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Article

Monitoring of Harmful Noctuid Pests with Synthetic Sex Pheromones and Semisynthetic Bisexual Lures (SBL): Benefits and Limitations of Separate, Parallel and Combined Use of the Methods

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Abstract

Sex pheromones and semi-synthetic bisexual lure (SBL) were used both in parallel and in combination within single traps to monitor four widely distributed noctuid pest species. For *Agrotis ipsilon*, the SBL proved to be more effective than the species-specific sex pheromone, and it can be used alone instead of them, as well as for monitoring the pest. In the case of *A. segetum* and *Lacanobia oleracea*, the lures did not inhibit each other, and their parallel and combined use provided a more accurate representation of swarming dynamics and abundance peaks, as well as enabled the monitoring of female flight activity. Observations revealed shifts in the life cycle of *L. oleracea* and further supported the migratory nature of *A. segetum*. The parallel and combined application of the newly developed SBL and conventional sex pheromone lures may significantly enhance the precision of pest monitoring and forecasting, thereby supporting more precise planning and timing and more effective implementation of plant protection treatments in IPM strategies.

Keywords: sex pheromone; semi-synthetic bisexual lure; traps; *Agrotis ipsilon*; *A. segetum*; *Lacanobia oleracea*

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1. Introduction

Various types of light- and semiochemical-baited traps have been used to monitor moth species of biological or economic importance [1–3]. Due to their high diversity and abundance, these moths occupy a crucial position in food webs as herbivores, serving as a substantial food source for parasitic and predatory taxa. Simultaneously, they act as sensitive indicators of environmental change and the natural value of their habitats. Monitoring their populations is essential for decision-making in both effective nature conservation and in effective and sustainable Integrated Pest Management (IPM) strategies. Recording, monitoring, and forecasting of pest species—particularly invasive alien species—have gained increasing importance in the context of ongoing climate change. Traditionally, such efforts have primarily relied on various, partially standardized types of light traps [4–6].

However, numerous studies demonstrated that light trap results are often biased due to sex-specific behavioral differences and are affected by a range of environmental and physiological factors [7–9]. Consequently, there is an urgent need to develop new, reliable, and standardized trapping methods and test their efficacy on known noctuid species in North American pest species.

The present study focuses on four economically important noctuid moth species: *Agrotis ipsilon* (Hufnagel, 1766), *Agrotis segetum* ([Denis & Schiffermüller], 1775), *Hadula trifolii* (Hufnagel, 1766), and *Lacanobia oleracea* (Linnaeus, 1758), all recognized as polyphagous pests across Europe. These moths belong to the pest-associated clade of the Noctuinae subfamily [10,11] but differ markedly in ecological preferences, voltinism, phenology, and migratory behavior—even the two *Agrotis* species belong to separate clades within the genus [12].

A. segetum (so called as turnip moth), a widely distributed Eurasian and Afrotropical species, is typically bi- or trivoltine and affects major crops such as *Arachis*, *Beta*, *Brassica*, *Glycine*, *Nicotiana*, *Solanum*, *Zea*, etc. It exhibits a long-distance migration, often mixing local populations that differ in phenology. *A. ipsilon* is a cosmopolitan pest species with a possible Neotropical origin. It is reported from all continents except Antarctica and is known to damage a broad range of herbaceous crops, including *Nicotiana*, *Phaseolus*, *Solanum*, *Zea*, etc. [12].

The two other target species belong to the tribe of Hadenini. *Hadula trifolii*, the clover cutworm, is a Holarctic and North African species. It is mostly bivoltine and is a known migrant pest. Its polyphagous larvae feed on numerous cultivated and wild plants, such as *Atriplex*, *Beta*, *Brassica*, *Chenopodium*, *Glycine*, *Helianthus*, *Medicago*, *Polygonum*, *Salsola*, *Trifolium*, *Zea*, etc. [12]. *Lacanobia oleracea*, the tomato moth, is common throughout temperate and subtropical Eurasia and in North Africa. It is a non-migratory species with one to two generations annually. Larvae feed on a range of herbaceous plants (e.g., *Atriplex*, *Brassica*, *Chenopodium*, *Chrysanthemum*, *Humulus*, *Lactuca*, *Pisum*, *Solanum*, and *Urtica*) and occasionally, woody plants such as *Corylus*, *Prunus*, *Salix*, and *Ulmus* spp.

For the detection and monitoring of the four target noctuid species, species-specific synthetic sex pheromones have been developed and are widely used in various regions [13]. These sex pheromone lures are highly effective but limited to attracting only males. In contrast, tools that attract both sexes, such as bisexual feeding attractant-based lures, offer broader applicability in pest monitoring and may contribute more effectively to decision-support systems in Integrated Pest Management (IPM) frameworks.

