Journal of Applied Entomology

WILEY

JOURNAL OF APPLIED ENTOMOLOGY

ORIGINAL ARTICLE OPEN ACCESS

Development of Pheromone-Based Mating Disruption for Three Lepidopteran Pests of Currant in Northern Europe

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Received: 13 February 2025 | **Accepted:** 22 April 2025

Funding: This study was supported by the Swedish farmers' foundation for agricultural research (SLF), project number O-20-20-452, and by the project TekMarja New techniques to control pests of berry crops, grant number 145143, which was funded by the European Agricultural Fund for Rural Development (EAFRD).

Keywords: *Euhyponomeutoides albithoracellus* | *Lampronia capitella* | Pest management | *Ribes* | *Synanthedon tipuliformis*

ABSTRACT

Currant, and in particular blackcurrant, *Ribes nigrum*, is widely grown in Europe. It is the host of a number of pest insects, but their occurrence and the damage they cause vary geographically. In northern Europe, three lepidopteran species, the currant shoot borer (*Lampronia capitella*), the currant clearwing (*Synanthedon tipuliformis*), and the currant bud moth (*Euhyponomeutoides albithoracellus*), are particularly damaging and sometimes cause decreased plant vigour and drastic yield losses. With fewer insecticides approved for use and with an increased interest in organic production of currants, the need for alternative methods to control these moths is urgent. We here applied pheromone-based mating disruption in small and sometimes well isolated plantations in Finland, Norway and Sweden against the three pests using 15–25 g of active ingredients and 300 dispensers per ha. A strong trap shutdown effect, up to 100%, was recorded for the currant clearwing and the currant bud moth, but no effect on the most widespread species, the currant shoot borer, was noted. After 1 year of treatment, however, it was not possible to detect any significant effect on the damage level or on the future adult population size of the pests. We conclude that for the currant clearwing and the currant bud moth, mating disruption is likely to work with higher pheromone doses or modified dispenser density, whereas the reason behind the lack of effect on the currant shoot borer needs to be addressed by new experiments and observations of behaviour.

1 | Introduction

Currant (*Ribes* spp.) is grown on about 140,000 ha worldwide according to the Food and Agriculture Organization of the United Nations (FAO), mainly in Europe. In total around 700,000 tons are produced yearly, with Russia and Poland being the largest producers taking 90% of the world production. In the remaining countries the acreage is small and so are the markets. However, in the Nordic countries and at high latitudes currant can locally still be an important crop and is one of the few nutritious and high-value crops that can be grown this far north. A number of pests and diseases can infest currant plantations and reduce both plant health and berry yield. Among these are three lepidopteran species, two of which have their main distribution in the Nordic countries, viz. the currant shoot borer, *Lampronia capitella* (Clerck) (Prodoxidae), and the currant bud moth, *Euhyponomeutoides albithoracellus* Gaj (Yponomeutidae). The third species, the currant clearwing, *Synanthedon tipuliformis* Clerck (Sesiidae), occurs in most parts of Europe and has been introduced to North America, Australia, and New Zealand.

In northern Europe, all three species have one generation per year, with adults emerging in May–June. Females oviposit on the developing fruits, leaves, or stems depending on the species. The young larvae of the shoot borer feed in the fruits until they leave for hibernation in a cocoon in the lower part of the plant, whereas the bud moth and the clearwing hibernate inside the bud or twig. The feeding of the larvae continues in the next spring and may cause severe damage to the plants (Scott and Harrison 1978; Hellqvist 1981, 1998; Grassi et al. 2002; Hellqvist et al. 2006; Öberg 2012). The damage they cause during this first year is usually minor, and it is not until next spring, when they resume food intake, that they may cause severe damage to the plants. Since larvae of all three species spend much time inside buds or twigs, they are protected from insecticidal applications, and such treatments have to be carefully timed to be effective (Tuovinen et al. 2008). Various chemical insecticides have been used against larvae or adults, but many of them are either banned or their use is very limited due to the environmental harm they cause. For organic growers, only treatment with *Bacillus thuringiensis var. kurstaki/aizawai* has been available (Jordbruksverket 2024), but often not effective (Öberg 2012). An aggravating circumstance when applying any kind of control measures aimed at the larvae in spring is that the soil is often too wet to support the machinery needed to apply pest control measures.

Because of these various factors, there has been, and still is, a demand for alternative effective and environmentally acceptable methods for controlling the three lepidopteran species. The possibility of using species-specific female-produced sex pheromones for monitoring and control of these moths was suggested already during the 1980-ies. The pheromone identification of the more widespread clearwing received most attention (Voerman et al. 1984; Szöcs et al. 1985; Priesner et al. 1986; Szöcs et al. 1990, 1991; Szöcs et al. 1998; Suckling et al. 2005; Mozuraitis et al. 2006) and a pheromone consisting of (*E,Z*)-2,13-octadecadienyl acetate and possibly (*E,Z*)-3,13-octadecadienyl acetate as a minor compound was identified. In some studies, the latter compound in a ratio around 3% increased the catches, but not in others. Also, this minor component seems to reduce catches of other clearwing species using the same main pheromone compound (Mozuraitis et al. 2006). The pheromone of the shoot borer, the most widespread of the species in northern Europe, was identified by Löfstedt et al. (2004) as a blend of three analogous compounds, (*Z,Z*)-9,11-tetradecadienol (Z,Z-14C) and the corresponding acetate and aldehyde in a 100:26:13 ratio. Finally, the pheromone of the bud moth was found to consist of a 25:75 to 50:50 blend of (*E*)-11-tetradecenyl acetate and (*Z*)-11-tetradecenyl acetate (Svensson et al. 2023). For monitoring purposes, lures are commercially available for all three species, taking into account that lures for the large fruit-tree tortrix, *Archips podana* (Scopoli) (Tortricidae), with a 50:50 ratio of the two (Δ)-11-tetradecenyl acetate isomers, can be used for the bud moth (Tuovinen 1989).

