig. 1). This trend was evident but less pronounced for *P. fasciatus* (Fig. 2).

We observed no significant differences in the capture of *S. carinatus* based on time of thinning (Table 1). In general, the number of beetles captured tended to be highest in the May

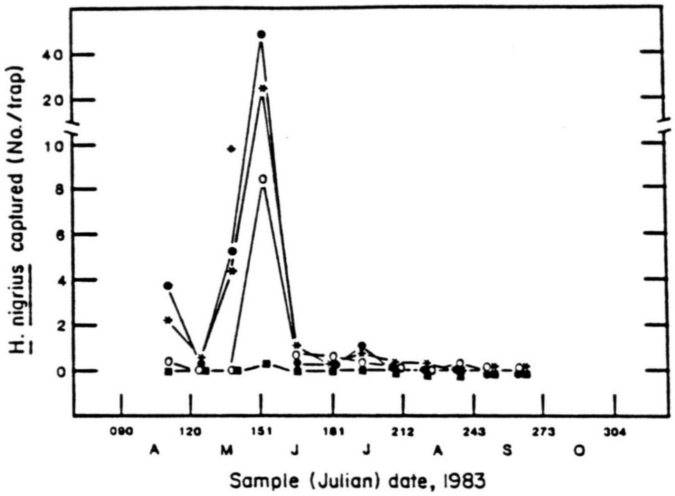

FIG. 1. Mean number of *Hylastes nigrinus* caught per trap on sticky traps during 1983 in precommercially thinned and unthinned 2-ha plots in two 12-year-old plantations of Douglas-fir ($n = 8$ plots per treatment). *, September 1982 thinning; ●, January 1983 thinning; ○, May 1983 thinning; ■, unthinned (control). Arrow indicates time of May thinning.

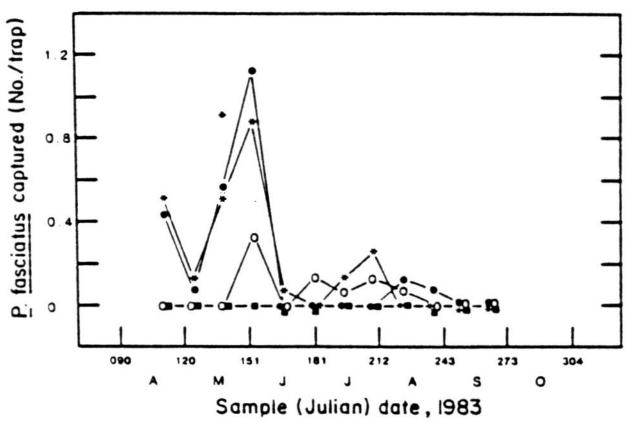

FIG. 2. Mean number of *Pissodes fasciatus* caught per trap on sticky traps during 1983 in precommercially thinned and unthinned 2-ha plots in two 12-year-old plantations of Douglas-fir ($n = 8$ plots per treatment). Symbols are as in Fig. 1. Arrow indicates time of May thinning.

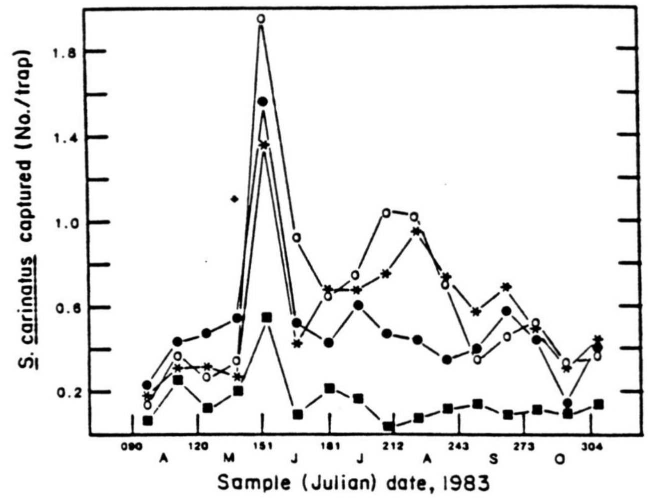

FIG. 3. Mean number of *Steremnius carinatus* caught per trap in pitfall traps during 1983 in precommercially thinned and unthinned 2-ha plots in two 12-year-old plantations of Douglas-fir ($n = 4$ plots per treatment). Symbols are as on Fig. 1. Arrow indicates time of May thinning.

TABLE 2. Mean (±SD) number of *Hylastes nigrinus*, *Pissodes fasciatus*, and *Steremnius carinatus* and egg galleries per tree in 1983, and emergence of *H. nigrinus* per tree during 1984 in precommercially thinned 2-ha plots in a 12-year-old plantation of Douglas- fir

Species	Sept. 1982 thinning	Jan. 1983 thinning	May 1983 thinning
H. nigrinus	166.1±155.7*b*	64.1±88.0*ab*	34.3±69.0*a*
Egg galleries	12.9±9.5*b*	7.8±5.4*b*	4.1±5.3*a*
Emergence	9.9±17.1*b*	8.6±13.0*b*	1.2±2.1*a*
P. fasciatus	3.4±5.8*a*	15.6±20.8*b*	11.9±19.2*ab*
S. carinatus	17.1±21.1*b*	10.3±15.2*b*	3.6±10.9*a*

NOTE: Values within rows followed by a different letter(s) are significantly different at $\alpha = 0.05$ (Kruskal–Wallis test for all paired comparisons, $n = 16$ trees per treatment).

treatment, but no consistent trend emerged over the entire year and trap capture varied considerably among treatments (Fig. 3).

