

Douglas-fir pitch moth, *Synanthedon novaroensis* (Lepidoptera: Sesiidae) in North-Central British Columbia: Flight Period and the Effect of Trap Type and Pheromone Dosage on Trap Catches

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ABSTRACT The synthetic pheromone (Z,Z)-3,13-octadecadien-1-yl acetate was tested in two trap types and at different loads for trapping the Douglas-fir pitch moth, *Synanthedon novaroensis* (Henry Edwards) (Lepidoptera: Sesiidae), in a lodgepole pine, *Pinus contorta* Douglas ex Loudon variety *latifolia* Engelmann, provenance trial at the Prince George Tree Improvement Station, Prince George, British Columbia. This moth causes considerable problems in lodgepole pine seed orchards at this location. No significant differences in trap catches were found between wing traps and Unitraps in two experiments. There were no significant differences between catches in Unitraps baited with 50, 100, or 200 μg of the pheromone loaded on red rubber septa. In a second experiment, Unitraps baited with four rubber septa, each loaded with 200 μg for a total load of 800 μg , captured significantly more Douglas-fir pitch moths than those baited with one septum (200 μg) or two septa (400 μg) of the pheromone. All pheromone loads caught significantly more moths than unbaited control traps. Based on trap catches in these trap bioassays, and catches in monitoring traps in four lodgepole pine seed orchards, 1996 through 2000, the flight period of *S. novaroensis* in north central British Columbia normally starts in early June, and lasts for 4–7 wk.

KEY WORDS (Z,Z) 3,13-Octadecadien-1-yl Acetate, Unitrap, wing trap, lodgepole pine, seed orchard

SESIID AND PYRALID PITCH moths cause considerable damage to trees by tunnelling in cambial tissue under bark causing stem deformities and weakness to the point of tree breakage. The Douglas-fir pitch moth, *Synanthedon novaroensis* (Henry Edwards) (Lepidoptera: Sesiidae), is a significant pest of lodgepole pine, *Pinus contorta* Douglas ex Loudon variety *latifolia* Engelmann, in seed orchards and provenance trials at the Prince George Tree Improvement Station (PGTIS) (Rocchini et al. 1999) in central British Columbia. It is the only lodgepole pine-feeding sesiid known to occur at the PGTIS (Rocchini et al. 1999). The pyralid pitch moth *Dioryctria cambiicola* (Dyar) also occurs throughout the area, but is primarily associated with stem rust cankers (Rocchini et al. 1999). This species is most prevalent in the provenance trials at the PGTIS.

Douglas-fir pitch moth females oviposit singly in cracks or crevices, particularly at wounds, along the bole of their host tree (Duckworth and Eichlin 1978). Each female can produce up to 50 eggs. Larvae enter

the cambium, and develop on the live tree protected from predators and parasites by a pitch mass resulting from the defensive reaction produced by the host. Pupation occurs in the pitch mass, and lasts ≈ 30 d. Flight may occur between March and September, but is primarily in June and July. Normal development from egg to adult is 2–3 years (Duckworth and Eichlin 1978).

The specific pheromone of *S. novaroensis* has not yet been identified, but a generic pheromone, (Z,Z)-3,13-octadecadien-1-yl acetate, has been reported as an effective trap bait for this sesiid (Johnson 1993). This pheromone was extracted from the ovipositor of two related sesiids, the peachtree borer, *Synanthedon exitiosa* (Say), and the lesser peachtree borer, *S. pictipes* (Grote and Robinson) (Tumlinson et al. 1974). No studies have been published on effective pheromone dose or trap type for *S. novaroensis*, and nothing is known about the flight period of this moth at the latitudes of our study.

Over the last few years pitch moths have become a significant problem in the PGTIS seed orchards (C. Fleetham, personal communication). Although pitch moths do not usually directly kill trees, damage re-

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sulting from larval feeding weakens the stem over time, and leads to an increased chance of tree breakage in high winds. Because of the breeding history and intensive management of each seed orchard tree at the station, every tree is of high value and the current level of damage is unacceptable.

