THE DEPENDENCE OF NORMAL AND BLACK LIGHT TYPE TRAPPING RESULTS UPON THE WINGSPAN OF MOTH SPECIES

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Abstract. In the last decade several researchers found relation between the wingspan size of moths and their light sensitivity. Generally, moths with larger wingspan have higher light sensitivity. We tested these findings using the catch data of 378 Macrolepidoptera species from 19 black light (BL, 125 W) and normal light trap (100 W) pairs of the Hungarian Light Trap Network. We have found that wingspan size of about 25 mm is the limit below which some species were trapped more effectively by normal light trap, compared to BL. However, BL trap catch ratio of moths with wingspan of over about 35 mm is nearly 100 %, compared to normal light trap. According to the catch results of a site where normal and BL traps were placed close enough for the moths to perceive both at the same time, 75 % of moths with even small wingspan were caught by BL traps. Regarding the fact that BL traps collected significantly more individuals of Macrolepidoptera species with their wingspan over 35 mm on all sites of observation, we can conclude that Wolfram light bulb of 100 W is hardly suitable to use for this purpose. Consequently, considering our results, the light trap type can more effectively be specialized to the purpose of the observation according to the wingspan of the targeted species from which fact plant protection applications and entomological research projects can successfully benefit.
Keywords: *Macrolepidoptera, wingspan, spectral sensitivity, light traps*

Introduction

For a long time, researchers have been investigating the catch results of light traps with different light sources and the spectral sensitivity of insects' eye.

A given type of light source determines, among others, the temperature, the colour temperature and the spectral distribution of the light energy it emits. Electroretinogram measurements are used to determine the spectral sensitivity of the insects' eye. In the literature, several studies are devoted to the results of laboratory measurements carried out on various species. No reports of such experiments are known in Hungary and data on the most important Hungarian pestilent species are also missing from the international literature of the subject.

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Review of literature

Mikkola (1972) established that moths and butterflies (Lepidoptera) and caddisfly species (Trichoptera) have an eye sensitivity that remains practically unchanged in the spectrum of 350-600 nm. Its maximum is around 550 nm (as the value of human eye during daytime). The sensitivity is mightily reduced at about 620 nm.

McFarlane and Eaton (1973) have reported that the responses of Cabbage Looper (*Trichoplusia ni* Hbn.) to monochromatic light stimuli have been investigated by electroretinogram (ERG) and electromyogram (EMG) techniques. The spectral sensitivity curves for male and female Cabbage Loppers show a major peak at 540 to 550 nm and a minor peak at 360 nm.

Agee (1973) showed by elektroretinogram test that the sensitivity of eyes of the Bollworm Moth (*Heliothis zea* Boddie) and Tobbacco Bollworm (*Heliothis virescens* F.) to 365 nm and 480-575 nm wavelengths light is highest.

Pappas and Eaton (1977) found that the ocelli of the Tobacco Hornworm (*Manduca sexta* L.) are more sensitive to 520 nm light, than to 360 nm light stimuli.

Similar results are reported by Eguchi et al. (1982) about the Sphingid moths. These moths possess the highest peak sensitivity at 540 nm.

Gui et al. (1942) reported that the colours on which comparable data are available arrange themselves in order from least to most attractive to insects, as follows: red, yellow, white and blue.

From tests of Taylor and Deay (1950) it appears that the maximum attractiveness for the European corn borer (*Ostrinia nubilalis* Hbn.) is in the near ultraviolet region between 320 and 380 nm.

Frost (1954) had a comparative experiment. He found that for all taxa of insects the black light was more attractive than the white light. The only exceptions were the Miridae and Chrysopidae families, which preferred white light.

Cleve (1954) found a strikingly successful ultraviolet fluorescent lamp to collect the insects, if it illuminated a white sheet.

Belton and Kempster (1963) caught more noctuid moths (Noctuidae) and geometrid ones (Geometridae) with the black light (BL) fluorescent tube than with the cold light (CW).

Jászainé (1964) analyzed the catching results of Common Meadow Bug (*Exolygus pratensis* Wagner) (Heteroptera: Miridae) in normal and BL light traps. The standard light traps caught more individuals.

In the comparative studies of Mészáros (1966), each of the Microlepidoptera species were more effectively collected by the BL traps than by normal light ones.

In the test of Day and Reid (1969) the 15 W fluorescent BL lamps were more attractive for the *Conoderus falli* Lane (Coleoptera: Elateridae) than similar yellow ones.

According to the experiment of Komlódi (1970) the standard light trap caught only a few specimens of the Eurasian Hemp Moths (*Grapholita delineana* Walker), a lamp operating with HgLS light source, however, caught numerous of these moths. Wingspan of the Eurasian Hemp Moths is 10-14 mm.

Sifter (1971) examined the swarming of the Chestnut Weevil (*Curculio elephas* Gyllenhal, Coleoptera: Curculionidae) by normal and BL traps. The body length of this beetle is only 6-9 mm. The normal light trap has not caught a single specimen, but the BL one was suitable for investigation of swarming.

Mikkola (1972) verified the results of his laboratory measurements with the help of light trap monitoring. He caught the highest number of insects with lamps emitting both black light and visible light. The catch dwindled when he used BL alone and visible light produced even poorer result.

Striking contradiction was found between light sensitivity and the attracting effect of different types of light, regarding six insect groups (Coleoptera, Trichoptera, Lepidoptera, Brachycera, and Nematocera Ichneumonoidea). The eyes of these insects were more sensitive to yellow light than to BL, but the attracting effect was the opposite.

