INFLUENCE OF THE LITTLE-STUDIED SUN'S AND MOON'S CHARACTERISTICS ON THE TRAPPING OF NIGHT ACTIVE INSECTS in Central Europe, Australia and USA

Editors

Nowinszky L., Hill L. and Puskás J.

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CONTENTS

CHAPTER 1
General Chapter

Nowinszky L., Kiss M., Puskás J., Hill L., Barta A., Kiss O., Bürgés Gy.

CHAPTER 2
(Central Europe, Hungary)

Light-trap Catch of the Lepidoptera Species in Connection with the Sun's and Moon's Characteristics (Jermy-type Light-traps)

Nowinszky L., Kiss M., Puskás J., Barta A.

CHAPTER 3
(Central Europe, Hungary)

Light-trap Catch of the Coleoptera Species in Connection with the Sun's and Moon's Characteristics (Jermy-type Light-traps)

Puskás J., Kiss M., Nowinszky L., Bürgés Gy., Barta A.

CHAPTER 4
(Central Europe, Hungary)

Light-trap Catch of the Trichoptera Species in Connection with the Sun's and Moon's Characteristics (Jermy-type Light-traps)

Kiss O., Kiss M., Puskás J., Nowinszky L., Barta A.

CHAPTER 5
(Central Europe, Serbia)

Light-trap Catch of the Lepidoptera Species in Connection with the Sun's and Moon's Characteristics (Becse-type Light-trap)

Kiss M., Nowinszky L., Puskás J., Barta A., † Mészáros Z.

CHAPTER 6
Australia (Tasmania)

Light-trap Catch of the Lepidoptera Species in Connection with the Sun's and Moon's Characteristics (160 W Mercury Vapour Light-trap)

Hill L., Nowinszky L., Kiss M., Puskás J., Barta A.

CHAPTER 7
USA (Nebraska and North Carolina)

Light-trap Catch of the Lepidoptera Species in Connection with the Sun's and Moon's Characteristics (BL Traps)

Nowinszky L., Puskás J., Kiss M., Barta A.

CHAPTER 8
(Central Europe, Hungary)

Pheromone Trap Catch of the Microlepidoptera Species in Connection with the Sun's and Moon's Characteristics

Puskás J., Nowinszky L., Kiss M., Barta A., † Barczikay G.

SUPPLEMENT
Light-trap types used in Hungary, Australia (Tasmania) and USA (Nebraska and North Carolina)

CONTENTS

CHAPTER 1 1-8
General Chapter
Nowinszky L., Kiss M., Puskás J., Hill L., Barta A., Kiss O., Bürgés Gy
CHAPTER 2 9-38
(Central Europe, Hungary)
Light-trap Catch of the Lepidoptera Species in Connection with the Sun's and Moon's Characteristics (Jermy-type Light-traps)
Nowinszky L., Kiss M., Puskás J., Barta A.
CHAPTER 3 39-50
(Central Europe, Hungary)
Light-trap Catch of the Coleoptera Species in Connection with the Sun's and Moon's Characteristics (Jermy-type Light-traps)
Puskás J., Kiss M., Nowinszky L., Bürgés Gy., Barta A.
CHAPTER 4 51-60
(Central Europe, Hungary)
Light-trap Catch of the Trichoptera Species in Connection with the Sun's and Moon's Characteristics (Jermy-type Light-traps)
Kiss O., Kiss M., Puskás J., Nowinszky L., Barta A.
CHAPTER 5 61-70
(Central Europe, Serbia)
Light-trap Catch of the Lepidoptera Species in Connection with the Sun's and Moon's Characteristics (Becse-type Light-trap)
Kiss M., Nowinszky L., Puskás J., Barta A., † Mészáros Z.
CHAPTER 6 71-104
Australia (Tasmania)
Light-trap Catch of the Lepidoptera Species in Connection with the Sun's and Moon's Characteristics
(160 W Mercury Vapour Light-trap)
Hill L., Nowinszky L., Kiss M., Puskás J., Barta A.
CHAPTER 7 105-112
USA (Nebraska and North Carolina)
Light-trap Catch of the Lepidoptera Species in Connection with the Sun's and Moon's Characteristics (BL Traps)
Nowinszky L., Puskás J., Kiss M., Barta A.
CHAPTER 8 113-122
(Central Europe, Hungary)
Pheromone Trap Catch of the Microlepidoptera Species in Connection with the Sun's and Moon's Characteristics
Puskás J., Nowinszky L., Kiss M., Barta A., † Barczikay G.
SUPPLEMENT 123-130
Light-trap types used in Hungary, Australia (Tasmania) and USA (Nebraska and North Carolina)