The key advancement in the development of bisexual lures for noctuid moths was the identification of iso-amyl alcohol and acetic acid, two volatile compounds released by fermenting substrates, as potent attractants for both male and female individuals [14]. These components were combined in a synthetic bisexual lure designed to attract several noctuid species in North America [15] and Europe [16]. Building on these findings, in Hungary, a more powerful semi-synthetic bisexual lure (SBL) was developed, with the addition of red wine extract or red wine to enhance attraction [17]. Field experiments in East Hungary and Transcarpathia (Western Ukraine) demonstrated the lure's high efficacy in attracting large numbers of noctuid species belonging mainly to the subfamilies, including the four target species of the present analysis (Acronictinae, Amphipyrinae, Xyleninae, Hadeninae, and Noctuinae) [18,19].

The parallel or combined use of sex pheromone and SBL within a single trap has the potential to offer synergistic advantages. While the sex pheromone provides high sensitivity and species specificity for early detection of the target species, SBL enables the capture of females, offering valuable insights into population structure, reproductive status, and female flight activity. These combined data streams can significantly increase the accuracy of population assessments and improve the timing and targeting of treatments in IPM strategies.

The present study was carried out to compare the relative trapping efficiency of SBL and synthetic sex pheromone lures for the four target noctuid pest species and to investigate potential interactions between the lures when applied simultaneously in the same trap. The findings are expected to contribute to the optimization of monitoring tools and support the integration of more robust volatile-based trapping systems into pest forecasting and management in IPM programs.

2. Materials and Methods

2.1. Field Tests

Field experiments were conducted with a sampling design widely used in trapping experiments of a similar nature in insect chemical ecology at two sites in Hungary. Traps were placed 20–25 m apart and were checked twice a week (every 3–4 days), at which time captured insects were recorded and removed.

2.2. Traps

CSALOMON® VARL + funnel traps (Plant Protection Institute, Hungary, CAR, HUN-REN, Budapest; photos of the trap can be viewed at www.csalomontraps.com (accessed on 1 December 2024)) were used in the study. Similar traps have been routinely used for trapping various noctuid species [16]. To kill the captured insects, a small piece (1 × 1 cm) of a household anti-moth insecticide strip (Chemotox® SaraLee, Temana Intl. Ltd., Slouth, UK) containing 15% dichlorvos as the active ingredient was placed inside the trap container.

2.3. Baits

The SBL and the used CLR dispenser (a custom-made polypropylene vial with lid; 4 mL capacity, wall thickness 1 mm) tested was the same as described earlier in detail [16,17], with the active ingredients of iso-amyl alcohol, acetic acid, and red wine (from the vinery of Dr. Géza Vörös (Szekszárd, Hungary), containing Blaufrankisch (70%), Merlot (15%), Kadarka (7.5%), and Blauburger (7.5%) grapevines. Alcohol content: 13.6–13.8%, acid (acetic acid) content 0.4–0.6 g/L) (1:1:1 mL).

The sex pheromone lures were obtained from the CSALOMON® trap family (Plant Protection Institute, Hungary, CAR, HUN-REN, Budapest) and had the following active ingredients:

A. ipsilon: (Z)-7-dodecenyl acetate + (Z)-9-tetradecenyl acetate + (Z)-11-hexadecenyl acetate [20,21].

A. segetum: (Z)5-decenyl acetate + (Z)-7-dodecenyl acetate + (Z)-9-tetradecenyl acetate [22].

H. trifolii: (Z)-11-hexadecenyl acetate + (Z)-11-hexadecenol [23].

M. oleracea: (Z)-11-hexadecenyl acetate + (Z)-11-hexadecenol [24].

The attractiveness and efficiency of the used sex pheromone baits and the SBL were assumed since they were formerly proven in several studies [17,18].

2.4. Field Experiment Design

Tests on the parallel use of traps with sex pheromone lure and SBL (Exp. 1 and Exp. 2): The attractivity of SBL, and the synthetic sex pheromones of *A. segetum*, *A. ipsilon*, and *L. oleracea* were compared. Traps were used in 5 reps, giving a total number of 20 traps. Exp. 1 ran from 15 July to 14 November 2015. Lures were changed to new ones monthly. The test was conducted in the surroundings of Csengersima (Szabolcs-Szatmár-Bereg County, NE Hungary), near the margin of a mixed oak forest (GPS: 47.8524858°, 22.7660031°). Exp. 2 ran from 16 July to 12 November 2015. The test was carried out in the surroundings of Tiszavasvári (Szabolcs-Szatmár-Bereg County; NE Hungary), in the margin of a mixed deciduous forest (GPS: 47.963998°, 21.471269°)

Test on the combined use of the lures in the same dispenser (Exp. 3 and Exp. 4): The attractivity of SBL and the synthetic sex pheromone of *L. oleracea* and their combination in one dispenser were compared. Each lure was used in 5 reps, giving a total number of 15 traps. Lures were replaced by new ones monthly. Exp. 3 ran between 28 May and 29 October 2017. The test was conducted in the surroundings of Jánkmajtis (Szabolcs-Szatmár-Bereg County, NE Hungary), near the margin of an orchard (Coordinates: 47°56′29.01″ É, 22°38′17.02″ K). Exp. 4 ran between 1 June and 2 November 2017. The test was carried out near Karcag (Jász-Nagykun-Szolnok County, E Hungary), in a margin of a maize field and woody edge (Coordinates: 47°22′41.69″ É, 20°54′39.28″ K)