Pheromone-based attempts to control these currant pests have mainly been reported for the clearwing. Thomas and Burnip (1991) reported successful trials of mating disruption (MD) in New Zealand from 1987 to 1990, with a strong reduction of males caught in pheromone traps (trap shutdown) and with virgin females remaining unmated within treated fields. This made MD the standard strategy with about 35% of the 800 ha of blackcurrant grown in New Zealand covered in 1991 (Thomas and Burnip 1991) and over 90% in 1993 (Cardé and Minks 1995). After that, the application strategy seemed to have become less intense or strict, and control failures were reported (Suckling et al. 2005). However, these changes of practice and recorded observations were not investigated further. A small-scale experiment was conducted in Italy during 1996–1999 resulting in a complete trap shutdown and a reduced proportion of infested branches (Grassi et al. 2002) and in the Netherlands during 2012–2014, where also reduced damages were noted (Helsen et al. 2014). From Finland, an experiment with "disappointing" results was reported by Kivijärvi et al. (2005). Dispensers for the clearwing are commercially available, in contrast to the two other moth species studied here. For the bud moth, one previous trial to disrupt mating with pheromone has been done, and the results indicated reduced trap catch as well as damage reduction in some of the treated blocks (Kivijärvi et al. 2005). No attempts to control the shoot borer with pheromones have been published.

In this study, we made attempts to control all three mentioned species with MD by distributing synthetic pheromones over entire, small, and often well isolated crop fields in Finland, Norway and Sweden. By following this strategy, we intended to minimise immigration of mated females from the surroundings, which potentially would reduce the effectiveness and obscure evaluation of the treatments. The effect of the MD was measured by estimating the damage (dead or injured twigs) in spring before and after MD and by trap catch the year before, during, and after the treatment and comparing these data with corresponding data from untreated fields. The trap catch and damage data have also been used to describe the occurrence and flight phenology of the three current pests, to correlate catch with damage, and to investigate the possibility to predict future population trends based on these parameters (Svensson et al. 2025).

2 | Methods

2.1 | Study Sites

In 2021, 10 blackcurrant fields in each of Finland, Norway, and Sweden were selected based on their size and isolation from other currant fields to be able to treat the fields completely and avoid the effect of moth dispersal from surrounding areas. Thus, in Finland, fields were located in the central-east part; in Norway, fields were concentrated in the southern part; and in Sweden, in the northern part, with the exception of one field in the southern part (Table S1 and also see map in Svensson et al. (2025)). The currant cultivars and management practices varied between fields, but only on one occasion was an insecticide applied in these fields, at FIN9 in 2021, when the pyrethroid Karate Zeon was used. Two fields (SE9 and FIN10) were only used in 2021, and one field (SE6) was removed before the 2024 season. One extra field (SE0) was adopted in 2022 to act as a comparison to SE1 when this was subject to MD of the clearwing in 2021, as all other fields were in other countries/regions.

2.2 | Pheromone Traps

In each field, one trap per species was placed in blackcurrant bushes at four positions approximately 50 m from each other before the expected start of the flight of the species. In smaller fields, the 50 m distance could not be applied. Traps used in 2021 were transparent RAG plastic delta traps with sticky inserts from Csalomon (Plant Protection Institute, Hungarian Academy of Sciences, Budapest, Hungary). During 2022–2024, white plastic Biobest delta traps (Borregaard BioPlant/Biobasiq, Malmö, Sweden) with sticky inserts were used. Traps were placed at 1 m height and baited with commercial lures purchased from BioChemTech (Amsterdam, the Netherlands) for all species in 2021 and for the clearwing and the bud moth also in the later years. For the bud moth, the lures for the large fruit-tree tortrix, *A. podana*, were used. Unfortunately, the lures for the shoot borer were non-functional in 2021, and therefore no comparable trap catch data are available for this year and species. Lures for the shoot borer were from Pherobank (Wijk bij Duurstede, the Netherlands) during 2022–2024. According to the suppliers, the lures had a pheromone formulation in accordance with the identification publications (see above). Lures were renewed after 4 weeks, and sticky bottoms were replaced every week during 2021 and every second week during the later years. For each field, year, and species, the total catch in the four traps over the season was used as an estimate of the adult flying population.