1 GENERAL CHAPTER

Nowinszky L., Kiss M., Puskás J., Hill L., Barta A., Kiss O., Bürgés Gy.

1. 1 Introduction

The aim of our work was to investigate the trapping results of hundreds of nocturnal insect species flying on three continents (Europe, Australia and North America) in relation to some features of the Sun and the Moon. The influence of these characteristics on light and pheromone trapping of insects has so far rarely or not been investigated.
Our goal was to compare the catch results of different species in different geographical environments on different continents, with different types of light traps in relation to several features of the sun and moon.
Several light trap stations collected insects in Central Europe (Hungary and Serbia), in Australia (Tasmania) and in two states in the USA (Nebraska and North Carolina). For many years, moth (Lepidoptera) species have been trapped in most places. In addition, beetles (Coleoptera) and caddisflies (Trichoptera) were collected in Hungary. Pheromone trapping has also been carried out in Hungary, during many years and the number of captured species were daily recorded.
Because we processed the catch results for the same set of characteristics of Sun and Moon and used the same methods for each geographic location, we found it advisable to report them in the General Chapter and to refer to this chapter in other chapters to avoid repetition.
Similarly, in the General Chapter, we provide all commonly used data, with discussion of results applicable to each chapter.
We also published Acknowledgments, Conclusions, and Literature in the General Chapter.
The Appendix contains some tables and figures, which are not strictly related to the subject of each chapter, but facilitate the interpretation of their results.

1. 2 Material

The values of sky polarization created by the Sun and the Moon were calculated by András Barta with his own computer program for all the light trapping sites for times of midnight or 6 p.m. (local times).
All other features of the Sun and the Moon were calculated by astronomer József Kovács.
We used the following features:

- Night sky polarization created by the Sun and the Moon (%),
- Gravitational polarization created by the Sun, Moon and Sun+Moon (μJ/kg),
- Altitude of the Sun's Arago-, Babinet- and Brewster points
- Altitude of the Moon's Arago-, Babinet- and Brewster points
- Azimuth value, zenith distance and height above the horizon of the Sun and the Moon (°)
- Apparent magnitude, fraction of illuminated surface (%) and moonlight (lux) of the Moon, moon phases and polarized moonlight

1. 3 Methods

We calculated the degree of polarization of clear sky lit by the Sun and by the Moon separately at the Zenith for every half hour between 1st January 1992 and 31st January 2019. For this we first determined the celestial position of the Sun and the Moon for every point in time of the above interval for a geographic position of Kecskemét, Hungary (54° 26'64"N and 19°41'30.12"E), Clay City, Nebraska, USA (40º36′20″N 98º31′18″W), Lenoir, North Carolina USA (35°54′50″ N and 81°32′20″ W), Stony Rise, Tasmania, Australia (146°19'E and 41°11'S) with the atmospheric refraction taken into account (Meeus, 1998). We then calculated the degree of polarization of the clear sky at the Zenith by using the Berry-method (Berry et al. 2004). For this calculation we assumed a neutral point distance of 27.5° and for the sake of simplicity a maximum of degree of polarization of 100%. Note, that during this paper we did not use the absolute degree of polarization, instead only their relative ratios, so assuming 100% maximum degree of polarization does not influence our end results, despite being a non-real scenario. We had only one collection data from a whole night, so we worked with the gravity and polarization data calculated for 23 hours (UT).
The astronomical data were calculated with a program based on the algorithms and routines of the VSOP87D planetary theory for Solar System ephemeris, which was written in C programming language by J. Kovács. The additional formatting of data tables and some further calculations were carried out using standard Unix and Linux math and text manipulating commands.
For computing the tidal potential generated by the Sun and the Moon we used the expansion of the gravitational potential in Legendre polynomials and expressed the relevant terms as a function of horizontal coordinates of the celestial objects.