Test on the combined use of the lures in the same trap together (Exp. 5 and Exp. 6): Attractivity of the SBL, the synthetic sex pheromones of *A. segetum, A. ipsilon, H. trifolii, L. oleracea*, and their combination (*A. ipsilon* synthetic sex pheromone + SBL; *A. segetum* synthetic sex pheromone + SBL lure; *H. trifolii* synthetic sex pheromone + SBL; *L. oleracea* synthetic sex attractant + SBL) were compared. Each treatment was used in 5 reps, giving a total of 45 traps. Exp. 5 ran between 12 June and 6 November 2022, near Debrecen-Józsa (Hajdú-Bihar County, E Hungary), at the margin of a maize field and a woody edge (Coordinates: 47°35′47.06″ É, 21°33′8.62″ K). Lures were replaced by new ones monthly. Exp. 6 ran between 12 June and 6 November 2022 near Olcsva (Szabolcs-Szatmár-Bereg County, NE Hungary), in a margin of maize field and woody edge (Coordinates: 48°6′7.04″ É, 22°20′15.33″ K). Lures were replaced by new ones monthly.

2.5. Sampling and Data Analysis

Insect samples caught by the traps were stored in paper bags in a deep freezer at −20 °C until they were sorted out by taxa, and Noctuids were identified at the species level according to [12].

The number of individuals caught was recorded, and the efficiency (attractiveness) of the tested lures was evaluated based on the mean number of individuals caught per sample (individuals/sample). These means were compared using the nonparametric Kruskal–Wallis test, and in cases of paired comparisons, the Mann–Whitney U-test was applied (at a 5% significance level, $p < 0.005$), as the data did not fulfill the assumptions required for parametric tests. Assumptions of homogeneity of variances and normality were assessed with the Levene test and Q-Q plots, respectively. For data processing, visualization, and statistical analysis, MS Office 365 and Statsoft Statistica 7 program packages were used.

Phenological changes in the species occurrence were described with the temporal variation in the number of individuals per trap and analyzed separately for both sexes and in total.

3. Results

3.1. Parallel Use of Traps with Sex Pheromone and SBL

In Exp. 1 and Exp. 2, the attractivity and selectivity of traps baited with sex pheromones of three species tested and SBL were compared. In these field tests, enough individuals of all tested species were collected for statistical analysis (Figure 1).

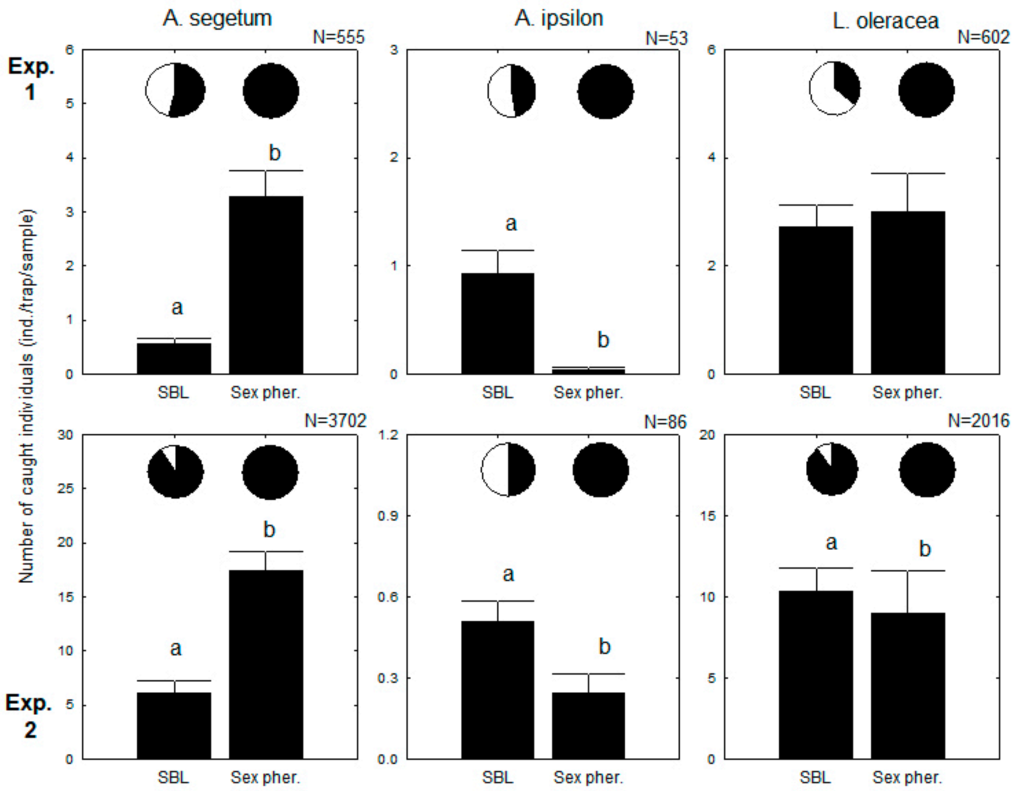

Figure 1. *Agrotis segetum*, *A. ipsilon*, and *Lacanobia oleracea* catches (mean ± SE) of sex pheromone and SBL lured traps in Csenger (Exp. 1) and Tiszavasvári (Exp. 2). Pies show sex ratios (male:female = black:white). Letters show significant differences based on the Mann–Whitney U test ($p < 0.005$).