Blomberg et al. (1976) compared two types of light trap catch results. One of them was the so-called blended light trap that contained a 160 W Tungsram mercury fluorescent lamp and the other one was BL that was provided with a 125 W Philips HPW lamp. The mercury fluorescent lamp caught approximately twice as many moths of the Macrolepidoptera families (Geometridae and Noctuidae) and Microlepidoptera species than the BL trap.

According to laboratory tests of Teel et al. (1976) the maximum sensitivity of the eye of Hickory Shuckworm (*Laspeyresia caryana* Fitch) is at 365 nm and 515 nm. At these two values, there were six times as many individuals responding to the near-ultraviolet light than ones responding to the green one.

According to Gál et al. (1976), Bürgés and Gál (1981) and Bürgés (1997) for the light trapping of the Chestnut Weevil (*Curculio elephas* Gyllenhal) and the Acorn Moth (*Cydia splendana* Hbn.) the most effective tool is the mercury vapour lamp (HgW).

Some observers report that there are species showing a greater attraction to regular light: some fruit flies (Theowald, 1963), virus vector cicadae (*Laodelphax striatella* (Fallén)) and *Javesella pellucida* (Fabricius) (Homoptera, Areopidae) (Jászainé, 1969); European Grapevine Moth (*Lobesia botrana* Den. et Schiff.) and Vine Moth (*Eupoecilia ambiguella* Hbn.) (Voigt and Vojnits, 1970).

Extremely valuable conclusions come from a series of experiments by Járfás et al. (1975) and Járfás and Tóth (1977) in which comparisons were made among the catch results yielded by 125W (HgVE 27) ultraviolet, 125W (HgLSE27) mercury vapour, 100 W (OHP 220-230 VAO) crypton, 100W (F_3) 50cm neon, 250W (E 27 9043 IMP) infra ruby and 50cm germicidal lamps. Silver Y moths (*Autographa gamma* L.), Pine Chafers (*Polyphylla fullo* L.), Vine Chafers (*Anomala vitis* Fabr.) and Scarab Beetles (*Anoxia orientalis* Kryniczky) flew to the mercury vapour lamps in the highest numbers, while infra ruby light proved to be practically unsuitable for trapping. Járfás (1975, 1977) published the results of his experiments, in which he examined the efficiency of light traps with respect to different moth species with the application of different light-sources. The most suitable traps for catching were the following, in descending order: mercury lamp (HgW), BL and normal light, in the case of the following species: Silver Y (*Autographa gamma* L.) (Járfás et al., 1975), the Codling Moth (*Cydia pomonella* L.) (Járfás et al. 1977), the Pea Podborer (*Etiella zinckenella* Tr.) (Járfás and Viola, 1984) and the Beet Webworm (*Loxostege sticticalis* L.) (Járfás and Viola, 1991). Járfás (1977) reports that the Apple Peel Tortrix (*Adoxophyes reticulana* Hbn.), the Pear Moth (*Laspeyresia pyrivora* Pan.) and the Plum Fruit Moth (*Grapholita funebrana* Tr) can be caught effectively with the mercury vapour lamp (HgW), the Strawberry Tortricid (*Pandemis dumetana* Tr.) and the Dark Fruit-tree Tortrix (*Pandemis heparana* Den. et Schiff.) are more attracted to a normal light bulb. The European Corn Borer (*Ostrinia*

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nubilalis Hbn.) was collected by the HgW traps more successfully than by the normal and the BL traps (Járfás, 1978).

Skuhravý et al. (1993) found a BL trap much more effective than either yellow, green or red lights in collecting the Saddle Gall Midge (*Haplodiplosis marginata* von Roser) (Diptera: Cecidomydae).

In our earlier study (Nowinszky and Puskás, 1994), we compared the composition of species of five Macrolepidoptera families based on the normal and BL trap data collected at two light trap stations, by the Sorensen index. The results are as follows: Geometridae: 0.607 and 0.518; Sphingidae: 0.750 and 0.500; Notodontidae: 0.444 and 0.429; Arctiidae: 0.714 and 0.609; Noctuidae: 0.608 and 0.527.

Wallner et al. (1995) carried out experiments of three lymantriid species in the Russian Far East. There were significantly more moths in the fluorescent black light lamp than either in the phosphor mercury or the high-pressure sodium lamps, in case of all three species: Gipsy Moth (*Lymantria dispar* L.), Nun Moth (*Lymantria monaca* L.) and the Pink Gipsy Moth (*Lymantria matura* Moore).

Nabli et al. (1999) studied the efficiency of catching agriculturally benficial insects by using different light sources. The Coccinellidae (Coleoptera) species preferred BL, the Ophion sp. (Hymenoptera: Ichneumonidae) had a preference for blue BL. *Chrysopa* spp. (Neuroptera: Chrysopidae) could be trapped equally well with white and BL, while every source of light had the same impact on some broad damsel bugs (Hemiptera: Nabidae) and Hemerobius spp. (Neuroptera: Hemerobiidae).

Bürgés et al. (2003) found the following characteristics of those families (Geometridae, Sphingidae, Notodontidae, Arctiidae and Noctuidae) that are rich in species: most of their species fly to both normal and BL traps, but the BL one catches significantly more species. The number of specimen caught was also less in the normal light trap.