Our objectives were to (1) determine the optimal pheromone dose of (*Z,Z*)-3,13-octadecadien-1-yl acetate for trapping the Douglas-fir pitch moth; (2) test two common trap types; and (3) determine the flight period of the moth. Results from these studies will be used to determine the potential for using pheromone-based management for this pitch moth at the PGTIS.

Materials and Methods

The PGTIS is located 20 km south of Prince George, BC, (N 53° 46', W 122° 43'). We conducted pheromone dosage and trap type experiments in a provenance trial (22 ha, 4 × 4 m spacing, ≈15,000 trees, planted 1973) containing lodgepole pine provenances from throughout British Columbia. Additional flight data were collected from traps placed in four lodgepole pine seed orchards from northern BC: Omineca Pinchi #201 (4.15 ha, 8 × 4 m spacing, 1002 trees, planted 1974); Omineca Pinchi #202 (1.73 ha, 6 × 4 m spacing, 362 trees, planted 1978); Willow-Bowron #203 (2.9 ha, 6 × 4 m spacing, 807 trees, planted 1978); and Smithers #204 (3.89 ha, 6 × 6 m spacing, 981 trees, planted 1979). Each orchard produces seed for particular geographic areas of British Columbia (seed planning zones), and are separated from each other by a minimum of 500 m. In the provenance trial, 17.5% of 795 trees sampled had been attacked by Douglas-fir pitch moth at least once (Rocchini et al. 1999). In the seed orchards, from 19.9% to 30.8% of the trees had been attacked at least once (Rocchini 1997).

Pheromone lures consisted of red rubber septa loaded with (*Z,Z*)-3,13-octadecadien-1-yl acetate (97.7% chemical purity, <1% isomeric impurities, same lot used for all experiments) (Phero Tech, Delta, BC, Canada). Release rates of most moth pheromones from such devices decline exponentially from an initial high rate. However, Butler and McDonough (1979) found that (*Z,Z*)-3,13-octadecadien-1-yl acetate has an exceedingly slow release, and they could not determine a half-life in 272 d of monitoring. Thus, the exact release rate is unknown. Identifications of Douglas-fir pitch moths captured in this study were verified by Dr. Thomas D. Eichlin. Voucher specimens have been deposited at the Pacific Forestry Centre, Victoria, BC.

Trap-Type Experiments. Wing traps and green Unitraps (Phero Tech, Delta, BC, Canada) were compared in two experiments. Moths entering wing traps were captured when they contacted the bottom, which was coated with Stikem Special (Phero Tech, Delta, BC, Canada). Moths entering Unitraps were killed by an ≈1 cm³ piece of Vapona No-Pest Strip (Monsanto Canada Inc, Mississauga, Ont.) placed inside the trap.

On 6 June, 1996, 10 replicates were set up in the lodgepole pine provenance trial a minimum of 15 m from the northern edge of the stand. Each pair consisted of one sticky wing trap, and one green Unitrap. Traps within each pair were randomly assigned positions 8–10 m apart, and replicates were separated by >25 m. Because Douglas-fir pitch moth attacks on lodgepole pine at the PGTIS occur along almost the entire bole of the tree (Rocchini et al. 1999), traps were suspended from the bottom branch of a lodgepole pine tree so that traps were ≈2–2.5 m above the ground, and 1–2 m from the bole of the tree. Traps were baited with red rubber septa loaded with 200 μg of (*Z,Z*)-3,13-octadecadien-1-yl acetate. Lures were replaced every 4 wk with fresh ones. Traps were checked for moths once or twice every week until the experiment was terminated on 30 August.