At both sites, *A. segetum* was significantly more attracted by the sex pheromone than by the SBL. However, SBL traps also caught some females. In the case of *A. ipsilon,* the result was nearly the opposite, as the efficiency of the SBL was higher in both experiments. Additionally, the ratio of females was relatively high and similar in the two experiments. However, the number of individuals caught was relatively low compared to the catches of *A. segetum*. Although in Exp. 1, *L. oleracea* was caught by both types of traps with similar efficiency, the SBL traps caught a notable number of females while the sex pheromone attracted only males. In Exp. 2, the SBL attracted significantly more *L. oleracea* and also *A. segetum* individuals, but parallelly with this higher density, the ratio of females was equally lower than in Exp. 1 (Figure 1).

3.2. Combined Use of the Lures in the Same Dispenser

In the Exp. 3 and 4, the combined use of *L. oleracea* sex pheromone and the SBL was tested. Although in Jánkmajtis (Exp. 3) fewer individuals were in the traps, it was still enough for statistical analysis. In this site (Exp. 3), both SBL and its combination with sex pheromone proved significantly more attractive than the sex pheromone alone, while at Karcag (Exp. 4), the sex pheromone attracted many more individuals than the SBL (Figure 2). In the SBL traps, the sex ratio was near 1:1 in both cases.

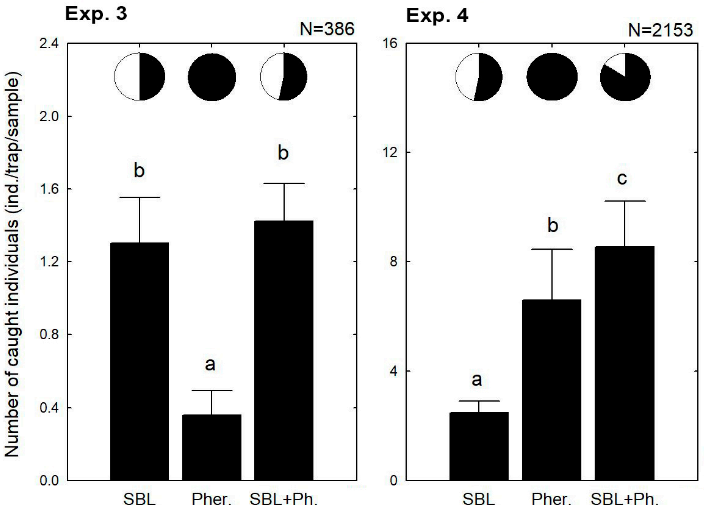

Figure 2. *Lacanobia oleracea* catches (mean ± SE) of traps baited with sex pheromone, SBL, and their combination in Jánkmajtis (Exp. 3) and Karcag (Exp. 4). Pies show sex ratios (male:female = black:white). Letters show significant differences based on the Mann–Whitney U test ($p < 0.005$).

3.3. Combined Use of the Lures in the Same Trap Together

In Exp. 5 and 6, the sex pheromone of four species was involved in the study, but only in the case of *A. segetum* were there enough catches for statistical analysis. Other species were less abundant, with fewer than 50 individuals caught per experiment in total, even *H. trifolii* traps could not collect any moths in both sites.

Sex pheromone, SBL, and their combination (attractants were placed into the same trap but in separate dispensers) showed different attractivity to *Agrotis segetum* in both Debrecen-Józsa (Exp. 5) and Olcsva (Exp. 6). In these experiments, the sex pheromone and its combination with SBL in the same trap showed similar efficiency that was significantly higher than the efficiency of SBL alone. Traps, including SBL, always caught some females too. The ratio of females in Exp. 6 was higher than in Exp. 5, and some females were also caught by sex pheromone traps at both sites (Figure 3).

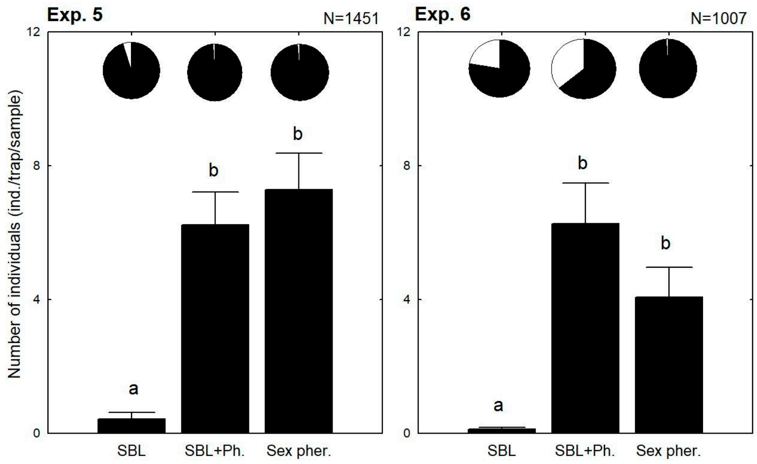

Figure 3. *Agrotis segetum* catches (mean ± SE) of unbaited control traps and traps baited with sex pheromone, SBL, and their combination in Debrecen-Józsa (Exp. 5) and Olcsva (Exp. 6). Pies show sex ratios (male:female = black:white). Letters show significant differences based on the Mann–Whitney U test ($p < 0.005$).

