New sex attractants for 14 boreal forest moth species (Lepidoptera)

Mikhail V. Kozlov[1]

1 *Department of Biology, University of Turku, 20014 Turku, Finland; mikoz@utu.fi*

https://zoobank.org/C1201C48-9679-4E38-B840-C08E23E0479F

Received 16 November 2025; accepted 23 February 2026; published: 14 April 2026
Subject Editor: Marcin Wiorek.

Abstract. Field screening was conducted in subarctic boreal forests of the central Kola Peninsula, northwestern Russia, using eight (*Z*)-monounsaturated aliphatic compounds associated with moth sex pheromones: (*Z*)-5-decenyl acetate, (*Z*)-7-dodecenyl acetate, (*Z*)-7-dodecen-1-ol, (*Z*)-5-tetradecenyl acetate, (*Z*)-7-tetradecenyl acetate, (*Z*)-9-tetradecenyl acetate, (*Z*)-11-hexadecenyl acetate, and (*Z*)-11-hexadecenal. These compounds were tested both singly and in binary combinations (in some cases at different ratios), yielding 26 lure types. A total of 260 traps, deployed from 17 July to 12 August 1993, captured 18 moth species: one Yponomeutidae, one Argyresthiidae, one Coleophoridae, one Crambidae, two Geometridae, and 12 Noctuidae species. For 14 of these species, this study provides the first information on attractive compositions of synthetic lures.

Introduction

The global fauna currently includes approximately 170,000 to 180,000 described species of moths and butterflies (Lepidoptera), as indicated by species counts from the late 2000s (van Nieukerken et al. 2011) combined with rates of new species descriptions (Kristensen et al. 2007; Mitter et al. 2017). Most Lepidoptera rely on pheromone communication for mate location (Löfstedt 1993; Allison and Cardé 2016), yet sex pheromones have been identified for only about 700 moth species, and field testing has demonstrated male attraction to synthetic pheromone mixtures in an additional 1,300 species (Ando and Yamamoto 2020). Consequently, sex attractant data are currently available for only about 2,000 Lepidoptera species, representing less than 2% of those presumed to use pheromone-based mate location.

Due to the cost and logistical constraints, pheromone research has focused primarily on agricultural and forest pests, making it unlikely that keystone, indicator, or threatened Lepidoptera species will be targeted in the near future. Nonetheless, synthetic sex attractants for many species can be developed at reasonable cost by screening lures containing common pheromone components characteristic of particular insect groups, and by monitoring species' attraction across varied environmental contexts (Roelofs and Comeau 1970; Millar et al. 2016; Barros-Parada et al. 2020).

Although often undervalued, field data on moth attraction to synthetic lures can provide critical insights when laboratory identification of sex pheromones is not available. Validated field screening results support the production of effective synthetic lures, which are powerful tools for environmental monitoring (Kozlov and Haukioja 1993; Ruohomäki et al. 1996), enabling long-term tracking of population dynamics, range shifts, and the detection of invasive species (Elkinton and Cardé 1981; Grant 1991). They are also widely applied in faunistic surveys to assess species richness and distribution (Kozlov 1987; Velcheva 2000; Witzgall et al. 2010; Razov et al. 2017).

Pheromone-based research has focused primarily on agriculturally important regions (Brockerhoff et al. 2013), which has resulted in a strong geographic bias in our knowledge of moth responses to synthetic lures (Larsson 2016). Particularly, synthetic attractant blends have rarely been developed for species restricted to high latitudes (Linnaluoto and Koponen 1983; Hällfors et al. 2021). Moreover, for widely distributed species, pheromone blends optimized for certain populations may perform suboptimally, or fail entirely, when deployed in another region due to among-population variation in pheromone composition (Duménil et al. 2014; Akinbuluma et al. 2024). This variation, combined with geographic bias, could compromise both insect conservation and pest management in high-latitude ecosystems.

The present study aimed to develop synthetic lures for monitoring owlet moth (family Noctuidae) populations along an environmental pollution gradient. The goal was to identify attractants for species rarely collected with fermented sugar bait traps (Kozlov et al. 1996) and to apply these attractants in studies of industrial pollution effects on terrestrial ecosystems, as part of the Entomological Bioindicators project on the Kola Peninsula. However, the termination of this project in 1993 prevented the implementation of these plans.

