ABSTRACT Collections of volatiles, ovipositor extracts, and electroantennography showed the sex pheromone of female currant borer moths, Synanthedon tipuliformis (Clerck), from Washington to be a 2-component (100:3) blend of (E,Z)-2, 13-octadecadienyl acetate and (E,Z)-3, 13-octadecadienyl acetate. Pheromone-baited sticky traps (rubber septa dispensers) captured male S. tipuliformis at one abandoned and two commercial red currant sites (one treated with insecticide, one untreated) in south central Washington from 19 May to 16 August 2000. Peak catches occurred during late May and June with up to 250-300 moths/trap/wk. Lowest numbers (overall mean: 4.8 ± 0.9 moths/trap/visit) were recorded at the insecticide-treated site and largest numbers (36.6 ± 5.5 moths/trap/visit) occurred at the untreated, commercial site.

KEY WORDS Synanthedon tipuliformis, sex pheromone, sticky traps, population monitoring

The currant borer, Synanthedon tipuliformis (Clerck), is a serious pest of black currants and red currants in Europe (Real and Balachowsky 1966) and New Zealand (Hardy 1981). It was first recorded in North America during the latter half of the 19th century (Solomon and Dix 1979) and is now distributed throughout the continent. Currants are a minor crop in the United States, with commercial production centered on a small area around Prosser in south central Washington. S. tipuliformis is a significant pest of red currants in Washington and one to four applications of a broad-spectrum insecticide (currently fenpropatrin) are applied during the adult flight period. However, control is often poor because of the short-term effect of the spray and imprecise knowledge of moth emergence and abundance.

In New Zealand, mating disruption is used to manage S. tipuliformis in commercial black currant production (Thomas and Burnip 1991). The female sex pheromone of European S. tipuliformis, a 100:3 blend of (E,Z)-2, 13-octadecadienyl acetate and (E,Z)-3, 13-octadecadienyl acetate, was identified in 1985 (Szocs et al. 1985) and the same blend was also found in New Zealand (Szocs et al. 1990) and Canadian females (Szocs et al. 1998). However, an Australian (Tasmania) strain of S. tipuliformis was found to respond optimally to the single component, E,Z-2, 13-octadecadienyl (Szocs et al. 1990). Elucidation of the sex pheromone composition of S. tipuliformis in Washington and demonstration of the bioactivity of a synthetic version, are necessary precursors to development of mating disruption.

Materials and Methods

Insects. Female moths were obtained from larvae collected from dormant red currant canes at Prosser during January 2000. Larvae were successfully reared to pupation (45-80% survival) in individual plastic cups (4.5 cm diameter) containing a general lepidopteran artificial diet (Southland Products, Lake Village, AR). Rearing was conducted at 25°C under continuous illumination and most mortality was caused by parasitism by an unidentified ichneumonid wasp. Pupae were shipped to Peoria where moths were allowed to emerge.

Pheromone Collection and Analysis. Ovipositor extracts and volatile collections were conducted on three virgin females 1-3 d old. The outside of an extracted ovipositor was gently rubbed with a Solid Phase Micro Extraction (SPME) fiber (100 μm polydimethylsiloxane, Supelco, Bellefonte, PA) ~1 h after 'calling' commenced. They were then extracted individually overnight in 50 μl of hexane.

Twenty-four hour volatile collections were made from individual female insects by methods and equipment generally described by Cossé and Bartelt (2000). Volatiles were trapped on Super Q porous polymer (80-100 mesh, Alltech, Deerfield, IL). The Super Q traps were rinsed with 250 μl hexane. Samples were concentrated to approximately 10 μl under a gentle stream of nitrogen and 1 μl was analyzed.

Volatile collections, SPME rubs, and ovipositor extracts were analyzed by coupled GC-mass spectrometry (GC-MS), and coupled gas chromatographic-
Electroantennographic detection (GC-EAD). GC-EAD analyses were made by methods and equipment generally described by Cossé and Bartelt (2000). Samples were injected in splitless mode using a Hewlett-Packard 6890 GC fitted with a 30-m EC-1 capillary column (0.25 mm inside diameter, 0.25 µm film thickness, Altech). Temperature programs were from 50–220°C at 10°C per minute (GC-MS) or from 50 to 275°C at 15°C per minute (GC-EAD). Injector temperature was maintained at 250°C and GC-EAD effluent interface from postcolumn splitter was kept at 275°C. Injectors were fitted with SPME liners (Supelco, Bellefonte, PA) for SPME analysis. Mass spectrometry was performed using a Hewlett-Packard 5973 instrument (electron impact, 70 eV). EAD-active compounds were identified by comparisons of mass spectra and GC retention times of natural materials with authentic samples of E.Z-2, 13-octadecadienyl acetate and E.Z-3, 13-octadecadienyl acetate (Pheroxbank, Wageningen, The Netherlands).