3.4. Effect of the Phenology

The effect of phenology on the catches of the tested traps was analyzed in the case of *L. olearacea* and *A. segetum*, and the species had sufficiently high abundances to make the study. Considering *L. oleracea*, it swarmed from late July, with a higher peak in mid-August, a second smaller one in mid-September, and even a nearly invisible third in mid-October in Exp. 1 and Exp. 2. In Exp. 1, the first mid-August peak was recorded with both types of lures and sexes swarms together in this period. The second and third peaks, formed by males only, were detected with sex pheromone traps. In these periods, the SBL was less effective (Figure 4).

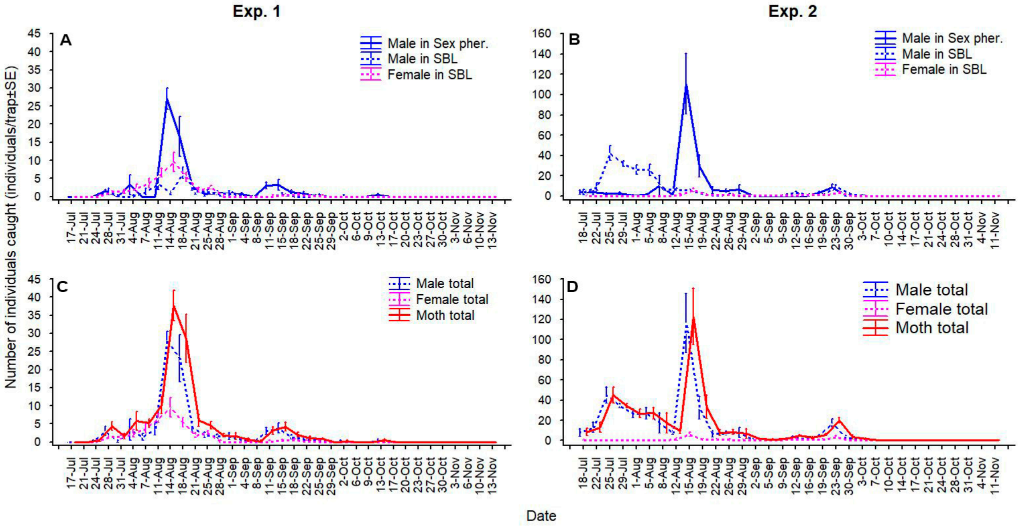

Figure 4. Temporal changes of *Lacanobia oleracea* catches in Exp. 1 (Csenger) and Exp. 2 (Tiszavasvári) according to sex pheromone (solid line) and SBL traps (dotted lines) (**A**,**B**) and pooled catches of different trap types (in parallel use) by sexes (dotted line) and in total (solid line) (**C**,**D**). Colors refer to sexes (blue: males, magenta: females), and their pooled data (red).

In Exp. 2, the SBL provided quite a different result regarding the male's flight. In the SBL traps, males appeared already in mid-July and drew an earlier peak before the mid-August swarming detected by both sex pheromone and SBL traps (Figure 4). Additionally, SBL traps detected a small peak on 29 August that sex pheromone traps did not record. In contrast, the last peak in September was detected only with sex pheromone traps, also as in Csenger (Exp. 1).

In Jánkmajtis (Exp. 3) and Karcag (Exp. 4) samplings started earlier, thus an earlier swarm in June could be detected, with both sex pheromone and SBL traps. The catches of sex pheromone were higher in this period, but later in August, the next peak was detected only with traps that included SBL in any form. This second peak was not registered with sex pheromone alone. The parallel and combined use of sex pheromone and SBL provided a similar curve that differed from the graph drawn by sex pheromone alone. The only difference between the parallel and combined use of two trap types was the time of the peak, as the peaks were earlier in both swarms in the case of parallel use. However, the swarming periods were the same in both cases (Figure 5). In Karcag (Exp. 4), a higher abundance of *L. oleracea* was detected. The first generation was on wing in June, and their flight was detected with both trap types, but the sex pheromone was more effective than SBL. In contrast with the parallel study (Exp. 3), the generation swarm in August was detected only with sex pheromone traps (Figure 5).