A comparison with Pherobase (El-Sayed 2025) revealed no published data on blends attracting 14 of the 18 species collected during our 1993 field screening of 26 lure types made of eight (*Z*)-monounsaturated aliphatic compounds associated with moth sex pheromones. Therefore, these preliminary findings are published here to support the development of future monitoring programs for boreal and subarctic forest moths.

Methods

Study area and study sites

The study was conducted in the central Kola Peninsula, northwestern Russia, within the subarctic boreal forest zone. Three sites were selected from those used by Kozlov et al. (1996, 2022) to represent the range of moth communities shaped by vegetation type and environmental disturbance.

The first site, located 17 km south of Monchegorsk (67°46'37"N, 32°47'53"E), was a sparse, dry Scots pine (*Pinus sylvestris* L.) forest severely damaged by emissions from the copper–nickel smelter in Monchegorsk. The second site, 27 km south of Monchegorsk (67°40'39"N, 32°49'32"E), comprised sparse Norway spruce (*Picea abies* (L.) H. Karst.) – mountain birch (*Betula pubescens* var. *pumila* (G. Zanoni ex Murray) Govaerts) forest slightly affected by pollution and adjacent to a sedge bog. The third site, 64 km southeast of Monchegorsk (67°32'16"N, 33°57'52"E), represented dense, old-growth spruce forest bordering a peat-moss bog. Detailed descriptions of vegetation at these sites are provided by Kozlov et al. (2009).

Composition of synthetic lures

The lure set was developed using available knowledge of noctuid moth pheromones and synthetic attractants accumulated by the early 1990s (e.g., Steck et al. 1982a, 1982b; Renou et al. 1988). Eight commercially available compounds were selected: (*Z*)-5-decenyl acetate (hereafter Z5-10Ac), (*Z*)-7-dodecenyl acetate (Z7-12Ac), (*Z*)-7-dodecen-1-ol (Z7-12OH), (*Z*)-5-tetradecenyl acetate (Z5-14Ac), (*Z*)-7-tetradecenyl acetate (Z7-14Ac), (*Z*)-9-tetradecenyl acetate (Z9-14Ac), (*Z*)-11-hexadecenyl acetate (Z11-16Ac) and (*Z*)-11-hexadecenal (Z11-16Ald). These were used to prepare 26 lure compositions, including eight single-component lures and ten binary mixtures, five of which were tested at multiple component ratios (Table 1). The particular mixtures and component ratios were chosen based on prior studies and known biologically active ranges, aiming to capture the most likely attractive combinations for the target moth species while keeping the number of lures manageable. Each compound or mixture was dissolved in hexane and impregnated into red rubber septa (Arthur H. Thomas Co.) at a dose of 1 mg per dispenser. In total, 260 dispensers were produced (10 replicates per lure composition).

Field experiment

Each of the 26 synthetic lure types was tested at three sites: three replicates at the first site, three replicates at the second site, and four replicates at the third site. Each dispenser was placed in an opaque white delta trap with an exchangeable sticky insert (Fig. 1; Atracon A trap and Pestifix glue; Flora Co., Tartu, Estonia). Traps were suspended from tree branches at a height of 1–2 m and spaced at least 10 m apart to reduce potential interference among lure plumes. Traps were positioned

Table 1. Number of moth individuals captured by ten traps baited with each lure composition (1 mg total amount).