Fayle et al. (2007) examined three Robinson type light traps equipped with 125W mercury bulbs. One of these contained materials which absorb the visible light, so this lamp was a BL type trap. Their results showed that the least moth was caught by the BL trap.

Barghini (2008) tested four lighting systems. Most insects were caught in the high-pressure mercury lamp (Hg). A further order was as follows: high-pressure sodium (Na) without a BL filter and the same type with BL filter.

In the last decade most researchers found connection between body size of the insects (larger eyes or wingspan) and their light sensitivity. Insects with larger eyes and wingspan tend to have higher light sensitivity than those with smaller eyes. Over the last decade, published studies supported the finding that the vision of insects with greater body weight is more sensitive to light than that of the smaller species. Such a statement was published concerning desert ants (Cataglyphis) (Zollikofer et al. 1995); pollen foraging bees (Apoidea) (Jander and Jander, 2002); the bumblebees (*Bombus terrestris* L.) (Spaethe and Chittka, 2003) and Kapustjanskij et al. 2007); the nymphalid butterflies (Nymphalidae) (Rutowski et al. 2009).

Moser et al. (2004) found a connection between the size of eyes of 10 Atta species (Hymenoptera: Formicidae) and the time of nuptial flight using digital photography. The diameter of compound eyes of the night flying species was significantly larger.

Yack et al. (2007) reported similar results concerning the *Macrosoma eliconiaria* Walker (Lepidoptera: Hedyloidea) species.

Experiments of Kino and Oshima (1978) suggest that moth and butterfly emanations could cause allergy-induced bronchial asthma in certain people. Since moths are readily attracted to artificial light and often fly into houses, these insects are especially suspected as important factors in extrinsic asthma.

Barghini and Medeiros (2010) assumed that in developing countries the growing light pollution will affect the spread of vector-borne human diseases.

Van Langevelde et al. (2011) established that moths are attracted to artificial light with smaller wavelength in higher species richness and abundance than to light with larger wavelength. This attraction was correlated with the body mass, wingspan and eye size of moths. The size dependent attraction of the artificial light sources cause distortions to the ecosystems.

In the above mentioned studies the catch coming from parallelly operated regular and black light (BL) traps offered a unique possibility to answer the following questions.

- Is there a significant difference in species and families between the catch yielded by the two types of traps?
- Which of the two types is more suitable for trapping what species?
- Are there any species that can be collected by either regular or BL traps alone?
- Does either of the two types indicate the presence of more species than the other?
- To what extent do the materials yielded by the two types of trap at the same observation site differ in their composition by species?

In the present study we examined how the wingspan of Macrolepidoptera species can influence the catch result of normal light traps and BL ones based on data from the Hungarian Light Trap Network.

Material

To compare the differences between the practical use of normal and BL traps the Hungarian Plant Protection Research Institute of Keszthely has been carrying out experiments since 1962 with parallel operation of two light trap types, one with a regular bulb and the other with BL. In 1962 the Plant Protection Service added a BL trap in Nagytétény to the ones running with regular light and in 1963 equipped all its county plant protection stations with BL traps. The national network of normal and BL traps operated in parallel opened up the possibility to a comprehensive analysis of the catch results.

The normal and BL traps operated in the following cities and villages:

Baj (47.38N, 18.21E)	Mikepércs (47.26N, 21.37E)
Csopak (45.58N, 17.55E)	Miskolc (48.5N, 20.46E)
Fácánkert (46.26N, 18.44E)	Nagytétény (47.38N, 18.97E)
Gyöngyös (47.46N, 19.55)	Pacsa (46.43N, 17.0E)
Győr-Kismegyer (47.39N, 17.39E)	Szederkény (45.59N, 18.27E)
Hódmezővásárhely (46.25N, 20.19E)	Tanakajd (47.11N, 16.44E)
Kaposvár (46.22N, 17.46)	Tarhos (46.48N, 21.12E)
Kállósemjén (47.51N, 21.55)	Tass (47.1N, 19.2E)
Kenderes (47.13N, 20.45E)	Velence (47.14N, 18.38E)
Keszthely (46.46N, 17.15E)	

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The most valuable information was provided by the light traps at Nagytétény where, according to the station register entries, regular and BL traps were placed at a mere 10 metres distance from one another. The proximity of the two traps meant homogeneity of microclimate, vegetation and the distances from the habitats of other species and so the insects were practically offered the choice of two different light sources.

The complete Macrolepidoptera material of the above listed light traps was processed in our work. We processed the data of 378 species of the data of the 18 light trap sites belonging to the National Network and the data of 222 species collected by the light traps of Nagytétény.

The data of the wingspan of the different Macrolepidoptera species we collected from the websites of “Moths of Hungary” József Szalkai Hungarian Lepidopterist Association (www.macrolepidoptera.hu) and UK moths (www.ukmoths.org.uk).

Methods

We summarized in each light trap site and each trap type the number of the Macrolepidoptera species and individuals caught from all generations, however, we did not separate the individuals within generations. Then, using the Mann-Whitney’s test we checked the significance of the homogeneity of the number of individuals captured by normal and BL traps, separately for all species and recorded significantly ($p<0.05$) higher normal trap or BL trap catches marked as N or BL, respectively, while insignificant differences were marked as E (*Table 1*). Particular attention was paid to the data of Nagytétény's normal and BL traps, since the two trap types were set close enough to represent homogeneous microclimate, vegetation and species habitat ranges so the moths were supposed to be able to choose directly between different light sources.