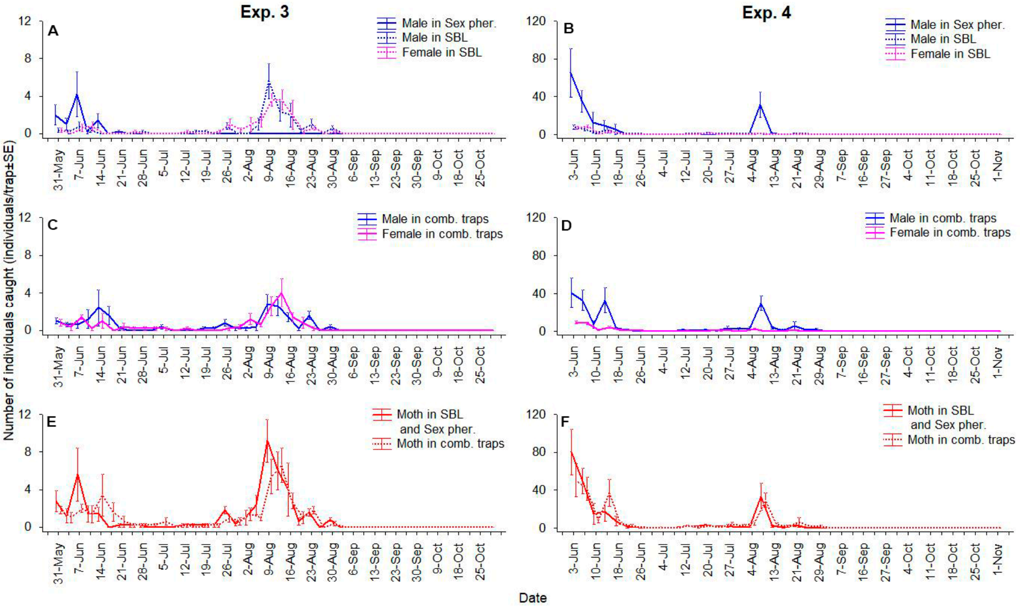

Figure 5. Temporal changes of *Lacanobia oleracea* catches in Exp. 3 (Jánkmajtis) and Exp. 4 (Karcag) using sex pheromone (solid line) and SBL (dotted line) parallelly in separated traps (**A**,**B**) and in combination in the same trap (comb. traps), by sexes (**C**,**D**) and in total by different use (solid line: parallel use; dotted line: combined use) of the tested lures (**E**,**F**). Colors refer to sexes (blue: males, magenta: females), and their pooled data (red).

In Exp. 1, the abundance of *A. segetum* was lower than in the parallel study (Exp. 2). Moths were caught mainly with sex pheromone traps, while the efficiency of the SBL traps was especially low. Nevertheless, individuals of both sexes appeared in the SBL traps when the sex pheromone traps recorded the flight of moths. Traps detected two long flight periods: one from mid-July to late August, with two peaks on 28 July and 18 August, and another, lower one from early September to late October, with a small peak on 29 September. In contrast, in Exp. 2, SBL traps caught a significant number of moths and provided data on two flights of *A. segetum* in Csenger, with peaks on 1st August and 30 September. The sex pheromone traps showed peaks on different dates and registered longer flight periods from mid-July to late August and from early to late September, and beyond that until November, with especially lower abundances. During the first flight, sex pheromone traps recorded two peaks on 25 July and 12 August. In the case of parallel use (summarized data of different traps), traps drew a more realistic curve of the two long swarming periods. Based on its first swarm, it had one peak on 25 July, while the later had double peaks (on 12 September and 30 September) and a long ending period until early November. The ratio of female catches was continuously low during the experiment (Figure 6).

In Debrecen-Józsa (Exp. 5) and Olcsva (Exp. 6) traps registered two flights of *A. segetum*. The first of them was a long period with high abundances from late June to early September, and the second was much lower abundances from late September to the end of trapping in late October.

SBL traps were much less effective than sex pheromone traps, but they could register the peak of the first flight in Exp. 5. The SBL and combined traps caught only a few moths. In the case of the combined use of different trap types, the same flight periods could be detected, but the peaks of the curves were on different dates in both experiments, and in the both flight periods. Although regarding the number of moths caught between the parallel and combined use of different traps, there were no differences, considering the seasonal changes, they drew slightly different curves (Figure 7).