2.3 | Damage Estimates

In late May or early June, the proportion of dead or severely damaged shoots was visually estimated on a scale from 0 (no damage) to 10 (all damaged) along eight 10 m stretches of bushes. Four of the stretches were at the four trap sites inside the field, and four were at the corners of the field (second row and 10 m from the edge). During 2021–2023, only the four interior stretches were inspected at the fields in Finland, due to pronounced edge effects. For each field and year, the average score of four or eight estimates was used.

2.4 | Mating Disruption

Attempts to disrupt the mate finding behaviour in male moths were performed with all three pest species during 2022 and 2023. The fields treated in the different years, their sizes, and the degree of isolation are shown in Table S1. In 2022, one species was treated per field, whereas in 2023, some fields were treated against two or all three species. For each species, 300 dispensers or SPLAT (Specialised Pheromone & Lure Application Technology) wax droplets (ISCA Technologies, Riverside, CA, USA) per ha were applied as evenly as possible before the flight period of the pests. Commercial dispensers were only available for the clearwing. Rope or bag dispensers were hung on branches of currant bushes, whereas SPLAT was applied as ≈1 g droplets onto the leaves of the plants using a caulking gun.

To disrupt mate finding in the clearwing, Shin-Etsu plastic rope dispensers (Isonet Z, CBC (Europe) S.r.l., Biogard Division, Vardeo, Italy) were used both years. Each dispenser contained at least 73 mg (*E*,*Z*)-2,13-octadecadienyl acetate and 2 mg (*E*,*Z*)-3,13-octadecadienyl acetate (average 81 and 3 mg, respectively), resulting in 25.2 g of active ingredients per ha (Table 1). The release rate was estimated by subtracting the average weight of 10 dispensers after 56 days in the field in 2021 (SE1) from the average weight of 10 dispensers kept in the freezer during the same period. This gave a release rate of 0.12 mg per day, which is about one quarter of the value (0.47 mg per day) provided by the producer and measured in Cesena, Italy, in 2010, but similar to the value measured by Grassi et al. (2002) from a similar dispenser for the same species and from the same company (Isomate, CCM).

TABLE 1 | Substances, their amounts, and dispensers used for mating disruption of the three pest species.

Species	Year	Chemical composition	Amount per release point (mg)	Amount per ha (300 release points, g)	Dispenser
Synanthedon tipuliformis	2022, 2023	(*E*,*Z*)-2,13-octadecadienyl acetate (*E*,*Z*)-3,13-octadecadienyl acetate	81 3	24.3 0.9	Izonet Z
Lampronia capitella	2022	(*Z*,*Z*)-9,11-tetradecadienol (*Z*,*Z*)-9,11-tetradecadienyl acetate (*Z*,*Z*)-9,11-tetradecadienal	34.5 9.0 4.5	10.4 2.7 1.4	Zip-bags
Lampronia capitella	2023	(*Z*,*Z*)-9,11-tetradecadienol (*Z*,*Z*)-9,11-tetradecadienyl acetate (*Z*,*Z*)-9,11-tetradecadienal	33.8 8.8 4.4	10.1 2.6 1.3	SPLAT
Euhyponomeutoides albithoracellus	2022	(*E*)-11-tetradecenyl acetate (*Z*)-11-tetradecenyl acetate	25 25	7.5 7.5	Zip-bags
Euhyponomeutoides albithoracellus	2023	(*E*)-11-tetradecenyl acetate (*Z*)-11-tetradecenyl acetate	34 34	10.2 10.2	SPLAT

Chemicals for the shoot borer were purchased from Pherobank. The pheromone mixture contained the three ZZ-14C compounds in the same ratio as identified from the females (Löfstedt et al. 2004). For the experiments in 2022, 0.15 g of the antioxidant 3-tert-butyl-4-hydroxanisole (BHA), to stabilise the active ingredients, was added to 20 g of the synthetic pheromone mixture. The mixture was manually distributed to 420 double LDPE zip-bags (Lyreco, Borås, Sweden) acting as dispensers and giving 48 mg per dispenser and 14.4 g per ha. For the trials in 2023, 80 g of the pheromone mixture were shipped to ISCA Technologies where the mixture was formulated in SPLAT. The total amount was distributed over 2.85 ha giving 94 mg per droplet and 28.2 g per ha. However, after this 1-year storage at 4°C the isomeric composition had changed so that the active ZZ-isomer of the three compounds had dropped to about 50% (checked by GC–MS) resulting in approximately the same amount of active compounds per ha both years of the study (Table 1).

Pheromone substances for the bud moth MD, (*E*)- and (*Z*)-11-tetradecenyl acetate, were purchased from Pherobank (isomeric purity 100% and 98%) and Bedoukian (Danbury, CT, USA) (isomeric purity 88% and 98%). For the experiment in 2022, double zip-bag dispensers were prepared as described above with 50 mg of the 50:50 E:Z pheromone blend (the different purities of the purchased isomers taken into account) per dispenser and 15.0 g per ha. In the experiments during 2023, the SPLAT formulation was used with 68 mg active ingredients (also here a 50:50 ratio) per droplet and 20.4 g per ha (Table 1).