We arranged all the species collected both by the national light trap network (NW) and by the Nagytétény (NT) traps in ascending order according to the wingspan sizes of insects. We calculated the percentages of species caught significantly more effectively by the black light traps (BL) and normal ones (N) and the percentages of the species caught insignificantly differently by the two types of traps (E) where the percentages were taken over the sum of all catches, separately for the data of National Light Trap Network (NW) and Nagytétény (NT).

The differences between the BL and N dominated results together with insignificantly different results for the species observed both in NW and NT sites were tested familywise by Z-tests at the 0.05 level (Moore et al. 2006).

For NW and NT results, separately, we compared the proportions BL, N and E familywise by Marascuillo’s test at the 0.05 level (National Institute of Standards and Techonololgy, 2010).

As a next step, we pooled the species of all families into one data set and ordered them by their average wingspan.

First, splitting the total range of the observed wingspan sizes into categories, we took the ratio BL over BL+N and compared these by Marascuillo’s test.

Then, using the ordered, pooled data set, the moving averages with a window size of 7 days were calculated for BL, N and E proportions of the observations of NW and NT.

To represent the wingspan dependency of the BL, N and E proportions, we defined a joint regression model containing models of three subranges of the following formula:

$$Y = \chi[X < s_1]*Y_1 + \chi[s_1 \le X < s_2]*Y_2 + \chi[X \ge s_2]*Y_3 + \varepsilon \quad \text{(Eq.1)}$$

where Y_1 , Y_2 and Y_3 are functions of the general formulas:

$$Y_1 = p_{11} + p_{12} * (1 - \exp(-p_{13} * (32 - X))) \quad \text{(Eq.2)}$$

$$Y_2 = p_{21} + (p_{22} - p_{21})/(1 + \exp(-p_{23} * (X - p_{24}))) \quad \text{(Eq.3)}$$

$$Y_3 = p_{31} + p_{32} * (1 - \exp(-p_{33} * (X - p_{34}))) \quad \text{(Eq.4)}$$

In the formulas Y denotes the moving average of the percentages of BL, N and E with window size 7 while X is for the wingspan size (mm) and ε is a normally distributed error term with expected value of zero;

s_1 and s_2 are wingspan values (mm) that indicate the borders of the wingspan subranges;

$\chi[X < s_1]$, $\chi[s_1 \le X < s_2]$ $\chi[X \ge s_2]$ are characteristic functions which take 1 if the conditions given in brackets $[X < s_1]$, $[s_1 \le X < s_2]$ or $[X \ge s_2]$ hold and zero else;

p_{ij} are the parameters of the functions Y_i ($i = 1, 2, 3$, $j = 1, 2, 3, 4$).

Y_1 and Y_3 are saturation functions with the following properties:

- $Y_1(32) = p_{11}$; $Y_3(p_{34}) = p_{31}$;
- The decrease of Y_1 and Y_3 from their values p_{11} or p_{31} are p_{12} or p_{32} as $X \to +\infty$, respectively. Obviously, if $p_{12} > 0$ then Y_1 is decreasing, otherwise it is increasing and if $p_{32} > 0$ then Y_3 is decreasing, otherwise it is increasing.
- $p_{13} > 0$ and $p_{33} > 0$ are the a velocity factors of the exponential term of Y_1 and Y_3, respectively.

Y_2 is a logostic function with the following properties:

- p_{21} is the limit Y_2 approaches as $X \to -\infty$;
- p_{22} is the limit Y_2 approaches as $X \to +\infty$;
- $p_{23} > 0$ is a velocity factor of the exponential term of Y_2;
- p_{24} is the inflexion point of Y_2.

Normality of the error terms was tested by Shapiro-Wilk's test ($p > 0.05$). Parameter estimations were calculated together with their t-values and significance levels. The regression models were tested by their F-values and their significance levels. Finally, the explained variances (R^2) were evaluated.

Results and discussion

Table 1 summarizes the average wingspan data (mm) of all the 378 trapped species sorted into families and presents the numbers of species that were collected significantly more effectively by the normal (N) or black light (BL) traps of the Hungarian Light Trap Network (Network) and, separately, of Nagytétény. The significant differences are based on Mann-Whitney's test at the $p < 0.05$ level.

Comparing the normal light trap dominated proportions of Macrolepidoptera species of the National Light Trap Network sites and Nagytétény (*Table 2*) by Z-tests, we detected no significant differences ($p > 0.05$). The BL dominated results of *Geometridae*, *Arctiidae* and *Noctuidae* catches, however, were significantly higher in Nagytétény ($p < 0.001$) where the potential chance for the species to choose between the two types of trap was higher.