The experiment was repeated in 1999 with traps placed in the same part of the provenance trial. However, based on the results of dose-response experiments (see below), red rubber septa loaded with 1,000 μg of the pheromone were used. Traps were set up on 8 June 1999, and checked as above until the termination of the experiment on 28 July 1999. Lures were replaced every 4 wk.

Dose Response Experiments. Effect of pheromone dose was determined with two experiments. On 4 June 1996, Unitraps were set up in the lodgepole pine provenance trial. Replicates were separated by >25 m. Each replicate consisted of three traps separated from each other by 8–10 m, each baited with red rubber septa loaded with 50, 100, or 200 μg. Treatment was assigned randomly within replicate. Lures were replaced once a month, and the experiment was terminated on 21 September 1996.

A second experiment was established on 4 June, 1997, in the lodgepole pine provenance trial. Green Unitraps baited with zero (control), one, two, or four septa were deployed in adjacent trees (5 m apart). Traps were suspended as described above. Treatment was assigned randomly within replicate. Each septum was loaded with 200 μg of (*Z,Z*)-3,13-octadecadienyl acetate, giving treatments of 0, 200, 400, and 800 μg/trap. Multiple septa were used rather than different loads, because previous research has shown that initial dose does not affect half-life (Maitlen et al. 1976, Flint et al. 1978, Greenway et al. 1981). Thus, four septa loaded with 200 μg each should release roughly the same amount as one septum loaded with 800 μg. Blocks (replicates) were separated by >25 m. Traps were checked once per week until the termination of the experiment on 15 August 1997.

Flight Periods. Flight data on the Douglas-fir pitch moth were gathered from the above experiments, as well as from traps used for monitoring purposes in the seed orchards. In 1996, five traps were placed in each of the four lodgepole pine seed orchards. Four of the traps were placed 15 m from the edge in the corners of each orchard, while the fifth trap was placed near the center. The same configuration was used 1998–2000, except that only two orchards were used 1998–1999, and three orchards were used in 2000. Each year

Table 1. Results of two experiments testing the effect of pheromone load on red rubber septa for capturing Douglas fir pitch moths. Prince George, BC, 4 June - 21 September, 1996 (N = 5), and 4 June - 15 August, 1997 (N = 10)

| Year Pheromone load (μg) | Mean number of moths captured (± 1 SD) |
|---|--|
| 1996 ^a | |
| 50 | 0.2 (± 0.45) |
| 100 | 0.6 (± 0.55) |
| 200 | 1.0 (± 1.41) |
| 1997 | |
| 0 (Control) | 0.0 (± 0.00)a |
| 200 | 1.6 (± 1.51)b |
| 400 (2 \times 200) | 1.9 (± 2.08)b |
| 800 (4 \times 200) | 3.5 (± 1.65)c |

Means followed by the same letter not significantly different, analysis of variance ($\alpha = 0.05$) followed by Tukey's test for mean separation.

^a Means do not differ significantly, analysis of variance ($\alpha = 0.05$).

the traps were set up between 15 May and 1 June, and left until mid- to late August. All traps were checked once or twice per week, and lures were replaced with fresh ones every 4 wk. Temperature data for Prince George Airport, located ≈ 10 km northeast of PGTIS, were purchased from Environment Canada, Climate Data Service, Vancouver, BC, to assess how temperature affected moth emergence and flight.

Analyses. Results from all experiments were analyzed by analysis of variance (ANOVA) ($\alpha = 0.05$) followed by Tukey's test for mean separation (Zar 1984) using SYSTAT statistical software (SPSS, Inc., Chicago, IL). Data were transformed as $x' = \log_{10}(x + 1)$ to correct for heterogeneity of variances before analysis.

Results

Trap-type Experiments. Twenty-two Douglas-fir pitch moths were caught between 26 June and 6 August 1996, and 26 Douglas-fir pitch moths were caught between 16 June and 13 July 1999. The data for the two experiments were analyzed together, with year as a factor. The mean catch per trap ± 1 SE in Unitraps was 1.5 ± 1.54 moths, whereas the sticky traps caught 0.9 ± 1.07 moths per trap. There were no significant differences between trap types in either experiment ($F = 0.958$, $df = 1,27$, $P = 0.336$), and no interaction between year (pheromone load) and trap type ($F = 0.004$, $df = 1,27$, $P = 0.953$).