The effects of the MD treatments were measured in different ways. First, the trap shutdown for each species during treatment was calculated as the relative reduction in trap catch compared to the previous year and in relation to non-treated fields. In addition, a possible effect on the adult population was looked for by comparing the trap catch the year before treatment with the catch the year after treatment. It should be noted that trap catches vary a lot between fields and years, as has been elaborated in Svensson et al. (2025). Also, the recorded damages the year with MD treatment were compared with the year after such treatment. Wilcoxon signed-rank tests were used for all these paired comparisons of MD fields and non-treated fields, using IBM SPSS Statistics (v27, New York, NY, USA).

3 | Results

3.1 | The Currant Shoot Borer, *Lampronia capitella*

Two fields in Sweden were subject to shoot borer MD in 2022, despite the lack of trap catch data from the previous year. Thus, the trap catches from the treated fields could only be compared with other non-treated fields the same year. The total catches in the treated fields were high, 775 and 2088 trapped males, respectively, compared to on average 624 for untreated fields (Table 2). In 2023, five fields (one of which, SE5, was also treated in 2022) were treated and had an average catch the year before (2022) of 755 males, compared to 661 for the fields not treated, making the background populations of treated and untreated fields comparable. During the pheromone treatment, still a large number of males were caught (mean = 643) and no difference in catch versus the previous year was observed in the treated fields ($z = -0.14$; $n = 5$; $p = 0.893$). In contrast, the catches in the untreated fields tended to be higher than the previous year (927; $z = -1.77$; $n = 22$; $p = 0.077$) (Tables 2, 5 and Figure 1a). When comparing catches the year before and the year after the treatment (Figure 3a), no effect was found for treated fields (755 vs. 1042; $z = -0.67$; $n = 5$; $p = 0.500$), whereas catches were significantly higher in the untreated fields (661 vs. 1404; $z = -2.16$; $n = 15$; $p = 0.031$). The ratio between the catch in 2023 and 2022 was on average 1.66 (range 0.37–3.81) for treated fields and 2.05 (range 0.13–10.50) for untreated fields (Table 2), thus showing

TABLE 2 | Catches of male currant shoot borer, *Lampronia capitella,* in individual fields treated with pheromones for mating disruption (MD) and in untreated fields (means, in bold) during the year of treatment and the year before.

	Catch year before		Catch treatment year		Catch ratio	Catch ratio
Year and field of MD treatment	**To be treated**	**To be untreated mean range *n***	**Treated**	**Untreated mean range *n***	**Treated MD year/year-1**	**Untreated MD year/year-1 mean range *n***
2022						
SE4	n/a	n/a	775	**624** 2–1808 26	n/a	n/a
SE5	n/a		2088		n/a	
2023						
SE2	356	**661** 2–1808 22	262	**927** 23–2777 23	0.736	**2.046** 0.585–11.500 22
SE5	2088		772		0.370	
NO7	949		930		0.980	
FIN2	244		929		3.807	
FIN8	136		324		2.382	

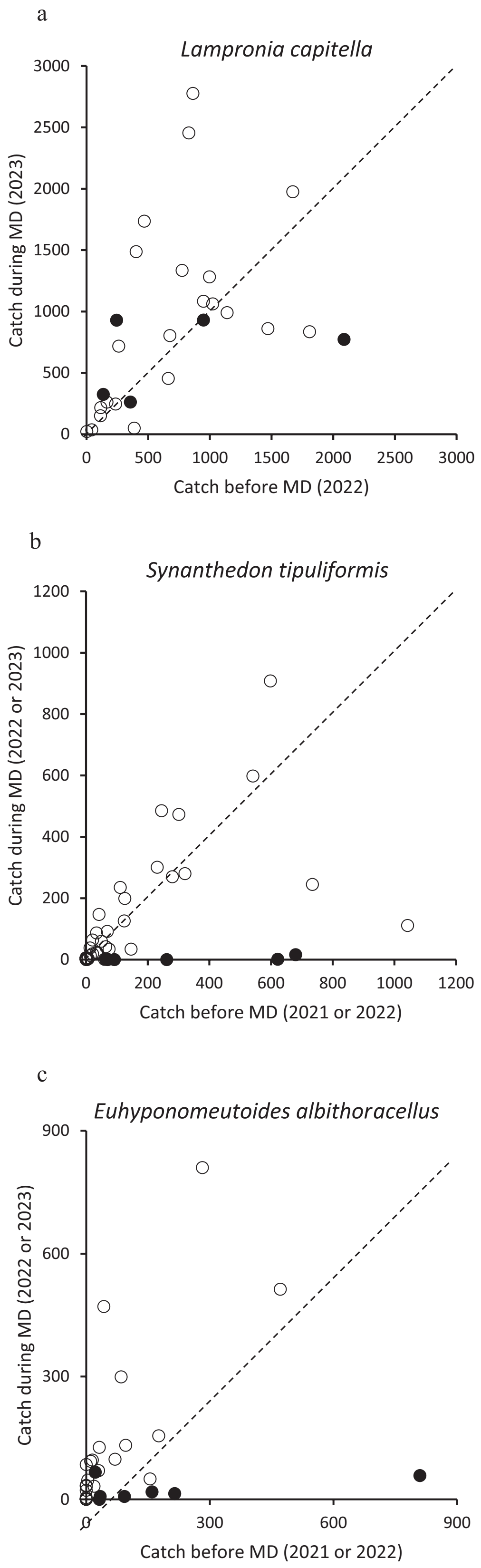

FIGURE 1 | Trap catch the year before MD treatment and the year of MD in treated (filled circles) and untreated (open circles) fields for (a) *Lampronia capitella*, (b) *Synanthedon tipuliformis*, and (c) *Euhyponomeutoides albithoracellus*.

no indication of population reduction as an effect of mating disruption, but possibly a general increase of population densities of the pest.