Table 1. *Numbers and average wingspan (mm) of Macrolepidoptera species collected significantly more effectively by normal (N) or black light (BL) traps of the Hungarian Light Trap Network (Network) and, separately, of Nagytétény. The significant differences are based on Mann-Whitney's test at the p < 0.05 level*

Family name	***Average wingspan (mm)***	***Network***				***Nagytétény***		
		No. of different species caught	***No. of trap pairs***	***No. of different species caught significantly more by***		***No. of different species caught***	***No. of different species caught significantly more by***	
				N	***BL***		***N***	***BL***
Nolidae	19.0	2	12	0	0	0	0	0
Syntominae	23.0	1	12	0	0	0	0	0
Geometridae	26.1	104	1122	17	7	58	13	38
Drepanidae	28.2	5	45	0	0	1	0	0
Thaumetopoidae	30.0	1	8	0	1	1	0	1
Noctuidae	34.4	194	2248	4	85	126	7	105
Arctiidae	34.5	22	267	0	6	15	1	12
Thyatiridae	37.3	3	16	0	1	0	0	0
Lymantriidae	38.8	7	65	0	2	3	0	2
Notodontidae	39.7	19	203	2	8	10	2	8
Lasiocampidae	42.2	8	85	0	3	2	0	1
Sphingidae	73.3	11	153	0	9	6	1	4
Saturniidae	82.5	2	12	0	2	0	0	0

Moreover, comparing those proportions of species the catches of which were significantly higher neither for the normal nor the BL light trap type (E) in Nagytétény or in other sites of the National Light Trap Network, we found that in Nagytétény these numbers were significantly lower ($p < 0.001$) for *Geometridae*, *Arctiidae* and *Noctuidae* families. These significant differences indicate that in case the species of *Geometridae*, *Arctiidae* and *Noctuidae* families can choose between the two light trap types, they prefer the BL type traps, while, in case the potential possibility of choice is low, then the trapping success of the two types of light traps is homogeneous.

Table 2. *Numbers of Macrolepidoptera species observed both in Network sites (NW) and Nagytétény (NT) with the numbers of species collected significantly more effectively by normal (N) or black light (BL) traps, or, insignificantly differently by the two types of traps (E) of the Hungarian Light Trap Network (NW) and, separately, Nagytétény (NT). The significant differences in boldface are based on Z-tests at the p < 0.05 level*

Family name	***Number of species observed both in NW and NT***	***Numbers of species collected insignificantly differently by BL and N***		***Numbers of species collected significantly more effectively by***			
		E		***BL***		***N***	
		NW	***NT***	***NW***	***NT***	***NW***	***NT***
Lasiocampidae	2	1	1	1	1	0	0
Drepanidae	1	1	1	0	0	0	0
Geometridae	58	**44 *****	**7**	**2**	**38 *****	17	13
Sphingidae	6	0	1	6	5	0	0
Notodontidae	10	**3 +**	**0**	5	8	2	2
Thaumetopoidae	1	1	0	0	1	0	0
Lymantriidae	3	1	1	2	2	0	0
Arctiidae	15	**10 *****	**2**	**5**	**12 *****	0	1
Noctuidae	126	**57 *****	**14**	**47**	**105 *****	**2**	**7 +**

+significant at the $p < 0.1$ level; *** significant at the $p < 0.001$ level; proportions are compared by Z-test

Table 3. *Numbers of Macrolepidoptera species collected significantly more effectively by normal (N) or black light (BL) traps, or, insignificantly differently by the two types of traps (E) of the Hungarian Light Trap Network (NW). The three proportions are compared, different letters are for significantly different proportions based on Marascuillo's test at the p < 0.05 level*

Family	***Average wingspan (mm)***	***Numbers of species collected insignificantly differently by BL and N***	***Numbers of species collected significantly more effectively by***	
		E	***BL***	***N***
Nolidae	19.0	**2 b**	0 a	0 a
Syntominae	23.0	**1 b**	0 a	0 a
Geometridae	26.1	**80 b**	7 a	17 a
Drepanidae	28.2	**5 b**	0 a	0 a
Thaumetopoidae	30.0	0 a	**1 b**	**1 *ab***
Noctuidae	34.4	**105 b**	**85 b**	4 a
Arctiidae	34.5	**16 b**	6 a	0 a
Thyatiridae	37.3	2 a	1 a	0 a
Lymantriidae	38.8	**5 b**	**2 *ab***	0 a
Notodontidae	39.7	9 a	8 a	2 a
Lasiocampidae	42.2	**5 b**	**3 *ab***	0 a
Sphingidae	73.3	2 a	**9 b**	0 a
Saturnidae	82.5	0 a	**2 b**	0 a

When we compared the proportions of Macrolepidoptera species collected significantly more effectively by normal (N) or black light (BL) traps, or, insignificantly differently by the two types of traps (E) of the Hungarian Light Trap Network (NW) by Marascuillo's test (*Table 3*), we saw that for families of smaller wingspan sizes (*Nolidae*, *Syntominae*, *Geometridae*, *Drepanidae*), the trapping success is typically rather homogeneous for the two trap types (E) while for families of greater wingspan

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sizes (*Lasiocampidae*, *Sphingidae, Saturnidae*), the BL trap types are significantly more preferred ($p < 0.05$).

Performing the same comparisons for the proportions recorded in Nagytétény (*Table 4*), we could state that independently from the wing size, the preference of the species is the BL type of trap. However, none of the families includes species that could be captivated by only one type of traps.

Table 4. *Numbers of Macrolepidoptera species collected significantly more effectively by normal (N) or black light (BL) traps, or, insignificantly differently by the two types of traps (E) in Nagytétény (NT). Different letters are for significantly different proportions based on Marascuillo's test at the p < 0.05 level*

Family	***Average wingspan (mm)***	***Numbers of species collected insignificantly differently by BL and N***	***Numbers of species collected significantly more effectively by***	
		E	***BL***	***N***
Geometridae	26.1	7 a	**38 b**	13 a
Drepanidae	28.2	**1 b**	0 a	0 a
Thaumetopoidae	30.0	0 a	**1 b**	0 a
Noctuidae	34.4	14 a	**105 b**	7 a
Arctiidae	34.5	2 a	**12 b**	1 a
Lymantriidae	38.8	1 a	2 a	0 a
Notodontidae	39.7	0 a	**8 b**	2 a
Lasiocampidae	42.2	**1 b**	**1 b**	0 a
Sphingidae	73.3	1 a	**4 b**	1 a

The results of the Marascuillo's tests for the BL/(BL+N) ratios calculated from the results of the Hungarian Light Trap Network for wingspan range categories (*Table 5*) show that above a wingspan of about 30 mm the preference of BL traps becomes obvious.