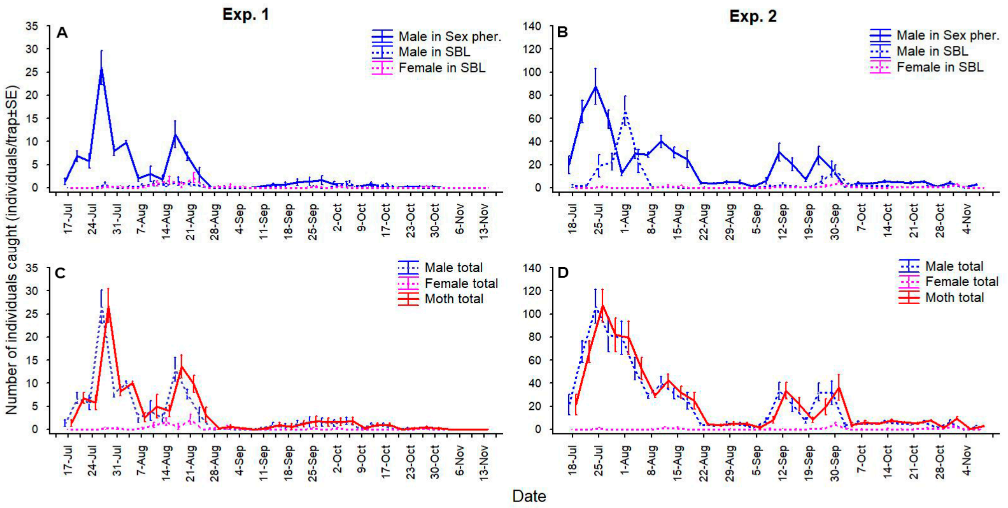

Figure 6. Temporal changes of *Agrotis segetum* catches in Exp. 1 (Csenger) and Exp. 2 (Tiszavasvári) according to sex pheromone (solid line) and SBL traps (dotted line) (**A**,**B**) and pooled catches of different trap types (in parallel use) by sexes (dotted lines) and in total (solid line) (**C**,**D**). Colors refer to sexes (blue: males, magenta: females), and their pooled data (red).

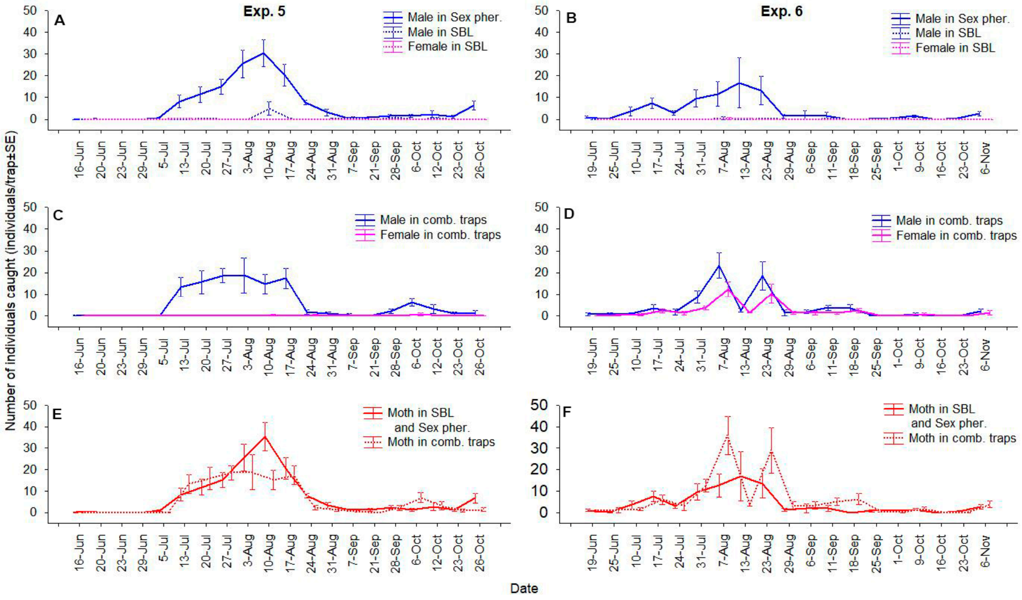

Figure 7. Temporal changes of *Agrotis segetum* catches in Exp 5 (Debrecen-Józsa) and Exp. 6 (Olcsva) using sex pheromone (solid line) and SBL (dotted line) parallelly in separated traps (**A**,**B**) and in combination in the same trap (comb. traps), by sexes (**C**,**D**) and in total by different use (solid line: parallel use; dotted line: combined use) of the tested lures (**E**,**F**). Colors refer to sexes (blue: males, magenta: females), and their pooled data (red).

4. Discussion and Conclusions

Since the selectivity and efficiency of traps used in faunistical, ecological studies, and monitoring of alien and pest species in plant protection [14–19,25–28] are different, their combined use might provide a new perspective for an efficient and sensitive way of insect sampling. In the present study, the relative efficiency and complementarity of synthetic sex pheromone and semi-synthetic bisexual lures (SBLs) in monitoring four key noctuid pest species were evaluated. Our results reinforce the utility of volatile-based attractants in pest monitoring and support their integration into more robust, sex-inclusive detection strategies. However, the implications of these findings extend beyond basic trap performance and merit consideration within broader ecological and pest management frameworks.

The combined use of sex pheromones and SBL offers clear advantages for pest monitoring in the Integrated Pest Management (IPM) strategy. Sex pheromone traps remain the classical standard for sensitive, species-specific monitoring of male moths, particularly in the early phases of the swarming. However, their specificity to males limits their utility for estimating population reproductive potential and the timing of oviposition. In contrast, SBLs that attract both sexes provide crucial data on female activity and sex ratios, contributing to more comprehensive assessments of population structure and helping the more precise timing of plant protection treatments, increasing their efficiency [16,17]. Our findings on *Lacanobia oleracea* and *Agrotis ipsilon* confirm that SBL can be equally or more effective than sex pheromones in attracting moths, with the additional benefit of female detection. In the case of *A. segetum*, although sex pheromone traps were more effective overall, the SBL also captured females, indicating their value in capturing population segments not detected by sex pheromone traps.