Basic data were the number of individuals and species caught by one night. Only summer catch data was used. In order to compare the differing sampling data, relative values were calculated from the number of individuals and species for each sampling night per year. The relative catch value (RC) was defined as the quotient of the number of specimen caught during a sampling time unit (1 night) per the average nightly catch of individuals and species within the relevant summer. For example, when the actual nightly catch was equal to the average nightly catch in the relevant summer, the RC was 1 (Nowinszky, 2003).
It would have been impossible to calculate RC values for each of several hundred species and to present the results individually in figures. Therefore, we grouped species into three groups, Microlepidoptera, Macrolepidoptera and migratory species. In processing, they form a single piece of data. This method has already been used successfully in our previous studies (Nowinszky et al. 2018a, 2018b).
We used IBM SPSS Statistics Ver. 19 computer program in the process. Factor analysis was used to select characteristics of Sun and Moon that have the greatest influence on the light-trap catch.
The selected feature values of the Sun and Moon were arranged into groups. The number of groups was determined according to Sturges' methods (Odor and Iglói, 1987). The corresponding catch data were arranged into these groups. We depicted the values of these groups in Figures. The Figures also show the confidence intervals.

1. 4 Results and Discussion

All results of Chapters 2-6 are shown in Table 1. 4. 1.

Table 1. 4. 1 Results of Chapters 2-6. Maximum Relative Catch occurs at the following values for each solar and/or lunar feature (rows) for each of the geographic-taxonomic groupings (columns).

		Hungary Microlepidoptera	Hungary Macrolepidoptera	Hungary Coleoptera	Hungary Trichoptera	Serbia Macrolepidoptera	Tasmania Microlepidoptera	Tasmania Macrolepidoptera	Tasmania Migratory	USA Macrolepidoptera	Hungary Microlepidoptera Pheromone
1	Sun Pol. (°)	70	63	66	60	57	23	41	51	38	60
2	Moon Pol. (°)	80	78	78	62	61	62	46	66	NS	70
3	Sun Grav. (μJ/kg)	-150	-100	-124	-200	-75	-140	-130	-125	-120	-79
4	Moon Grav. (μJ/ kg	-500	-400	-500	-280	-215	-134	-240	-490	NS	-367
5	Sun+Moon Grav. (μJ/ kg)	-600	-500	-600	-680	-260	-365	-600	-670	-200	-490
6	Sun Ar. Alt. (°)	46	51	48	52	55	47	36	49	28	54
7	Moon Ba. Alt. (°)	18	5 - 27	7	9	-13	0	5	51	98	11
8	Moon Phase	NM	LQ	NM	NS	LQ	NM	FQ	FM	FQ	FM
9	Moon App Magn.	-10	-11 – -7	-7	-12	-11	-7	-10	-12,7	-10	-9
10	Moon Illum. Fraction (%)	10	33	12	98	30	0	12	NS	4	NS
11	Moonlight (lux)	0,03	0,08	0,001	0,25	0,07	0	0,03	NS	0,03	0,25
12	Polarized moonlight (%)	NS	NS	NS	NS	NS	LQ	LQ	NS	NS	NS

Notes: NS = Not significant or not interpretive,
NM = New Moon, FQ = First Quarter, FM = Full Moon, LQ = Last Quarter

The maximum of catch is different. Differences may be due in part to different geographical conditions. Another reason is that species in each group fly massively during different months of the year and at different hours of the night. The polarization of the sky caused by the Sun is the highest at dusk and dawn, the lowest around midnight. In contrast, the polarization of the sky caused by the Moon is the lowest at dusk and dawn, the highest around midnight (Supplement Figures 1. 8. 5). The celestial polarization and gravity of the celestial bodies are