Table 5. *Numbers of Macrolepidoptera species collected significantly more effectively by normal (N) or black light (BL) traps of the Hungarian Light Trap Network (NW) with the BL ratio over (BL+N). The multiple ratios were compared, different letters indicate significantly different ratios based on Marascuillo's test at the p < 0.05 level*

Wingspan range (mm)	***Average wingspan (mm)***	***Numbers of species collected significantly more effectively by***		***BL/(BL+N) ratio***
		BL	***N***	
11 – 23	19.48	4	10	0.29 a
24 – 28	26.07	9	7	0.56 ab
29 – 31	30.17	11	3	0.79 ab
32 – 34	32.85	22	1	0.96 b
35 – 36	35.39	11	1	0.92 b
37 – 40	38.15	22	0	1.00 b
41 – 45	42.57	15	1	0.94 b
46 – 48	47.00	9	0	1.00 b
49 – 57	51.46	10	0	1.00 b
58 – 115	84.18	10	0	1.00 b

Performing the same comparisons for the BL/(BL+N) ratios recorded in Nagytétény (*Table 6*) we can conclude that the preference of BL type traps is independent from the wingspan size.

Considering the above results together with this, we can state that normal type light traps can be *at most* as successful as BL type traps, independently from the wingspan size. Over the wingspan of about 35 mm the BL/(BL+N) ratio is nearly 100 percent in all sites except for in Nagytétény, where the normal and the BL traps were close enough for moths to be able to choose between them, the BL/(BL+N) ratios of the species with even the smallest wingspan were over 75%.

Table 6. *Numbers of Macrolepidoptera species collected significantly more effectively by normal (N) or black light (BL) traps in Nagytétény (NT) with the BL ratio over (BL+N). The multiple ratios were compared, no significantl differences were detected by Marascuillo's test at the p < 0.05 level*

Wingspan range (mm)	***Average wingspan (mm)***	***Numbers of species collected significantly more effectively by***		***BL/(BL+N) ratio***
		BL	***N***	
11 – 23	19.48	24	8	0.75
24 – 28	26.07	21	6	0.78
29 – 29	29.00	7	1	0.88
30 – 35	32.51	50	2	0.96
36 – 40	37.74	31	2	0.94
41 – 44	42.07	15	2	0.88
45 – 48	46.29	5	1	0.83
49 – 57	51.46	5	1	0.83

The results of the regression joint model optimized for the BL, N and E proportions are summarized in *Table 7* for the Hungarian light Trap Network data and in *Table 8* for the data recorded in Nagytétény (see Eq.1 to Eq.4). The observed total wingspan range was split into three subranges cutted by $s_1 = 32$ and $s_2 = 36$ (*Figure 1*, black vertical lines or $s_2 = 39$ (*Figure 1*, blue vertical line) in case of the Hungarian Light Trap Network data and by $s_1 = 33$ and $s_2 = 40$ (*Figure 2*, black vertical lines) in case of the data recorded in Nagytétény.

Subrange 1

In the wingspan subrange below 32 mm (Network) or 33 mm (Nagytétény) the N and E proportions can be modelled by decreasing exponential (i.e. saturation) functions (Eq.2). The BL proportions can be modelled by increasing exponential (i.e. saturation) functions (Eq.2). In case of N proportions the functions of the Network and Nagytétény observations are very similar. In case of BL proportions, however, the values of Network model are much lower than the ones of Nagytétény while in case of E proportions the relation is reverse: the values of Network model are much higher than the ones of Nagytétény. Moreover, some species of wingspan size below 25 mm were trapped more effectively by normal light trap, compared to BL.

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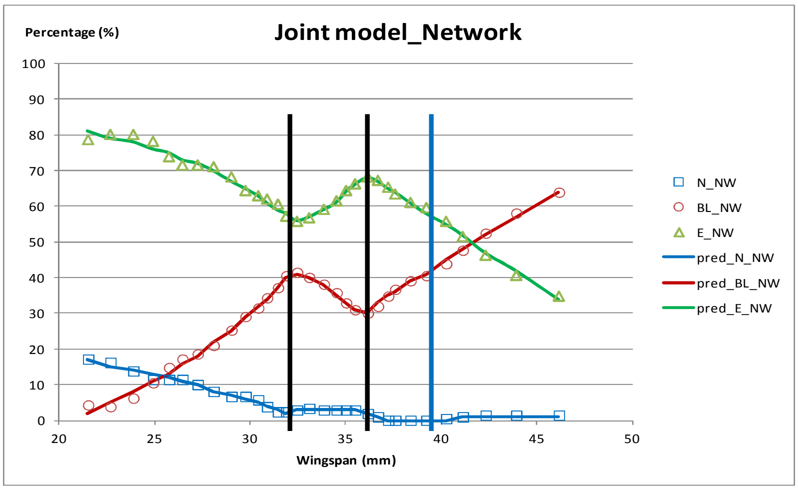