Hylastes nigrinus exhibited a distinct period of flight into the study sites in 1983 (Fig. 1). Although beetles were caught during the first sample period, observations during the 21 days prior to placement of the stickey traps indicated that flight had not begun because of unstable weather, rain, snow, and temperatures continuously below the 15°C threshold for flight of *H. nigrinus* (Daterman et al. 1965; Zethner-Møller and Rudinsky 1967). The first episode of flight, in April, was followed by a 2-week period of unstable weather, rain, snow, and low temperatures. The peak flight occured in May over a 28-day period. Following this peak, very few beetles were caught. A similar trend was observed for emerging *H. nigrinus* during 1984.

Pissodes fasciatus was caught only in thinned plots in 1983 (Fig. 2, Table 1). The pattern of flight was similar to that observed for *H. nigrinus*, although more activity was noted during July and August. Very few *P. fasciatus* were caught during 1984.

In 1983, *S. carinatus* abundance peaked during late May or June and extended through August (Fig. 3). Two peaks were observed, one at 2 June and another at 28 July. In 1984, only a single pronounced peak appeared, which was intermediate to the two peaks observed in 1983.

The numbers of beetles caught in the unthinned, interspersed control plots and the unthinned, isolated check plots did not differ significantly. Thus, insect activity in the interspersed unthinned plots was not greatly affected by thinning of surrounding plots.

Results of the excavations of stumps are presented in Table 2. Significantly more egg galleries and individuals of *H. nigrinus* were observed during 1983 in the September and January treatments than in the May treatment. Subsequent emergence of *H. nigrinus* in 1984 exhibited the same trend (Table 2). More larvae of *P. fasciatus* were recovered from the January and May treatments than from the September treatment. Significantly more larvae of *S. carinatus* were recovered from the September and January treatments than from the May treatment. There was no evidence of insect damage on trees sampled in the unthinned plots.

Results of random surveys of crop trees within each plot indicated that significantly ($P < 0.05$) more crop trees were wounded in the thinned plots (5% in the May treatment, 11% in the September treatment, and 17% in the January treatment) than in the unthinned plots (0%). Significantly more wounding of crop trees occurred in the January and September treatments than in the May treatment.

Discussion

A growing body of knowledge is linking insect and disease incidence with forest disturbance (Goheen and Cobb 1978; Goheen and Hansen 1978; Hansen 1978; Harrington et al. 1983; Harrington et al. 1985; Schowalter 1985; Witcosky and Hansen 1985; Witcosky 1985). Our study demonstrated that precommercial thinning at any time increased the abundance of insect vectors of black-stain root disease. Stumps were colonized by these root-infesting insects and were susceptible to infection and colonization by *V. wageneri* for at least 7 months following thinning (Witcosky 1985). In addition, crop trees were wounded throughout the roots and root collar region by *H. nigrinus* following precommercial thinning during both years of this study and were susceptible to infection and colonization by *V. wageneri* (Witcosky 1985). Some of these wounds penetrated to the xylem and were, therefore, suitable infection courts (Hessburg 1984). Similar wounds have been shown to result in transmission of *V. wageneri* to Douglas-fir (Witcosky 1985).

We conclude that in areas where black-stain root disease is present and widespread, some beetles will introduce inoculum into plantations following precommercial thinning, either through the root systems of thinned hosts or through the root systems of the crop trees. The activity of vectors in plantations undergoing self-thinning is undocumented. Whether these plantations will develop new foci of *V. wageneri* as the result of insect activity cannot be determined at this time.

We have demonstrated that time of precommercial thinning can affect immigration of *H. nigrinus* and *P. fasciatus*, two principal vectors of *V. wageneri*, into disturbed 2-ha plots within plantations. The capture of these two species was lower in plots thinned in May, during or after the peak of flight activity, relative to plots thinned the previous September or January.

These results suggest that in areas of high risk to black-stain root disease, precommercial thinning should be avoided. Alternatively, thinning should be initated during the months of June or July following peak beetle flight in May. Plantations thinned at this time would gain at least 9 months of protection from colonization by *H. nigrinus* and *P. fasciatus* (Figs. 1 and 2). During the following months, the host material provided by thinning degrades, becoming less susceptible to colonization by *V. wageneri* (Witcosky 1985) and, perhaps, less attractive to host-seeking vectors during the following flight season. Current studies indicate that immigration of vectors, colonization of host material, and wounding of crop trees in thinnned plantations can be reduced by thinning during June or July (J. J. Witcosky, unpublished data). Mean attack intensity (number per tree) of *H. nigrinus* on stumps of Douglas-fir in plantations thinned during June and July was 2.9, compared with 14.6 in plantations thinned in September–January. The mean proportion of crop trees wounded by *H. nigrinus* was 0.02 for plantations thinned during June and July versus 0.14 for plantations thinned during September–January.

Flight-activity patterns of *H. nigrinus* (Daterman et al. 1965) and *Hylastes* spp. (apparently *H. macer* LeC., *H. nigrinus*, and *H. minutus* Blkm.) (Gara and Vité 1962) were qualitatively similar to the flight activity observed for *H. nigrinus* in this study. These studies demonstrated peak flight early in the season in other areas. Management recommendations derived from this study may be effective in other areas, but should be based on a thorough knowledge of the flight period of the principal vector, *H. nigrinus*, and on the rate of deterioration in stump suitability for *V. wageneri* (Witcosky 1985; W. D. Bedard, personal communication).

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