Pheromone Trapping in Current Fields. Male S. tipuliformis were trapped in 3 red currant fields near Prosser, Washington, during May–August 2000 using Pherocon IC sticky traps (Trecce, Salinas, CA) baited with the two-component pheromone blend. Voucher specimens are held at WSU-IAREC, Prosser. The pheromone was impregnated on red rubber septa (1.5 mg/ septum) (E.Z-2, 13-octadecadienyl acetate [97%], E.Z-3, 13-octadecadienyl acetate [3%], Pheroxbank, Wageningen, The Netherlands). The three sites included a 10-acre commercial field exposed to 4 insecticide (fenpropathin) applications for S. tipuliformis adults during May and June (site A), a 30-acre commercial field that received a single treatment of fenpropathin for the currant stem girdler, Janus integer (Norton), in early May, but no treatments during the flight period of S. tipuliformis (site B), and a 5-acre abandoned red currant field (site C). The abandoned field was nonirrigated and most canes were in poor condition. The sites were separated by at least 5 mi.

Three traps baited with pheromone and three traps without pheromone were placed at each site on 15 May. Traps were hung from canes or posts, 1–1.5 m above the ground and were separated by at least 15 m. Baited and unbaited traps were positioned alternately in two rows separated by at least 15 m. Traps were checked three times a week (Monday, Wednesday, Friday) and moths were counted and removed using forceps. The sticky liners of traps were replaced when wing scales impaired trapping efficacy. Differences in trapping means between sites were examined using the Student t-test.

Results

Pheromone Identification. GC-EAD analyses of female volatile collections, SPME rubs, and ovipositor extracts revealed 2 distinct depolarizations in the male antennal signal (n = 3), being matched by at least 1 compound in the GC-FID trace. No traceable amount of compound could be associated with the earlier depolarization. The retention times of these two an-

tennal signals matched those from the synthetic standards E.Z-3, 13-octadecadienyl acetate and E.Z-2, 13-octadecadienyl acetate, respectively (Fig. 1).

GC-MS analysis showed that a compound eluting at 21.15 min. had a GC retention time and mass spectrum identical to E.Z-2, 13-octadecadienyl acetate. In addition, the GC-MS analysis showed that a compound eluting at the same retention time of the synthetic E.Z-3, 13-octadecadienyl acetate had identical mass fragments compared with synthetic E.Z-3, 13-octadecadienyl acetate. However, amounts were too limited for an optimal mass spectrum. Based on the combined results from GC-EAD and GC-MS analyses, female S. tipuliformis release a 2-component blend comprising 98.2% E.Z-2, 13-octadecadienyl acetate (±0.4% SD, n = 3) and 1.8% E.Z-3, 13-octadecadienyl acetate (±0.4% SD, n = 3). A single Super Q volatiles collection of an individual calling female showed that E.Z-2, 13-octadecadienyl acetate was collected at a rate of 45 ng/d.
Pheromone-Trapping. Male S. tipuliformis were first trapped on 19 May and the last moth was trapped on 16 August (Fig. 2). Trap catches were largest at the insecticide-free site (overall mean, 39.6 ± 5.5 moths/trap/visit). Mean trap catch at the abandoned field site (14.4 ± 2.4), while significantly less than at the insecticide-free site (t = 4.38, df = 34, P = 0.0001), was significantly greater than at the insecticide-treated site (4.8 ± 0.9) (t = 3.86, df = 34, P = 0.0005).

Peak trap catches generally occurred during late May and throughout June with weekly catches of 200–300 per trap at site C. Numbers began declining in early July and by the end of the month only 3–6 moths/trap/wk were caught (Fig. 2). Unbaited traps did not catch any moths except during peak abundance at site C, when an occasional female became stuck in an unbaited trap, subsequently recruiting males.

Discussion

The Washington strain of S. tipuliformis shares the 2-component blend of female-produced pheromone previously shown to occur in European, New Zealand, and Canadian strains of this species (Szocs et al. 1985, 1990, 1998). Thus, the commercially available pheromone-impregnated septa (for population monitoring) and twist tie dispensers (for mating disruption), both of which use this blend, should be suitable for use with Washington populations. Research on developing mating disruption as a strategy to manage S. tipuliformis in Washington red currants is now underway.

Male S. tipuliformis were readily trapped using the commercially available septa. Pheromone trapping provided data on flight period and abundance of S. tipuliformis in red currant fields. Although initial emergence of the day-flying S. tipuliformis can be detected by growers (moths usually appear during the third week of May), the field abundance of moths is harder to estimate visually. The pheromone traps offer an easy indication of emergence and a more precise assessment of population size. Duration of the flight period in Washington has not been reported but currant growers do not monitor or control moths after middle to late June, just before harvest. The data presented here indicate that moth activity, and presumably oviposition on canes, continues at a high level during June and most of July. Similarly, in Australia and New Zealand, flight period and oviposition of S. tipuliformis extends for at least 3 mo (Hardy 1985, Thomas and Burnip 1989).

The abundance of S. tipuliformis as indicated by pheromone trap catches was significantly greater at the insecticide-free commercial site than at the abandoned or insecticide-treated site. The relatively small population in the abandoned field (compared with the insecticide-free commercial site) was probably a consequence of the poor condition of the red currant plants. The small population at the insecticide-treated site suggests the degree of control provided by four applications of fenpropath. In contrast, the largest population of moths occurred at the untreated commercial site. The adult population at this site was clearly damaging as shown by examination of canes in September 2000. An average of 1.1 larvae per cane was found compared with 0.06 larva per cane at the insecticide-treated site.

Resolution of the chemistry of S. tipuliformis pheromone together with field evidence of its bioactivity against Washington moths (James, unpublished data) should lead to development of mating disruption as an improved, noninsecticidal way of managing this pest in Washington red currants.

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