Figure 1. *Proportions of the numbers of Macrolepidoptera species collected significantly more effectively by normal (N) or black light (BL) traps or, insignificantly differently by the two types of traps (E) of the Hungarian Light Trap Network (NW) and their joint models containing the models of three subranges. The vertical lines represent the borders of the wingspan subranges (see also Table 7)*

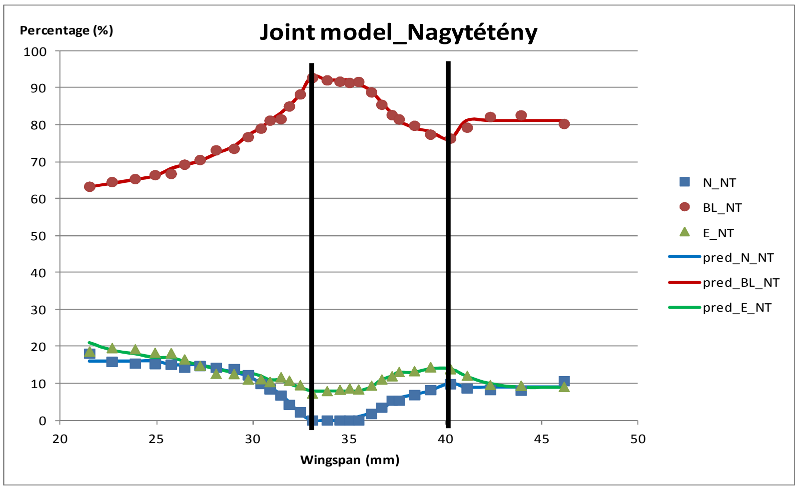

Figure 2. *Proportions of the numbers of Macrolepidoptera species collected significantly more effectively by normal (N) or black light (BL) traps or, insignificantly differently by the two types of traps (E) in Nagytétény (NT) and their joint models containing the models of three subranges. The vertical lines represent the borders of the wingspan subranges (see also Table 8)*

Subrange 2

The catch results of species of wingspan in Subrange 2 refer to a different trend of attraction of the moths and this surprisingly modified trend were detected both for the data of Network and Nagytétény.

In the wingspan subrange above 32 mm (Network) or 33 mm (Nagytétény) and below 36 mm (Network) or 40 mm (Nagytétény) the E proportions can be modelled by increasing, the BL proportions by decreasing logistic functions (Eq.3). The values of E proportions are much higher in case of Network data while the BL proportions are higher in Nagytétény.

In the wingspan subrange above 32 mm (Network) or 33 mm (Nagytétény) and below 39 mm (Network) or 40 mm (Nagytétény) the N proportions can be modelled by logistic functions (Eq.3) differently for the data of Network and Nagytétény. The first is decreasing while the second one is increasing; nevertheless, the values of both functions are very small.

Table 7. *Results of the regression joint model optimized for the BL, N and E proportions of the Hungarian Light Trap Network: parameter estimations with their t-values and significance levels, the F-values of the models and their significance levels as well as the explained variances (R^2) with their significance levels*

	Subrange 1 $\chi[X<32]$,			**Subrange 2** $\chi[32\leq X<36]$			**Subrange 3** $\chi[X\geq 36]$			**Joint Model**	
	Estimated parameters		***t***	**Estimated parameters**		***t***	**Estimated parameters**		***t***	***F***	R^2
E	p_{11}	0.57	62.78 ***	p_{21}	0.56	23.82 ***	p_{31}	0.66	93.33 ***	8023.60 ***	0.99 ***
	p_{12}	0.32	7.57 ***	p_{22}	0.70	13.31 ***	p_{32}	-6.32	0.21 n.s.		
	p_{13}	0.13	3.76 ***	p_{23}	1.28	2.38 ***	p_{33}	0.01	0.20 n.s.		
				p_{24}	34.82	65.08 ***	p_{34}	37.00	fixed		
	Subrange 1 $\chi[X<32]$,			**Subrange 2** $\chi[32\leq X<39]$			**Subrange 3** $\chi[X\geq 39]$			**Joint Model**	
	Estimated parameters		***t***	**Estimated parameters**		***t***	**Estimated parameters**		***t***	***F***	R^2
N	p_{11}	0.02	5.12 ***	p_{21}	0.03	10.81 ***	p_{31}	-0.36	0.00 n.s.	376.17 ***	0.99 ***
	p_{12}	0.41	1.98 +	p_{22}	0.00	fixed	p_{32}	0.05	4.22 ***		
	p_{13}	0.04	1.59 n.s.	p_{23}	3.22	9.75 ***	p_{33}	7.03	5.27 ***		
				p_{24}	36.40	146.56 ***	p_{34}	40.00	fixed		
	Subrange 1 $\chi[X<32]$,			**Subrange 2** $\chi[32\leq X<36]$			**Subrange 3** $\chi[X\geq 36]$			**Joint Model**	
	Estimated parameters		***t***	**Estimated parameters**		***t***	**Estimated parameters**		***t***	***F***	R^2
BL	p_{11}	0.40	57.10 ***	p_{21}	0.41	28.10 ***	p_{31}	0.34	59.72 ***	3749.06 ***	0.997 ***
	p_{12}	-0.60	9.34 ***	p_{22}	0.29	12.01 ***	p_{32}	7.77	0.19 n.s.		
	p_{13}	0.10	5.62 ***	p_{23}	1.54	1.97 +	p_{33}	0.004	0.19 n.s.		
				p_{24}	34.61	117.93 ***	p_{34}	37.00	fixed		