3.2 | The Currant Clearwing *Synanthedon tipuliformis*

Also for the clearwing, the background catch data (year before treatment) were comparable between fields to be treated and fields aimed as untreated controls, with all MD fields having catches within the range of the untreated fields (Table 3). During the MD treatment, zero or one moth was caught in total per field in seven of the eight fields compared to, on average, 144 and 262 for the untreated fields in 2022 and 2023, respectively. There were significantly lower catches in treated fields during the MD treatment versus the previous year ($z = -2.52$; $n = 8$; $p = 0.012$; Tables 3, 5 and Figure 1b), but no such difference among years in untreated fields ($z = -1.13$; $n = 29$; $p = 0.261$). Consequently, the ratio between years became very low for treated fields, whereas catches in untreated fields were unchanged (ratio 0.94) in 2022 or showed an increase (ratio 1.84) in 2023, indicating a strong trap shutdown/mating disruption. However, this effect was not long-lasting (Figure 3b), as there was no difference in catch in MD fields the year after versus the year before such treatment ($z = 0.00$; $n = 8$; $p = 1.000$), and the same pattern was observed for untreated fields ($z = 0.46$; $n = 18$; $p = 0.647$).

3.3 | The Currant Bud Moth, *Euhyponomeutoides albithoracellus*

Six of the seven fields to be MD-treated for the bud moth had comparable catches the year before as the fields to be untreated (Table 4). The MD field SE5, however, had the highest trap catch of all fields the year before treatment. Six of the MD fields showed strongly reduced trap catches during the treatment, resulting in a ratio between years from 0.06 to 0.21, compared to a three- to fourfold increased catch in untreated fields (Tables 4, 5 and Figure 1c; the field FIN8 showed a higher catch during the treatment (66) than the year before (22)). There was a strong trend for lower catches in MD-fields the year they were treated compared to the year before ($z = -1.86$; $n = 7$; $p = 0.063$), whereas the opposite pattern was observed for untreated fields, i.e., significantly higher catches the year when MD was performed ($z = -3.22$; $n = 21$; $p < 0.001$). Also, catches were significantly higher in both treated ($z = -2.37$; $n = 7$; $p = 0.018$) and untreated ($z = -2.09$; $n = 10$; $p = 0.037$) fields when comparing the years before and after the treatment year (Figure 3c).

3.4 | Effects on Damage

If the MD treatment has an effect on the mating frequency and results in fewer eggs and larvae the following generation, there should be an effect on the damage as well as on the coming

TABLE 3 | Catches of male currant clearwing moth, *Synanthedon tipuliformis*, in individual fields treated with pheromones for mating disruption (MD) and in untreated fields (means, in bold) during the year of treatment and the year before.

	Catch year before		Catch treatment year		Catch ratio	Catch ratio
Year and field of MD treatment	**To be treated**	**To be untreated mean range *n***	**Treated**	**Untreated mean range *n***	**Treated MD year/year-1**	**Untreated MD year/year-1 mean range *n***
2022						
SE1	262	**241** 14–1043 15	0	**144** 13–598 14	0	**0.94** 0.23–3.05 14
NO4	680		16		0.024	
NO7	622		1		0.002	
FIN2	70		0		0	
FIN9	70		1		0.014	
2023						
NO9	92	**164** 21–598 11	0	**262** 19–908 11	0	**1.84** 0.68–3.50 11
FIN4	60		1		0.017	
FIN8	64		1		0.016	

Note: Fields in northern Sweden (SE2-SE10) were excluded because of very low catches.

TABLE 4 | Catches of male currant bud moth, *Euhyponomeutoides albithoracellus*, in individual fields treated with pheromones for mating disruption (MD) and in untreated fields (means, in bold) during the year of treatment and the year before.

	Catch year before		Catch treatment year		Catch ratio	Catch ratio
Year and field of MD treatment	**To be treated**	**To be untreated mean range *n***	**Treated**	**Untreated mean range *n***	**Treated MD year/year-1**	**Untreated MD year/year-1 mean range *n*[a]**
2022						
SE4	215	**41** 0–282 14	14	**136** 0–810 14	0.065	**4.80** 0.89–10.95 7
SE7	160		18		0.113	
2023						
SE2	34	**101** 0–471 9	7	**141** 1–513 9	0.206	**3.35** 0.32–11.75 7
SE5	810		58		0.072	
FIN2	93		7		0.075	
FIN4	32		0		0	
FIN8	22		66		3	

Note: Fields in northern Sweden (NO1-NO10) were excluded because no bud moths were caught.