closely but not completely negative correlated with each other (Figure 1. 8. 1 and Figure 1. 8. 2). This relationship changes slightly from one year to another, but the close relationship remains (Nowinszky et al. 2017). It follows from this fact that the influence of gravity on the catch is also significant, but contrary to the effect of polarization.
In our opinion, however, the effect of polarization is primary because it can be easily explained by differences in the peak of activity at different hours of each night (Table Supplement 1. 8. 1). However, it would be difficult to find a similar explanation for the maximum catch for different values of gravity.
Recently, however, based on our calculations, we have demonstrated (Nowinszky et al. 2018a) that high catch on negative values of gravity and low catch on positive values can be interpreted as independent effects of gravity (Figure 1. 8. 6). Negative gravity means that the suction effect of the celestial body (Sun, Moon) is experienced in this case. For example, if the value of negative gravity reaches -500 μJ/kg, the insect does not have to use energy to take off up to 0.051 mm. This time the resulting gravitational potential is 0, but the energy required for take-off is reduced by 5% if the rise is 1 mm. The energy decreases by 0.005% at 1 m rise. In contrast, with the same positive gravity, when the gravity of the celestial body is added to the gravity of the Earth, it requires the same amount of energy to fly. This fact may also explain the higher catch values for negative gravity and the low catch values for positive gravity.
During the night hours, the Arago point of the Sun and the Babinet point of the Moon are above the horizon (Figures 1. 8. 3 and 1. 8. 4). Catch results belonging to Sun's Arago point and Moon's Babinet point above the horizon are also high at different values. This may also be explained by the fact that the maximum activity of each species at night is different and occurs at different hours. The height of the neutral points also changes during the night hours and it is the highest around midnight. High catches may be related to this.

1. 5 Acknowledgements

We would like to thank Dr. József Kovács PhD (ELTE Astrophysical Observatory, Szombathely) for calculating the Moon and Sun data and describing the method of investigation. We thank Dr. Zsuzsanna Kúti PhD for the photos of the Jermy-type light traps.

1. 6 Conclusions

The results of our factor analysis studies show that some features of the Sun and the Moon influence light trapping of insect collection on all the three continents.

The polarization of the night sky is used by insects for their spatial orientation. Although the polarization of the Moon at night is higher than the polarization of the Sun, there is still a closer relationship between the polarization of the Sun and the efficiency of the light-trap than the Moon produces. Perhaps, the reason for this is that the polarization from the Sun changes much less dramatically from night to night than from the Moon. It therefore provides "more reliable" information for insects.
It is also proven that the gravitational potential of celestial bodies also influences the efficiency of trapping. In cases where the negative gravity value reaches -500 μJ/kg, the insect does not have to use energy to take off up to 0.051 mm, and the resulting gravitational potential is 0. Above this value, the energy required for take-off is reduced by 5% at 1 mm rise and 0.005% at 1 m rise as the suction effect occurs. In contrast, with the same positive gravity, when the gravity of the celestial body is added to the gravity of the Earth, it requires the same amount of energy to fly.

We found that the neutral points of the sky that are above the horizon at night are also significantly related to the catch results.
Apart from our own studies, similar results have not been reported by other researchers.
The apparent illumination of the Moon and the phases of the Moon influenced the success of catch on every continent and in all groups of insects, although maximum and minimum catch appeared in different phases of the Moon.
The above mentioned characteristics influenced the efficiency of trapping on all the three continents and in all insect groups, however, other lunar features (illuminated surface ratio and moonlight) are not considered to be a widespread modifying factor, although we have not been able to justify their influence only on Australian migratory species. Although the influence of polarized moonlight has been proven by several researchers, our current investigation has only confirmed this in the case of the Australian Microlepidoptera and Macrolepidoptera species.
However, in our opinion, this may be due to the fact that polarized moonlight is not present in the full lunar month. Therefore, its significance lags behind the other characteristics and therefore it was not classified as a significant influencing factor by factor analysis.