Dose-Response Experiment. In 1996, only nine Douglas-fir pitch moths were captured (Table 1), and there was no effect of dose on captures ($F = 1.361$, $df = 2,8$, $P = 0.31$). In 1997, 70 Douglas-fir pitch moths were captured. Catches were significantly higher in traps baited with the highest dose (800 μg) of the pheromone than in traps baited with any other dose ($F = 16.240$, $df = 3,27$, $P < 0.001$) (Table 1). The zero catch in control traps confirmed that the moths were attracted to the pheromone.

Flight Period. A total of 35 moths were captured in 1996, 70 moths in 1997, 27 moths in 1998, 39 moths in

1999, and 25 moths in 2000. Based on these results, the flight period of Douglas-fir pitch moth at the PGTIS normally occurs some time between 31 May and 9 August (Fig. 1). Commencement of flight occurred as late as 25 June 2000, and we never caught moths after 9 August in any year. Total flight period ranged from 30 d (1997) to 55 d (1996).

Discussion

Results from 5 yr of pheromone trapping in the seed orchards and the provenance trial confirmed that *Synanthedon novarocensis*, the predominant pitch moth attacking *P. contorta* at the PGTIS (Rocchini et al. 1999), is attracted to (Z,Z)-3,13-octadecadien-1-yl acetate. Thus, our results concur with those found by Johnson (1993) in central Washington.

Trap design is often important when trapping insects, because variations of insect flight behavior may dictate which trap is most efficient. Traps of varying design are efficient at catching two other species of *Synanthedon*, *S. pictipes*, the lesser peachtree borer, and *S. exitiosa*, the peachtree borer. Pherocon 1C sticky traps (Trécé, Salinas, CA), similar in design to the sticky traps used in this study, efficiently trap males of both species (Knodel and Agnello 1990, Yonce et al. 1979). Multi-pher one traps (Bio-control Services, Ste. Foy, Quebec, Canada), similar in design to Unitraps, were as effective at catching *S. pictipes* as Pherocon 1C traps, and somewhat less effective at capturing *S. exitiosa* than Pherocon 1C traps (Knodel and Agnello 1990). Given that both trap types we tested worked equally well for trapping Douglas-fir pitch moth, the Unitrap may be a better choice because it is reusable, sturdier, has a higher capacity, and does not destroy specimens. The recovery of intact specimens for identification is particularly important, because many of the known pheromones for sesiid moths are generic. During this and a separate study at PGTIS, several other clearwing moth species were captured, two of which represented major range extensions (Bennett et al. 2000, 2001).

Efficacy of traps can also depend on qualitative and quantitative properties of the pheromone used. *Synanthedon pictipes* males were observed on numerous occasions entering Pherocon 1C traps and then flying out (Holloway et al. 1977). *S. pictipes* males were also observed hovering above and below the horizontal plane of a pheromone source when approaching it (Holloway et al. 1977). During our 1996 experiment, we observed one male Douglas-fir pitch moth that had landed on top of a wing trap, and another male hovering at the entrance of a Unitrap before flying away. The latter behavior is commonly seen in clearwing moths in response to incomplete pheromone composition (N. Ryrholm, personal communication). The optimal concentration of pheromone in trap lures for male moth capture is also an important factor to consider. A minimum threshold concentration of an appropriate sex pheromone is required to elicit a response from male moths (Roelofs 1978). This threshold is higher if, in a multi-component phero-