[a] Excluding fields with zero catch year 1.

adult population. Since at least two moth species occur in all fields and the damages caused by each of them are difficult to distinguish, the damage estimate is not necessarily reflecting effects of a particular species. With this in mind, there was no difference in damage between years in MD-fields ($z = -0.22$; $n = 15$; $p = 0.826$) or untreated fields ($z = -1.36$; $n = 22$; $p = 0.173$). Overall, the damage on the currant plants seems to have increased during the course of the project, as more fields are found above the "equal-damage" diagonal than below it (Figure 2). However, the MD treated fields were overrepresented in the group of fields with decreasing damage, 7 out of 14 fields, compared to eight out of 24 fields with increasing damage index (Figure 2). It was difficult to find enough fields for treatment that were both small and well isolated. Thus, all but three treated fields had a neighbouring field within 1 km distance (Figure S1). However, when correlating the ratio of

TABLE 5 | Summary of Wilcoxon signed-rank tests of catches of moth pests in pheromone-baited traps in *Ribes nigrum* crop fields treated for mating disruption (MD) and in untreated crop fields (Control) before (MD-1), during (MD) and after (MD + 1) the treatment.

Species	Field type	Parameter 1	Parameter 2	*z*	*N*	*p*
Euhyponomeutoides albithoracellus	MD	Catch year MD-1	Catch year MD	−1.86	7	0.063
Euhyponomeutoides albithoracellus	Control	Catch year MD-1	Catch year MD	−3.33	21	< 0.001
Euhyponomeutoides albithoracellus	MD	Catch year MD-1	Catch year MD + 1	−2.37	7	0.018
Euhyponomeutoides albithoracellus	Control	Catch year MD-1	Catch year MD + 1	−2.09	10	0.037
Lampronia capitella	MD	Catch year MD-1	Catch year MD	−0.14	5	0.893
Lampronia capitella	Control	Catch year MD-1	Catch year MD	−1.77	22	0.077
Lampronia capitella	MD	Catch year MD-1	Catch year MD + 1	−0.67	5	0.500
Lampronia capitella	Control	Catch year MD-1	Catch year MD + 1	−2.16	15	0.031
Synanthedon tipuliformis	MD	Catch year MD-1	Catch year MD	−2.52	8	0.012
Synanthedon tipuliformis	Control	Catch year MD-1	Catch year MD	−1.13	29	0.261
Synanthedon tipuliformis	MD	Catch year MD-1	Catch year MD + 1	0.00	8	1.000
Synanthedon tipuliformis	Control	Catch year MD-1	Catch year MD + 1	−0.46	18	0.647

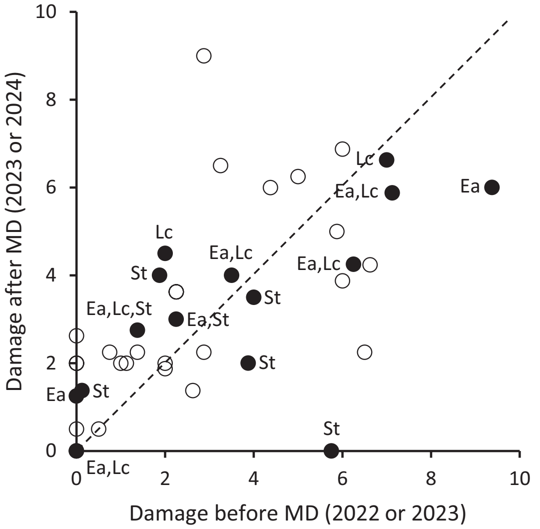

FIGURE 2 | Average damage index before MD treatment and the year after of treated (filled circles) and untreated (open circles) fields. Initial letters of the species names (Lc = *Lampronia capitella*, St = *Synanthedon tipuliformis*, Ea = *Euhyponomeutoides albithoracellus*) indicate which species were subject to mating disruption in the different fields. Most fields were treated for one species only, but some for two and one for all three species.

damage after and before a treatment with the distance to nearest neighbouring field, no significant relationship was found (*r* = −0.181) (Figure S2).

4 | Discussion

Our study demonstrates a clear potential for successful control of the clearwing and the bud moth by means of mating disruption with pheromones. However, no effect was observed for the shoot borer, neither in terms of trap shutdown nor reduced damage. The three moth species investigated in this study are all specialist herbivores on currant and gooseberry (*Ribes* spp.) and have a 1-year life cycle with a short adult life. The larvae of all three species also share a lifestyle where they spend a large part of their time hidden inside their host. However, when it comes to geographical distribution and the amount of research they have attracted, they differ. The clearwing spread during the 19th century from its original area, mainly Europe, to both North America and New Zealand/Australia. In these new areas, the species was relaxed from several natural enemies and soon became a significant threat to currant production. Being the most widespread lepidopteran currant pest and also introduced to new areas, several research groups (see above) set out to identify or fine-tune the clearwing sex pheromone from the 1980:ies and pheromone-producing companies began to manufacture lures for monitoring purposes. When direct pheromone-based control of pest insects using the MD strategy developed, Shin-Etsu (Japan) began to produce dispensers aimed at the clearwing, and this strategy became widespread at least in New Zealand (Thomas and Burnip 1991; Cardé and Minks 1995). The pheromone identification of the other two species had to wait until 2004 for the shoot borer (Löfstedt et al. 2004) and 2023 for the bud moth (Svensson et al. 2023), respectively. No large-scale attempts to use MD to control these two species have been reported before the present study.