1. 7 References

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1. **8 Supplement**

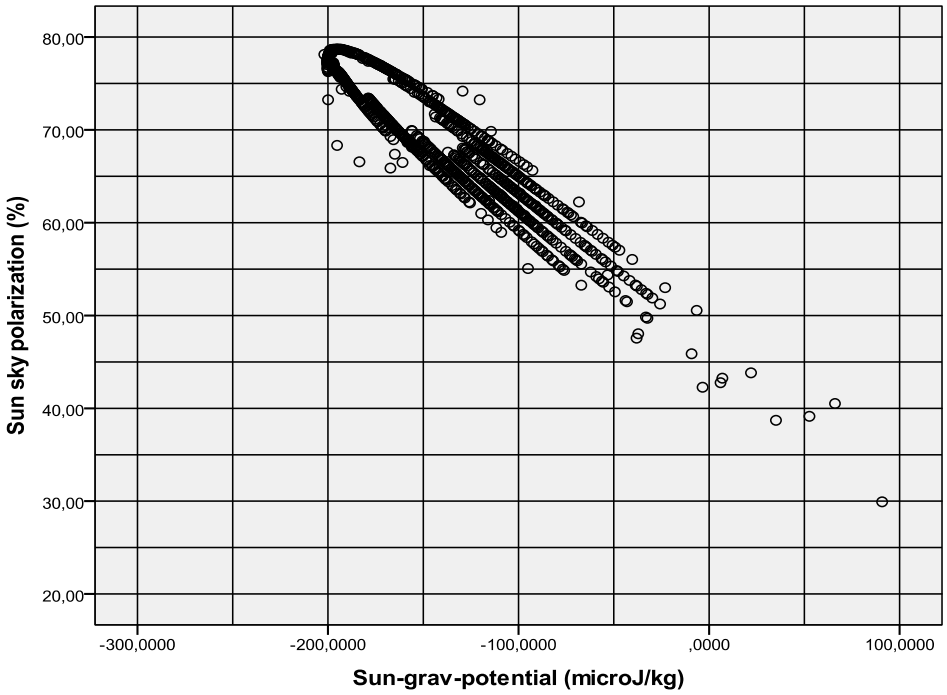


Figure 1. 8. 1 Night sky polarization of Sun in connection with the gravitation potential of Sun

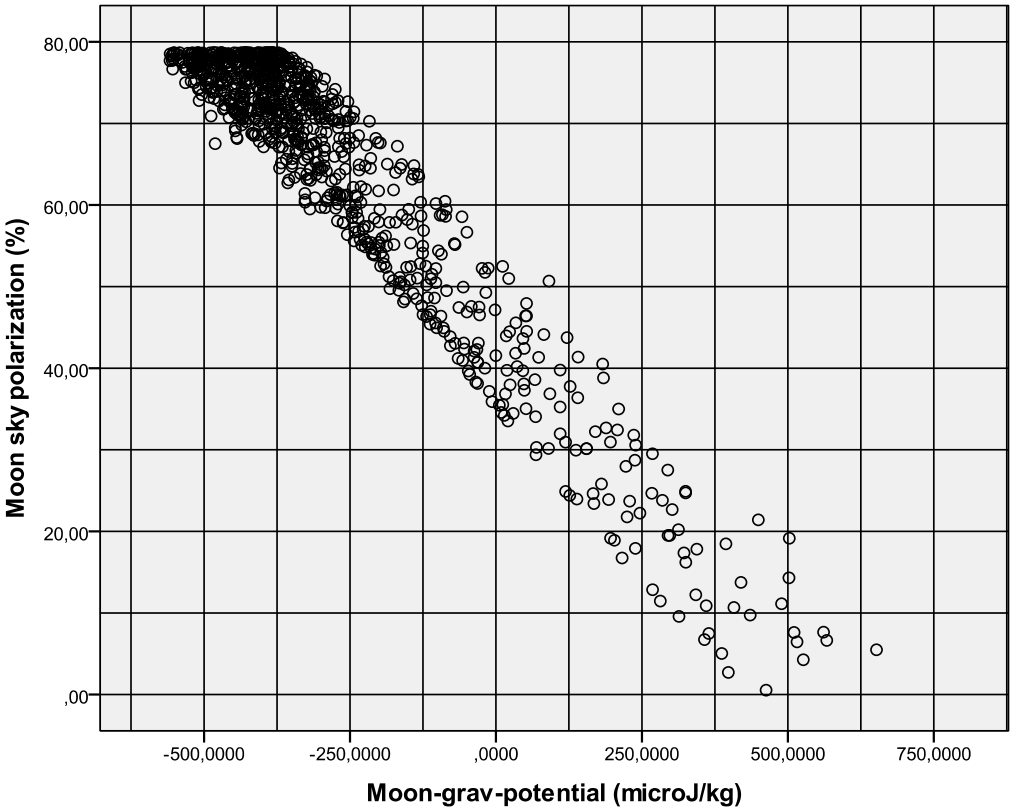


Figure 1. 8. 2 Night sky Polarization of Moon in connection with the gravitation potential of Moon