Compound 1	Compound 2	Compound ratio	*Paraswammerdamia conspersella*	*Argyresthia pygmaeella*	*Coleophora* sp.	*Eudonia murana*	*Entephria caesiata*	*Eulithis populata*	*Syngrapha parilis*	*Syngrapha diasema*	*Syngrapha interrogationis*	*Sympistis funebris*	*Sympistis heliophila*	*Sympistis lapponica*	*Enargia paleacea*	*Mniotype adusta*	*Coranarta cordigera*	*Diarsia mendica*	*Eurois occulta*	*Xestia tecta*
5-10Ac	-	-			36		1	1												
Z7-12Ac	-	-							10		7		4							
Z7-12OH	-	-																		
Z5-14Ac	-	-																		
Z7-14Ac	-	-	5*										104							
Z9-14Ac	-	-												9			2*	10		
Z11-16Ac	-	-		20		23														
Z11-16Ald	-	-			10															
Z5-10Ac	Z7-12Ac	10:1			160															
Z5-10Ac	Z7-12OH	10:1			10*															
Z5-10Ac	Z7-12OH	1:5						1												
Z7-12Ac	Z7-12OH	1:1							1	5	1									
Z7-12Ac	Z9-14Ac	1:1									2	6								
Z7-12Ac	Z9-14Ac	1:10																		
Z7-12Ac	Z9-14Ac	1:100												16			6	1		
Z7-12Ac	Z9-14Ac	100:1					1		12		8		5							
Z7-12Ac	Z11-16Ac	1:10			5*		4		2		7									
Z5-14Ac	Z7-14Ac	1:10	1800				2*													
Z7-14Ac	Z9-14Ac	1:1										3*					4*			
Z7-14Ac	Z9-14Ac	1:10					1					35					7	7		
Z9-14Ac	Z11-16Ac	1:1														15			1	1
Z9-14Ac	Z11-16Ac	1:10														5			1	
Z9-14Ac	Z11-16Ac	10:1					1								2	2				
Z9-14Ac	Z11-16Ald	100:1					1										18	27		1
Z11-16Ac	Z11-16Ald	1:10																		
Z11-16Ac	Z11-16Ald	10:1																		

*All specimens were caught in a single trap.

Figure 1. Atracon A trap deployed in a pristine forest 64 km southeast of Monchegorsk. Photo: M. V. Kozlov.

haphazardly and not rotated among positions, and lures were not replaced during the study period. All traps were deployed on 17.vii.1993 and inspected on 23.vii, 29.vii, and 12.viii.1993.

Captured moths were identified in the field; several problematic individuals were later confirmed by T. Tammaru. Species nomenclature and ordering follow Aarvik et al. (2017). Because our focus was on whether a lure elicited attraction of some species rather than on site-level differences, catches from replicate traps were pooled across sites. For each lure type, the total number of individuals of each species collected over the entire exposure period is reported in Table 1.

Artificial Intelligence (AI) use

ChatGPT (OpenAI) was used exclusively for language editing.

Results and discussion

Five lure compositions failed to attract any moths. Traps baited with the remaining 21 compositions captured a total of 352 individuals belonging to 12 Noctuidae species, along with nearly 2100 specimens from six species of other families (Table 1).

Yponomeutidae

Paraswammerdamia conspersella (Tengström, 1848)

A binary 1:10 mixture of Z5-14Ac and Z7-14Ac proved highly attractive to this species. In contrast, Z7-14Ac alone attracted only a few individuals, while Z5-14Ac alone showed no attractiveness (Table 1). Notably, Z7-14Ac, but not Z5-14Ac, was previously identified as an attractant for the related species *P. nebulella* (Goeze, 1783) (Mozūraitis et al. 1998).

Argyresthiidae

Argyresthia pygmaeella (Denis & Schiffermüller, 1775)

Twenty individuals were attracted by Z11-16Ac (Table 1), which has previously been used in synthetic sex attractants for several other *Argyresthia* species (Booij and Voerman 1984; Jaastad et al. 2002). However, as *A. pygmaeella* is the second most abundant moth species in the study region (Kozlov et al. 2022), the modest catch suggests that further testing with additional known *Argyresthia* sex-attractant components is needed to develop an effective lure.

Coleophoridae

***Coleophora* sp.**

This unidentified species responded to five lure types, with the strongest attraction to a 10:1 mixture of Z5-10Ac and Z7-12Ac (Table 1). Three of these five lures contained Z5-10Ac, a compound known to attract multiple *Coleophora* species (Sziràki 1980; Priesner 1987; Willemse et al. 1987; Subchev et al. 1990; Tóth et al. 1992).

Crambidae

***Eudonia murana* (Curtis, 1827)**

A moderate number of individuals were attracted by Z11-16Ac (Table 1), the same lure that attracted *A. pygmaeella*. This compound has previously been reported to attract an *Eudonia* species in New Zealand (Clearwater et al. 1986).

Geometridae

***Entephria caesiata* (Denis & Schiffermüller, 1775)**

Eleven individuals were collected by traps baited with seven lure types (Table 1). Given this species' high abundance at study sites (Kozlov et al. 2022), incidental captures cannot be excluded, and it is therefore not possible to assign definite attractiveness to any of the tested compounds.