Our experiments with the clearwing and the bud moth resulted in a strong trap shutdown in all but one field with the bud moth (FIN8, Table 4; possibly due to uneven dispenser distribution since 49 of the 66 males were caught in one trap). Thus, in general, the males had problems orienting to and finding the monitoring traps and presumably also to find females, in analogy with the findings of Thomas and Burnip (1991) for the clearwing. It was interesting to note that the trap shutdown was of the same magnitude for the bud moth irrespective of pheromone release method, zip-bags or SPLAT, indicating a

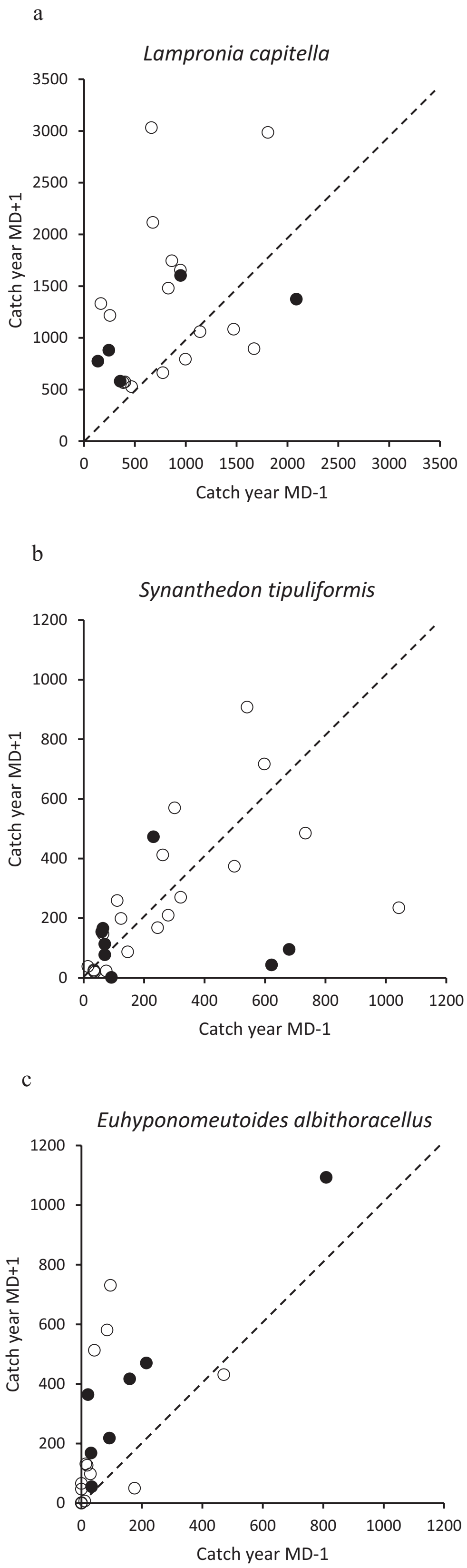

FIGURE 3 | Trap catch of (a) *Lampronia capitella*, (b) *Synanthedon tipuliformis*, and (c) *Euhyponomeutoides albithoracellus* during the year preceding the mating disruption and the year after the treatment. Filled symbols for MD treated fields and open symbols for untreated fields.

reasonable release of the pheromone in both cases. After 1 year of treatment, no apparent effect on the degree of damage or population size was detected; however, this was contrary to the reduced damage noted for the clearwing in the Netherlands after 1 or 2 years of MD using similar amounts of pheromone per ha (Helsen et al. 2014). For the clearwing, we used the lower of the two doses recommended by the manufacturer (300 dispensers/ha), but in the future, higher doses should be applied, e.g., 600 dispensers per ha as suggested for high population levels. The same strategy may be successful also for the bud moth. Some, but not all, of the treated fields were well isolated from other currant fields, and in future experiments, the distance to other currant fields should be larger than in some cases in this study. Alternatively, all fields within an area should be treated.

A more unexpected result was the complete lack of trap shutdown for the shoot borer. Neither of the two types of dispensers used seemed to cause any pheromone-mediated behavioural changes among the male moths. We cannot recall any other study with an obviously functional pheromone in which no effects of MD treatment on trap catch have been recorded, and we can only speculate what the reasons are in this case. Since the MD dispensers contained the same blend of pheromone compounds from the same manufacturer as the functional monitoring lures, which effectively catch the moth, it is not likely that there is anything wrong with the pheromone composition. The shoot borer has an unusual pheromone blend of three analogous conjugated (*Z*9,*Z*11)-dienes, each of them only rarely found among the numerous moth pheromones identified until now (Pherobase 2025). In a screening study, Reed and Chisholm (1985) reported attraction of male *Leptostales ferruminaria* (Geometridae) to a 100:10 blend of (*Z*,*Z*)-9,11-tetradecadienal and the corresponding alcohol. Later, Zhu et al. (1996) identified the corresponding acetate from female gland extracts of *Idaea aversata* (Geometridae) and the activity was confirmed by electrophysiological responses and in field trials. Finally, Do et al. (2011) identified the same three compounds as in the shoot borer in *Spulerina astaurota* (Gracillariidae).