It is generally assumed that the feeding attractants are equally effective for both sexes and therefore provide a more accurate estimation of sex ratios than light traps or other trapping methods [19,28]. Although our SBL traps yielded varying sex ratios depending on the species and location, they consistently detected female activity, offering a valuable opportunity to enhance monitoring and management strategies for the studied pests. Moreover, our results indicate that sex ratios can differ significantly not only between species but also among populations of the same species, likely influenced by both environmental and intrinsic factors, such as species-specific behavior and population density.

The well-documented long-distance migratory nature of *A. segetum* [29–31] complicates the monitoring of local populations and challenges the interpretation of trap catches. Our phenological data, which revealed extended flight periods and asynchronous peaks between different trap types, suggest that migratory influxes may overlay local population dynamics. Notably, late-season swarming events detected by SBL traps but not by sex pheromone traps could reflect immigration phases, sex-specific behavior, or swarming types. These findings underscore the importance of using complementary trap types to capture the full scope of spatio-temporal dynamics in migratory species. In this context, the SBL serves as a useful tool to detect the onset of female immigration and mating activity—critical moments for timely intervention in IPM.

Importantly, the parallel and combined use of lures did not result in mutual inhibition. Additionally, in some cases, such as *L. oleracea* in Exp. 4, additive or even synergistic effects were observed when SBL and sex pheromone lure were deployed together in a single dispenser. This suggests that integrating multiple attractants can increase trap efficiency without compromising specificity, especially during periods of low pest density or in less suitable habitats and/or cultures. Moreover, phenological differences observed between SBL and sex pheromone lure—such as differing flight peaks or additional generations (e.g., in the case of *L. oleracea* in July in Tiszavasvári, Exp. 2)—highlight the need to employ multiple attractants to fully describe population dynamics.

The temporal shifts in catch efficiency between lures may also reflect differences in sex-specific behavior, mating status, preferences, and physiological needs. Males may be more actively seeking mates during peak sex pheromone responsiveness, while females may prioritize feeding and oviposition site selection, making them more sensitive to food-based attractants [32–36]. These small behavioral differences, while not directly tested here, could be addressed in future investigations. With dissection or molecular methods, reproductive biology and status, including the presence of spermatophore(s), polyandry, and phenology of mating seasons, can be studied, which may help understand the adaptation of pests and the processes underlying their spread and population outbreaks [37–43].

Furthermore, our data suggests phenological plasticity and changing life cycle characteristics in both *A. segetum* and *L. oleracea*, as it could be recently revealed in connection with climate change in the case of several noctuid species [44–47].

Both species are traditionally considered bivoltine in the Carpathian Basin; however, our findings suggest the occurrence of a possible third generation or extended flight activity lasting into late autumn (e.g., *L. oleracea* and *A. segetum* in September to October, as observed in Exp. 1 and 2). In some cases (Exp. 5 and 6), *A. segetum* exhibited late swarming in November, a pattern typically characteristic of migratory species such as *Helicoverpa armigera* [48,49]. While this could partly be attributed to favorable weather conditions during the study years, it may also reflect broader shifts driven by climate change. Such shifts reinforce the importance of year-round monitoring with sensitive tools like combined-lure traps to detect changes in pest phenology that could affect damage risk in cultures with different phenology [28].

The limitation of our findings is their geographic scope, which was restricted to selected sites in the Carpathian Basin (Hungary). Although the results are consistent across sites, which strengthens them, broader geographic validation, including in differing agro-ecological zones, would enhance generalizability. Additionally, not all the targeted species yielded sufficient data for full statistical analysis, particularly *Hadula trifolii* and *Agrotis ipsilon*, limiting conclusions about these taxa. Consequently, future research should primarily aim to validate the combined lure strategy in regions with diverse climates and cropping systems. Furthermore, the mating status and fecundity of females caught in SBL traps, temporal differences in trap catches corresponding with migratory influxes should be investigated, and economic assessments of combined lure deployment in IPM, including cost-benefit analysis and reduction in pesticide use, should also be made.

Summarily, the integration of SBL and sex pheromone lures offers a significant advancement in monitoring the most harmful noctuid pests by expanding the demographic and temporal resolution of trap data. While sex pheromone traps remain indispensable for species-specific early warning systems, bisexual feeding attractants such as SBL tested in the present studies add value by capturing females and revealing broader population dynamics. Together, these lures support more accurate forecasting, improved timing of interventions (with both chemical and biological pesticides, as well as beneficial control agents (BCAs), such as pest parasitic wasps (*Trichogramma* spp.)), and ultimately, more sustainable pest management. Their combined or parallel use is therefore recommended as part of an adaptive IPM strategy, particularly in the face of climate-driven shifts in insect phenology and distribution.

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