***Eulithis populata* (Linnaeus, 1758)**

Single individuals were attracted by two lure types, both containing Z5-10Ac (Table 1).

Noctuidae

***Syngrapha parilis* (Hübner, 1809)**

All four attractive lure types for this species contained Z7-12Ac, either alone or in combinations with other compounds (Table 1). This agrees with earlier findings from Northern Finland (Linnaluoto and Koponen 1983).

***Syngrapha diasema* (Boisduval, 1829)**

Five individuals were attracted to a 1:1 mixture of Z7-12Ac and Z7-12OH (Table 1). A similar composition, in a 3:2 ratio, has previously been reported as an attractant for *S. ain* (Hochenwarth, 1785) (Inomata et al. 2005).

***Syngrapha interrogationis* (Linnaeus, 1758)**

This species was attracted by five lure types containing Z7-12Ac (Table 1), either alone or in mixtures. Z7-12Ac has previously been identified as attractive to five other *Syngrapha* species (Priesner et al. 1977; Steck et al. 1982a; Linnaluoto and Koponen 1983; Inomata et al. 2005), and also for *S. diasema* (see above).

***Sympistis funebris* (Hübner, 1809)**

This species responded most strongly to a 1:10 mixture of Z7-14Ac and Z9-14Ac and was also captured by traps baited with two other binary lures, both containing 50% Z9-14Ac (Table 1).

***Sympistis heliophila* (Paykull, 1793)**

Z7-14Ac was the most attractive lure for this species. The previously reported attractiveness of Z7-12Ac (Linnaluoto and Koponen 1983) was also confirmed, although this compound was an order of magnitude less effective than Z7-14Ac (Table 1).

***Sympistis lapponica* (Thunberg, 1791)**

This species was best attracted by a 1:100 mixture of Z7-12Ac and Z9-14Ac, with Z9-14Ac alone being slightly less effective (Table 1).

***Enargia paleacea* (Esper, 1788)**

Two individuals were captured using a 10:1 mixture of Z9-14Ac and Z11-16Ac (Table 1). The same components, though in a very different ratio (1:500), have been reported as attractants for the North American species *E. infumata* (Grote, 1874) (Steck et al. 1982a, 1982b).

***Mniotype adusta* (Esper, 1790)**

This species was attracted to mixtures of Z9-14Ac and Z11-16Ac, with the 1:1 ratio being most effective (Table 1). The same compounds have previously been reported to attract the North American species *M. ducta* (Grote, 1878) (Byers and Struble 1987).

***Coranarta cordigera* (Thunberg, 1788)**

This species was attracted to five lure types containing Z9-14Ac, with the highest catch obtained from a lure with a minor addition of Z11-16Ald (Table 1).

***Diarsia mendica* (Fabricius, 1775)**

Moths were captured using four lure types containing Z9-14Ac, again with the largest catch associated with a lure containing a minor proportion of Z11-16Ald (Table 1), the same composition that was most effective for *C. cordigera*. Z11-16Ald has not previously been reported as an attractant for *Diarsia* species, whereas Z9-14Ac is known to attract *D. deparca* (Butler, 1879) (Ando et al. 1977) and was used as a minor lure component for *D. dahlii* (Hübner, 1813) (Priesner 1985).

Eurois occulta **(Linnaeus, 1758)**

Two individuals were captured using a mixture of Z9-14Ac and Z11-16Ac (Table 1), a combination long known to attract this species in Canada (Steck et al. 1976). However, because *E. occulta* is common in the region and six individuals were captured simultaneously by fermented sugar bait traps (Kozlov et al. 1996), the tested lures are considered insufficiently effective for monitoring. Three-component mixtures including Z11-16Ald have proved effective in North America (Steck et al. 1982a, 1982b).

Xestia tecta **(Hübner, 1808)**

Single individuals were captured by two lure types containing Z9-14Ac (Table 1), which has been previously identified as an attractant for five other *Xestia* species (Priesner 1984, 1985; Struble and Byers 1985). Neither Z11-16Ac nor Z11-16Ald, which were also present in the lures, has been reported as attractive to closely related species (El-Sayed 2025).