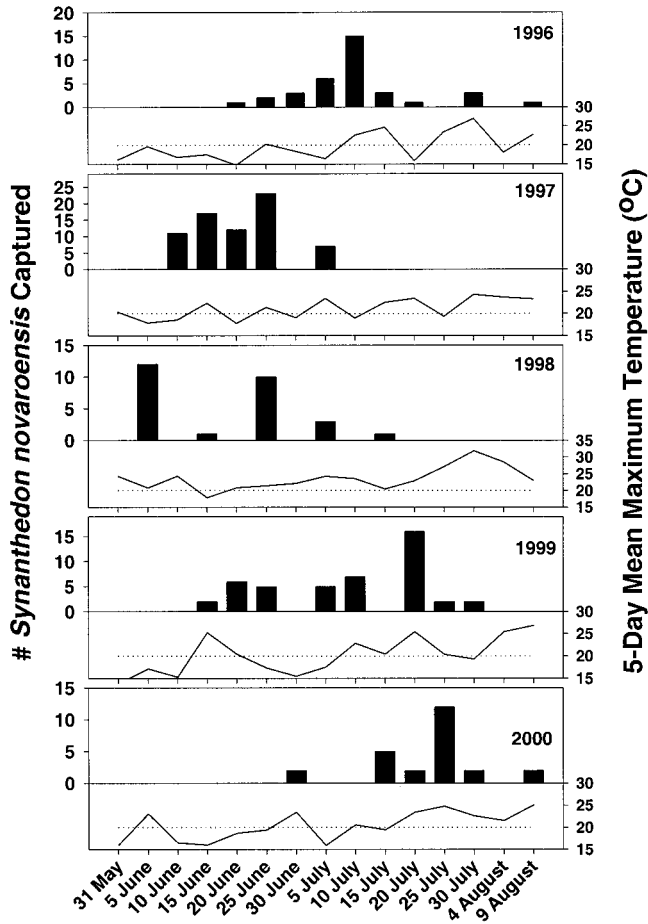


Fig. 1. Catches of the Douglas-fir pitch moth, *Synanthedon novaroensis*, in traps baited with (Z,Z)-3,13-octadecadien-1-yl acetate, Prince George Tree Improvement Station, Prince George, BC, 1996–2000, and mean maximum temperature at the Prince George Airport. The dashed horizontal line in temperature graphs denotes 20°C, and is for reference only.

... mone, the components are present in ratios significantly different from what is naturally emitted by the female, or if only one of the components is used (Roelofs 1978). This may explain the increasing responses with dose observed in our experiments. There is, however, an upper limit on pheromone concentration beyond which its attractiveness may decrease; i.e., very high pheromone concentrations disrupt long-distance anemotactic responses of males (Roelofs 1978). These upper and lower concentration-limits define species-specific areas of attraction effective in trapping male moths. For monitoring purposes, it is important to use the amount of pheromone that elicits the greatest response from the males without exceeding the attraction area. Based on the dose-response results, we expected the trap type experiments in 1999 to capture significantly higher numbers of moths than in 1996. However, the roughly equal total catch in the 2 yr may be because of local population effects, i.e., the population may have been lower in 1999 in the area in which the experiment was conducted. It is also possible that the 1,000 µg dose was at or near the upper

response threshold (Roelofs 1978) for the male Douglas-fir pitch moth, or the high pheromone concentration may have exerted a local mating disruption effect in 1999.

In the nonsignificant ($P > 0.05$) results we obtained in the 1996 experiment, the magnitude of change in pheromone release was not high enough to separate the treatments given the relatively few moths captured and the resulting high variance. In one study, lesser peachtree borer males responded to female sex pheromone in a dose dependent manner, exhibiting a significant linear increase in trap catches from concentrations of 10 µg to 100 µg (Nielsen and Purrington 1980). In that study, loads much lower than 1000 µg were highly attractive, but when clearwing moth population sizes are low pheromone concentrations much higher than 100 µg may be required to attract male moths (Nielsen and Purrington 1980). Although the highest dose captured significantly more moths than the lower doses in our 1997 experiment, we cannot conclude that the 800 µg load we used is optimal, because higher doses were not tested. Given the ex-

ceedingly slow release rate of this pheromone from rubber septa (Butler and McDonough 1979), it may be necessary to investigate other substrates as dispensers. Nevertheless, our 1997 experiment shows that attractiveness varies with dose, and given the fairly inexpensive pheromone, rubber septa may be preferable for small-scale monitoring.