These conjugated compounds are challenging to synthesise as pure isomers and they easily isomerize, as shown by the difference in purity of our blend between the first and second year of application. Still, the amount applied in the field should be enough to reduce trap catches of males, but the question remains if the expected compounds were released from the bag or wax dispensers or if something happened to them in the field. The lures for the monitoring traps consist of rubber septa and are more protected from the environment inside the traps. These remain active at least during the 4 weeks of use in our fields. The pea moth, *Cydia nigricana*, uses the conjugated (*E*,*E*)-8,10-dodecadienyl acetate as a sex pheromone and this compound has been used in MD experiments (Bengtsson et al. 1994). After 9 days in the field, the isomeric purity had decreased from 99% to 92% and the other three isomers (*E*,*Z*-, *Z*,*E*-, and *Z*,*Z*-) increased to 8%. In the pea moth, these three isomers are inhibitory and act as repellents, and male moths were no longer observed within the treated field. In the shoot borer, however, nothing is known about the possible behavioural effect of the isomers not being used in the attractive lures and in the blend for MD. In the identification publication (Löfstedt et al. 2004), only the relative order of electroantennographic (EAG) responses was mentioned and the isomers were at most 91% pure. Access to all isomers and of high purities is necessary to be able to tease out the role of each of them and thus come closer to understanding the pheromone communication in the shoot borer.

We used an estimate of the overall damage caused by the currant pests to measure effects on the plants, which proved to be insufficient if effects due to individual species were to be documented. As the shoot borer is the most abundant species in most of the fields included in the study (Svensson et al. 2025) and we could not even obtain any trap shutdown with this species, a large part of the damage recorded most likely originated from feeding by shoot borer larvae. Thus, if the pheromone treatments worked to some extent for the other two moth species, this would not influence the degree of damage to any large extent. However, the treatments against the bud moth and clearwing were not found to affect the population density (trap catch) the year after the treatments (Figure 3 and Table 5).

When performing MD experiments, immigration of mated females into treated areas from other fields in the surrounding should usually be considered and minimised. Wild blackcurrant and plants in abandoned gardens occur in many places in Finland and northern Sweden, but not in numbers that should generate significant background populations of the target species of moths that would affect the results of the experiments. The distance to the nearest non-treated field ranged from 100 m to more than 10 km, but no effect on the reduction of damage was noted. It is interesting to compare with the MD study of the clearwing in the Netherlands (Helsen et al. 2014), where control fields were adjacent to treatment fields and still a clear reduction of the damage was noted. Based on this, the immigration of mated clearwing females into a treated area seems negligible.

The ultimate measurement of successful control of pests and diseases is an increased yield. From some of the growers, we received figures for the fields involved in the study, but sometimes several fields were harvested at the same time without separating the outcome. However, based on the values we obtained, it is obvious that the variation is huge both within fields between years and especially between fields or regions. In this study, the yield per ha ranged between 0.1 and 12 tons per ha. Obviously, much of the variation is due to other factors than pest insects, e.g., soil conditions and climate, and comparisons should probably be restricted to individual or neighbouring fields.

In conclusion, for two of the pest species studied, the clearwing and the bud moth, our results indicate that MD could be a successful method of management if the correct pheromone dosage and release technique are used. However, the largest challenge when it comes to breaking the declining production of currants in especially northern Sweden (Enocksson and Spendrup 2017) is to understand the male behaviour of the shoot borer when exposed to high doses of its pheromone to cause MD. Both behavioural observations in the field and investigations to elucidate the fate of the pheromone blend during release are needed.

Author Contributions

Olle Anderbrant: conceptualisation; formal analysis; funding acquisition; investigation; visualisation; writing – original draft preparation. **Hanh Huynh:** investigation; writing – review and editing. **Ann-Kristin Isaksson:** funding acquisition; investigation; writing – review and editing. **Line Beate Lersveen Myhre:** investigation; writing – review and editing. **Sigrid Mogan:** funding acquisition; investigation; writing – review and editing. **Elisabeth Öberg:** investigation; writing – review and editing. **Christer Löfstedt:** conceptualisation; funding acquisition; writing – review and editing. **Marja Rantanen:** funding acquisition; investigation; writing – review and editing. **Gunda Thöming:** funding acquisition; writing – review and editing. **Glenn P. Svensson:** conceptualisation; data curation; formal analysis; funding acquisition; investigation; visualisation; writing – original draft preparation.

Acknowledgements

We thank the growers for allowing us to use their currant fields and, in some cases, for checking the monitoring traps. We are also grateful to ISCA for formulating SPLAT for two of the species. We thank Johanna Jonasson, Markus Karlsson, Aulis Leppänen, Karri Pasanen, and Saara Tuohimetsä for professional field assistance and Erling Jirle for logistics support. Financial support was provided by the Swedish farmers' foundation for agricultural research (SLF), project number O-20-20-452, and by the project TekMarja New techniques to control pests of berry crops, grant number 145143, which was funded by the European Agricultural Fund for Rural Development (EAFRD).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The trap catch and damage estimate data have been deposited in the DORIS database at the Swedish National Data Service at the following link: https://doi.org/10.5878/vrak-4t29.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.