Conclusions

Field screening of 26 lure types composed of eight common (*Z*)-monounsaturated aliphatic pheromone analogues in subarctic taiga forests has provided the first synthetic sex attractant data for 14 moth species. These results show that straightforward, widely accessible screening approaches can reveal attractant blends for species rarely targeted in pheromone studies. At the same time, this study did not confirm the previously reported attractiveness of *Z*11-16Ac for *Anarta melanopa* (Thunberg, 1781) (Linnaluoto and Koponen 1983), although this species occurs in the study region (Kozlov and Jalava 1994) and was on the wing during the trap-exposure period.

Several lures attracted multiple moth species, replicating the patterns detected in several previous studies. For example, synthetic pheromones targeting *Grapholita funebrana* Treitschke, 1835 and *G. molesta* (Busck, 1916) in Bulgarian orchards attracted, in addition to the focal species, 29 and 12 other leafroller species, respectively (Velcheva 2000). Similarly, synthetic lures developed for six economically important forest pest moths in Czechoslovakia attracted a total of 32 moth species (Brewer et al. 2009). These non-target species share one or more key pheromone components with the focal species.

Only four of the 12 noctuid moth species attracted to our lures (*E. paleacea*, *M. adusta*, *D. mendica* and *E. occulta*) were shared with the 21 species collected using fermented sugar bait traps at the same study sites in 1991–1993 (Kozlov et al. 1996). This limited overlap suggests that combining these two trapping methods would substantially enhance the efficiency of monitoring of moth populations in subarctic forests. Notably, our lures did not attract *Acronicta auricoma* (Denis & Schiffermüller, 1775), *Hyppa rectilinea* (Esper, 1788), *Polia conspicua* (A. Bang-Haas, 1912), *Xestia alpicola* (Zetterstedt, 1839) or *X. rhaetica* (Staudinger, 1871), all of which were among the most abundant species in fermented sugar bait trap catches (Kozlov et al. 1996). The attractants of these species remain unknown (El-Sayed 2025).

For several captured species, the identified attractants closely match or extend earlier findings, often from distant regions. For others, further tests are needed before reliable lure formulations can be developed. By making these preliminary but unique results available, this study helps fill a major geographic gap in the chemical ecology of boreal moths and supports the development of more effective monitoring tools for high-latitude forest ecosystems.

Acknowledgements

I thank †K. Mikkola for initiating and supporting this research from a grant provided by the Academy of Finland, and I gratefully acknowledge C. Löfstedt for generously providing the baits and commenting an earlier draft of this manuscript. I am deeply indebted to †A. L. Lvovsky, V. Zverev, and E. Melnikov for their participation in the fieldwork and T. Tammaru for identification of problematic specimens and inspiring suggestions on how to improve this manuscript. The publication was supported by the Societas Europaea Lepidopterologica (SEL).

References

Aarvik L, Bengtsson BÅ, Elven H, Ivinskis P, Jürivete U, Karsholt O, Mutanen M, Savenkov N (2017) Nordic-Baltic checklist of Lepidoptera. Norwegian Journal of Entomology, Supplement 3: 1–236.

Allison JD, Cardé RT [Eds] (2016) Pheromone communication in moths: Evolution, behavior, and application. University of California Press, Oakland, CA, USA, 416 pp.

Akinbuluma MD, van Schaijk RAH, Roessingh P, Groot AT (2024) Region-specific variation in the electrophysiological responses of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) to synthetic sex pheromone compounds. Journal of Chemical Ecology 50(11): 631–642. https://doi.org/10.1007/s10886-024-01479-w

Ando T, Yamamoto M (2020) Semiochemicals containing lepidopteran sex pheromones: Wonderland for a natural product chemist. Journal of Pesticide Science 45(4): 191–205. https://doi.org/10.1584/jpestics.D20-046

Ando T, Yoshida S, Tatsuki S, Takahashi N (1977) Sex attractants for male Lepidoptera. Agricultural and Biological Chemistry 41(8): 1485–1492. https://doi.org/10.1080/00021369.1977.10862690

Barros-Parada W, Bergmann J, Čurkovic T, Fuentes-Contreras E, Castro-Carrasco P, Roque F, Oyarzún MP (2020) 3,7-dimethylpentadecane: A novel sex pheromone component from *Leucoptera sinuella* (Lepidoptera: Lyonetiidae). Journal of Chemical Ecology 46(9): 820–829. https://doi.org/10.1007/s10886-020-01208-z