+ significant at the p < 0. 1 level; * significant at the p < 0.05 level
** significant at the p < 0.01 level; *** significant at the p < 0.001 level

Table 8. *Results of the regression joint model optimized for the BL, N and E proportions recorded in Nagytétény: parameter estimations with their t-values and significance levels, the F-values of the models and their significance levels as well as the explained variances (R^2) with their significance levels*

	Subrange 1 $\chi[X<33]$			**Subrange 2** $\chi[33\le X<40]$			**Subrange 3** $\chi[X\ge 40]$			**Joint Model**	
	Estimated parameters		***t***	**Estimated parameters**		***t***	**Estimated parameters**		***t***	***F***	R^2
E	p_{11}	0.10	20.94 ***	p_{21}	0.08	13.89 ***	p_{31}	0.15	11.41 ***	600.24 ***	0.99 ***
	p_{12}	0.44	0.63 n.s.	p_{22}	0.14	16.31 ***	p_{32}	-0.06	4.67 ***		
	p_{13}	0.03	0.55 n.s.	p_{23}	-1.79	1.97 +	p_{33}	0.64	1.65 n.s.		
				p_{24}	36.68	118.00	p_{34}	40.00	fixed		
	Subrange 1 $\chi[X<33]$			**Subrange 2** $\chi[33\le X<40]$			**Subrange 3** $\chi[X\ge 40]$			**Joint Model**	
	Estimated parameters		***t***	**Estimated parameters**		***t***	**Estimated parameters**		***t***	***F***	R^2
N	p_{11}	0.04	8.42 ***	p_{21}	-0.002	0.75 n.s.	p_{31}	0.14	fixed	393.29 ***	0.98 ***
	p_{12}	0.12	18.29 ***	p_{22}	0.07	9.21 ***	p_{32}	-0.02	3.56 ***		
	p_{13}	0.42	7.54 ***	p_{23}	1.62	4.22 ***	p_{33}	0.55	1.62 n.s.		
				p_{24}	38.85	208.55 ***	p_{34}	40.00	fixed		
	Subrange 1 $\chi[X<33]$			**Subrange 2** $\chi[33\le X<40]$			**Subrange 3** $\chi[X\ge 40]$			**Joint Model**	
	Estimated parameters		***t***	**Estimated parameters**		***t***	**Estimated parameters**		***t***	***F***	R^2
BL	p_{11}	0.86	13.61***	p_{21}	0.93	36.52 ***	p_{31}	0.74	22.86 ***	21435.19 ***	0.99 ***
	p_{12}	-0.25	24.61 ***	p_{22}	0.77	70.24 ***	p_{32}	0.81	125.61 ***		
	p_{13}	0.207	12.83 ***	p_{23}	1.50	4.40 ***	p_{33}	12.108	2523.38 ***		
				p_{24}	36.81	230.85 ***	p_{34}	40.00	fixed		

+ significant at the p < 0.1 level; * significant at the p < 0.05 level
** significant at the p < 0.01 level; *** significant at the p < 0.001 level

Subrange 3

In the wingspan subrange above 36 mm (Network) or 40 mm (Nagytétény) the E proportions can be modelled by decreasing, the BL proportions by increasing exponential (i.e. saturation) functions (Eq.4). The values of E proportions are much higher in case of Network data while the BL proportions are higher in Nagytétény.

In the wingspan subrange above 39 mm (Network) or 40 mm (Nagytétény) the N proportions can be modelled by exponential (i.e. saturation) functions (Eq.4) differently for the data of Network and Nagytétény. The first is increasing while the second one is decreasing; nevertheless, the values of both functions are very small.

These characteristics of the models correspond to the results of the comparisons of proportions (Z-tests and Marascuillo's tests) and can be reasoned by the fact that in Nagytétény the preference of the species can be more effectively observed and it is definitely BL, especially for the species of wingspan sizes above 39-40 mm.

When the normal and BL type traps were very close to each other, the BL traps were chosen by even the moths of small wingspans en masse. However, occasionally, such choices are suspected to be random and the proof of the preferences desires more observations.

We stress that the fact that the preference of the species of large wingspans is unambiguously BL does not mean that these species cannot be collected with a normal light trap successfully. We only state that the preference of BL type traps is significant and thus the Wolfram light bulb of 100 W is less effective.

When choosing a suitable light trap type for a special aim, the harmful effects of light traps should also be considered. Kollings (2000) has established that there is a definite difference in the composition of the catch from two neighbouring street lamps of different types. Our results coincide with the observations of Kolling as we also confirmed that the different light sources can damage different species and to different degrees. In an experiment by Eisenbei and Hassel (2000), the use of natrium vapour street lamps reduced the number of insects caught by 50%, including a 75% reduction in the number of moths. According to Frank (2006), if some moth species are more attracted to light than others, the traits related to this attraction could help us to predict effects of artificial light on communities of nocturnal species. Since the artificial light sources of different wavelengths attract different species to different degrees, thus this effect on the community can distract the balance of a local ecosystem.

Our results can be applied in plant protection and entomological research projects when the aim is to find the most effective type of light traps for special purposes and different targeted species. Before a responsible decision, the type and rate of damage risk, the targeted species with their wingspan sizes and also environmental aspects should be deliberately considered.

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