Depending upon latitude, Douglas-fir pitch moth emergence may occur from March to September, with peak emergence in June and July (Duckworth and Eichlin 1978, Johnson 1993). Peak emergence in western Washington State in 1 yr took place between the last week of July and the first week of August (Johnson 1993). In our study, peak emergence varied considerably over 5 yr from 1996 to 2000 (Fig. 1). Some variation may be a result of increases when lures were changed, because release from rubber septa has high initial release. However, our objective was not to determine magnitude of flight, but rather the time of year during which flight could be expected to occur. Heat accumulation and weather during the flight period probably account for these differences. For example, accumulated degree-days (dd) above 10°C by 31 May were 177, 215, and 205 in 1996, 1999, and 2000, respectively, when flight started in mid-late June, whereas they were 295 dd in 1997 and 460 in 1998, when flight started in early June. Degree-day accumulation does not explain the commencement of flight, however, because flights in 1997 and 1998 started only 1 wk apart. Thus, high temperature may trigger emergence only after some threshold heat accumulation has been reached (Fig. 1). Daylength may also be a factor in determining emergence. In 1998, 200 dd above 10°C was reached on 8 May, but no moths were caught until 5–10 June, even though 21 of 28 d in the period before this had maximum temperatures of 20°C or higher. Johnson (1993) found that emergence of Douglas-fir pitch moth in Washington was associated with increasing temperature and decreasing humidity. Fig. 1 shows that most catches occurred during periods when the mean maximum temperature for the period approached or exceeded 20°C. Emergence may be highly dependent on climatic factors, which differ substantially between Washington State and central British Columbia. The shorter growing season and colder winter temperatures in Prince George may cause this insect's life cycle to be extended. Thus, in Washington larvae may complete development to emerge late in their first or second year of development, whereas in central British Columbia, emergence may not occur until the following spring, i.e., early in their second or third year. Seemingly mature larvae (based on size) from many viable pitch masses sampled in June 1996 (Rocchini 1997) did not emerge at all. The cause of this is unknown, but may be a result of a colder than average spring in 1996 (177 dd by 31 May compared with 205 or higher in all other years) prolonging emergence to the following year.

The primary host plant in Washington is Douglas-fir, *Pseudotsuga menziesii* (Mirbel) Franco (Johnson 1993), whereas in Prince George it is lodgepole pine. The effects of host species on moth flight period are

not known but physiological tree differences, e.g., qualitative and/or quantitative differences in the oleoresin may affect larval development. Rocchini et al. (2000) did not find any effects of resin flow on susceptibility of lodgepole pine to attack by the Douglas-fir pitch moth, but high relative levels of δ -3-carene reduced susceptibility.

It is likely that the true pheromone of the Douglas-fir pitch moth has additional components to those we used based on evidence from numerous Eurasian *Synanthedon* species (N. Ryrholm, unpublished data). Therefore, it may be necessary to identify the complete chemical makeup of the pheromone before effective pheromone-based management of this species is feasible. If (Z,Z)-3,13-octadecadien-1-yl acetate is used in future experiments, monitoring, or pheromone-based management, doses of at least 800 μ g of (deployed in Unitraps or similar traps) are recommended. Furthermore, the flight period of the local population should be determined to ensure that research or management coincides with the period of activity of adults. For this purpose, the generic pheromone (Z,Z)-3,13-octadecadien-1-yl acetate (coupled with expert identification of trapped specimens) should be effective.

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