Booij CJH, Voerman S (1984) (*Z*)-11-hexadecenyl compounds as attractants for male microlepidoptera of the subfamilies Argyresthiinae, Glyphipteryginae, and Crambinae. Entomologia Experimentalis et Applicata 36(1): 47–53. https://doi.org/10.1111/j.1570-7458.1984.tb03406.x

Brewer JW, Krampl F, Skuhravý V (2009) Forest Lepidoptera attracted to six synthetic pheromones in Czechoslovakia. Journal of Applied Entomology 100(1–5): 372–381. https://doi.org/10.1111/j.1439-0418.1985.tb02794.x

Brockerhoff EG, Suckling DM, Roques A, Jactel H, Branco M, Twidle AM, Mastro VC, Kimberley MO (2013) Improving the efficiency of Lepidopteran pest detection and surveillance: Constraints and opportunities for multiple-species trapping. Journal of Chemical Ecology 39(1): 50–58. https://doi.org/10.1007/s10886-012-0223-6

Byers JR, Struble DL (1987) Monitoring population levels of eight species of noctuids with sex-attractant traps in southern Alberta, 1978–1983: Specificity of attractants and effect of target species abundance. Canadian Entomologist 119(6): 541–556. https://doi.org/10.4039/Ent119541-6

Clearwater JR, Galbreath RA, Benn MH, Young H (1986) Female-produced sexual pheromone of *Sceliodes cordalis* (Lepidoptera: Pyralidae). Journal of Chemical Ecology 12(9): 1943–1964. https://doi.org/10.1007/BF01041857

Duménil C, Judd GJ, Bosch D, Baldessari M, Gemeno C, Groot AT (2014) Intraspecific variation in female sex pheromone of the codling moth *Cydia pomonella*. Insects 5(4): 705–721. https://doi.org/10.3390/insects5040705

Elkinton JS, Cardé RT (1981) The use of pheromone traps to monitor distribution and population trends of the Gypsy Moth. In: Mitchell ER (Ed.) Management of insect pests with semiochemicals. Springer, Boston, MA, 41–55. https://doi.org/10.1007/978-1-4613-3216-9_5

El-Sayed AM (2025) The pherobase: Database of pheromones and semiochemicals. https://www.pherobase.com [accessed 10.06.2025]

Grant GG (1991) Development and use of pheromones for monitoring lepidopteran forest defoliators in North America. Forest Ecology and Management 39(1–4): 153–162. https://doi.org/10.1016/0378-1127(91)90173-S

Hällfors MH, Pöyry J, Heliölä J, Kohonen I, Kuussaari M, Leinonen R, Schmucki R, Sihvonen P, Saastamoinen M (2021) Combining range and phenology shifts offers a winning strategy for boreal Lepidoptera. Ecology Letters 24(8): 1619–1632. https://doi.org/10.1111/ele.13774

Inomata S, Watanabe A, Nomura M, Ando T (2005) Mating communication systems of four Plusiinae species distributed in Japan: Identification of the sex pheromones and field evaluation. Journal of Chemical Ecology 31(6): 1429–1442. https://doi.org/10.1007/s10886-005-5295-0

Jaastad G, Bengtsson M, Anderson P, Kobro S, Knudsen G, Witzgall P (2002) Sex pheromone of apple fruit moth *Argyresthia conjugella* (Lepidoptera: Argyresthiidae). Agricultural and Forest Entomology 4(3): 233–236. https://doi.org/10.1046/j.1461-9563.2002.00140.x

Kozlov MV (1987) Leafrollers (Lepidoptera, Tortricidae) as plant pests in the Murmansk Region. In: Sinadskij YV (Ed.) Migration of Pest Organisms with Introduced Plants. Kola Science Centre, Apatity, 33–38. [in Russian]

Kozlov MV, Haukioja E (1993) Density and size of *Archips podana* (Lepidoptera, Tortricidae) males in an air pollution gradient as revealed by pheromone traps. Environmental Entomology 22(2): 438–444. https://doi.org/10.1093/ee/22.2.438

Kozlov MV, Jalava J (1994) Lepidoptera of Kola Peninsula, Northwestern Russia. Entomologica Fennica 5(1): 65–85. https://doi.org/10.33338/ef.83797

Kozlov MV, Jalava J, Lvovsky AL, Mikkola K (1996) Population densities and diversity of Noctuidae (Lepidoptera) along an air pollution gradient on the Kola Peninsula, Russia. Entomologica Fennica 7(1): 9–15. https://doi.org/10.33338/ef.83882

Kozlov MV, Zvereva EL, Zverev VE (2009) Impacts of point polluters on terrestrial biota: Comparative analysis of 18 contaminated areas. Springer, Dordrecht, the Netherlands, 466 pp. https://doi.org/10.1007/978-90-481-2467-1

Kozlov MV, Castagneyrol B, Zverev V, Zvereva EL (2022) Recovery of moth and butterfly (Lepidoptera) communities in a polluted region following emission decline. Science of the Total Environment 838: 155800. https://doi.org/10.1016/j.scitotenv.2022.155800

Kristensen NP, Scoble M, Karsholt O (2007) Lepidoptera phylogeny and systematics: The state of inventorying moth and butterfly diversity. Zootaxa 1668(1): 699–747. https://doi.org/10.11646/zootaxa.1668.1.30

Larsson MC (2016) Pheromones and other semiochemicals for monitoring rare and endangered species. Journal of Chemical Ecology 42(9): 853–868. https://doi.org/10.1007/s10886-016-0753-4

Linnaluoto ET, Koponen S (1983) Northern moths (Lepidoptera) attracted by synthetic pheromones. Annales Entomologici Fennici 49: 64.

Löfstedt C (1993) Moth pheromone genetics and evolution. Philosophical Transactions of the Royal Society B 340(1292): 167–177. https://doi.org/10.1098/rstb.1993.0055

Millar JG, McElfresh JS, Haynes KF, Paine TD (2016) Sex attractant pheromone of the Luna Moth, *Actias luna* (Linnaeus). Journal of Chemical Ecology 42(9): 869–876. https://doi.org/10.1007/s10886-016-0751-6

Mitter C, Davis DR, Cummings MP (2017) Phylogeny and evolution of Lepidoptera. Annual Review of Entomology 62: 265–283. https://doi.org/10.1146/annurev-ento-031616-035125

Mozūraitis R, Būda V, Borg-Karlson A-K, Ivinskis P, Karalius V, Laanmaa M, Pleys D (1998) New sex attractants and inhibitors for 17 moth species from the families Gracillariidae, Tortricidae, Yponomeutidae, Oecophoridae, Pyralidae and Gelechiidae. Journal of Applied Entomology 122(1–5): 441–452. https://doi.org/10.1111/j.1439-0418.1998.tb01524.x

Priesner E (1984) Analysis of a sex-attractant system in the noctuid moth *Rhyacia baja* Schiff. Zeitschrift für Naturforschung C 39(7–8): 845–848. https://doi.org/10.1515/znc-1984-7-827

Priesner E (1985) Specificity of sexual attractants in *Xestia triangulum* Hufn. and *X. ditrapezium* Schiff. (Lepidoptera: Noctuidae). Zeitschrift für Naturforschung C 40(11–12): 939–942. https://doi.org/10.1515/znc-1985-11-1236

Priesner E (1987) (*Z*)-5-dodecen-1-ol, another inhibitor of pheromonal attraction in *Coleophora laricella*. Zeitschrift für Naturforschung C 42(11–12): 1349–1351. https://doi.org/10.1515/znc-1987-11-1236

Priesner E, Bestmann HJ, Vostrowsky O, Rösel P (1977) Sensory efficacy of alkyl-branched pheromone analogues in noctuid and tortricid Lepidoptera. Zeitschrift für Naturforschung C 32(11–12): 979–991. https://doi.org/10.1515/znc-1977-11-1218

Razov J, Efetov KA, Franin K, Toshova TB, Subchev MA (2017) The application of sex pheromone traps for recording the Procridinae fauna (Lepidoptera: Zygaenidae) in Croatia. Entomologist's Gazette 68(1): 49–53.

Renou M, Lalanne-Cassou B, Michelot D, Gordon G, Doré J-C (1988) Multivariate analysis of the correlation between Noctuidae subfamilies and the chemical structure of their sex pheromones or male attractants. Journal of Chemical Ecology 14(4): 1187–1215. https://doi.org/10.1007/BF01019346

Roelofs WL, Comeau A (1970) Lepidopterous sex attractants discovered by field screening tests. Journal of Economic Entomology 63(3): 969–974. https://doi.org/10.1093/jee/63.3.969

Ruohomäki K, Kaitaniemi P, Kozlov MV, Tammaru T, Haukioja E (1996) Density and performance of *Epirrita autumnata* (Lep., Geometridae) along three air pollution gradients in northern Europe. Journal of Applied Ecology 33(4): 773–785. https://doi.org/10.2307/2404947

Steck WF, Bailey BK, Underhill EW, Chisholm MD (1976) A sex attractant for the great dart, *Eurois occulta*: A mixture of (*Z*)-9-tetradecen-1-ol acetate and (*Z*)-11-hexadecen-1-ol acetate. Environmental Entomology 5(3): 523–526. https://doi.org/10.1093/ee/5.3.523

Steck WF, Underhill EW, Chisholm MD (1982a) Structure-activity relationships in sex attractants for North American noctuid moths. Journal of Chemical Ecology 8(4): 731–754. https://doi.org/10.1007/BF00988315

Steck WF, Underhill EW, Bailey BK, Chisholm MD (1982b) Trace co-attractants in synthetic sex lures for 22 noctuid moths. Experientia 38(1): 94–96. https://doi.org/10.1007/BF01944547

Struble DL, Byers JR (1985) Identification of sex-pheromone components of the sibling species *Euxoa ridingsiana* (Grt.) and *Euxoa maimes* (Sm.) (Lepidoptera: Noctuidae), and blends for their specific attraction. Canadian Entomologist 117(4): 495–504. https://doi.org/10.4039/Ent117495-4

Subchev MA, Krusteva IA, Ganev JA, Milkova TS (1990) Some new lepidopteran sex attractants and attractant inhibitors in Bulgaria. Journal of Applied Entomology 109(1–5): 189–193. https://doi.org/10.1111/j.1439-0418.1990.tb00036.x

Sziràki G (1980) Notes on *Coleophora* and *Cnephasia* species trapped by synthetic attractants (Lepidoptera: Coleophoridae and Tortricidae). Folia Entomologica Hungarica 33(1): 161–166.

Tóth M, Szőcs G, Sziràki G, Sauter W (1992) Sex attractants for male microlepidoptera found in field trapping tests in Hungary. Journal of Applied Entomology 113(1–5): 342–355. https://doi.org/10.1111/j.1439-0418.1992.tb00674.x

van Nieukerken EJ, Kaila L, Kitching IJ, Kristensen NP, Lees DC, Minet J, Mitter C, Mutanen M, Regier JC, Simonsen TJ, Wahlberg N, Yen S.-H, Zahiri R, Adamski D, Baixeras J, Bartsch D, Bengtsson BE, Brown JW, Bucheli SR, Davis DR, De Prins J, De Prins W, Epstein ME, Gentili-Poole P, Gielis C, Hättenschwiler P, Hausmann A, Holloway JD, Kallies A, Karsholt O, Kawahara A, Koster S, Kozlov MV, Lafontaine JD, Lamas G, Landry J-F, Lee S, Nuss M, Park KT, Penz C, Rota J, Schmidt BC, Schintlmeister A, Sohn JC, Solis MA, Tarmann GM, Warren FD, Weller S, Yakovlev R, Zolotukhin V, Zwick A (2011) Order Lepidoptera Linnaeus, 1758. In: Zhang Z-Q (Ed.) Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness. Zootaxa 3148: 212–221. https://doi.org/10.11646/zootaxa.3148.1.41

Velcheva N (2000) Faunistic notes on the Tortricidae attracted by synthetic sex pheromones for *Grapholita funebrana* Tr. and *Grapholita molesta* Busck. Rastenievadni nauki (Plant Science, Sofia) 37: 181–187. [in Bulgarian]

Willemse LPM, Booij CJH, Voerman S (1987) New sex attractants for male Lepidoptera (Coleophoridae, Gelechiidae, Momphidae, Oecophoridae, and Yponomeutidae) found by field screening in the Netherlands. Journal of Applied Entomology 103(1–5): 508–515. https://doi.org/10.1111/j.1439-0418.1987.tb01016.x

Witzgall P, Kirsch P, Cork A (2010) Sex pheromones and their impact on pest management. Journal of Chemical Ecology 36(1): 80–100. https://doi.org/10.1007/s10886-009-9737-y