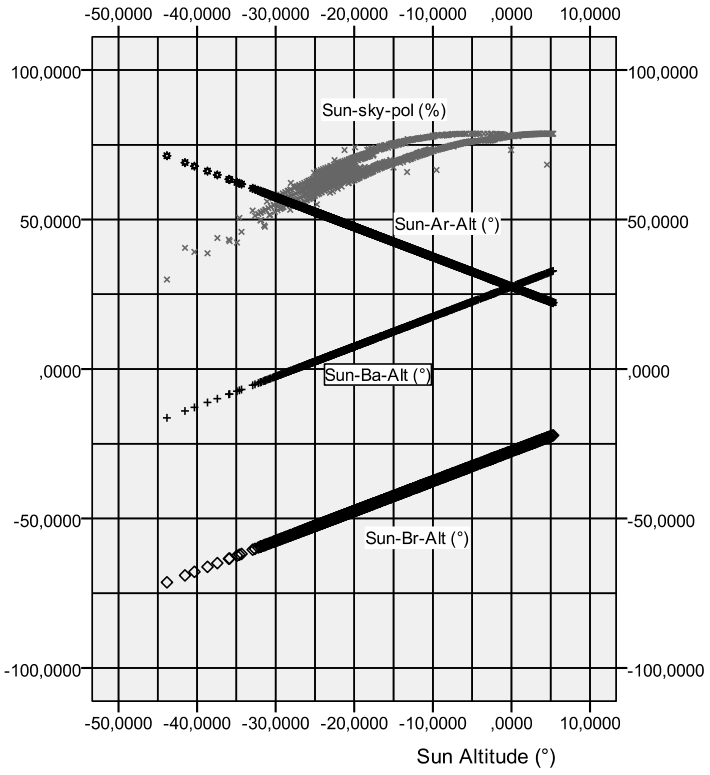


Figure 1. 8. 3 The neutral points of Sun in connection of altitude of Sun above horizon

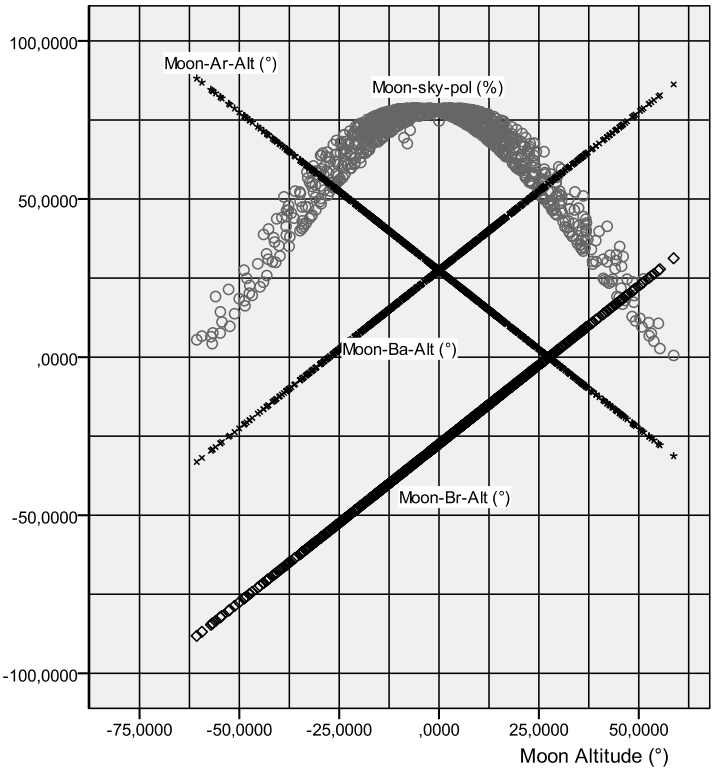
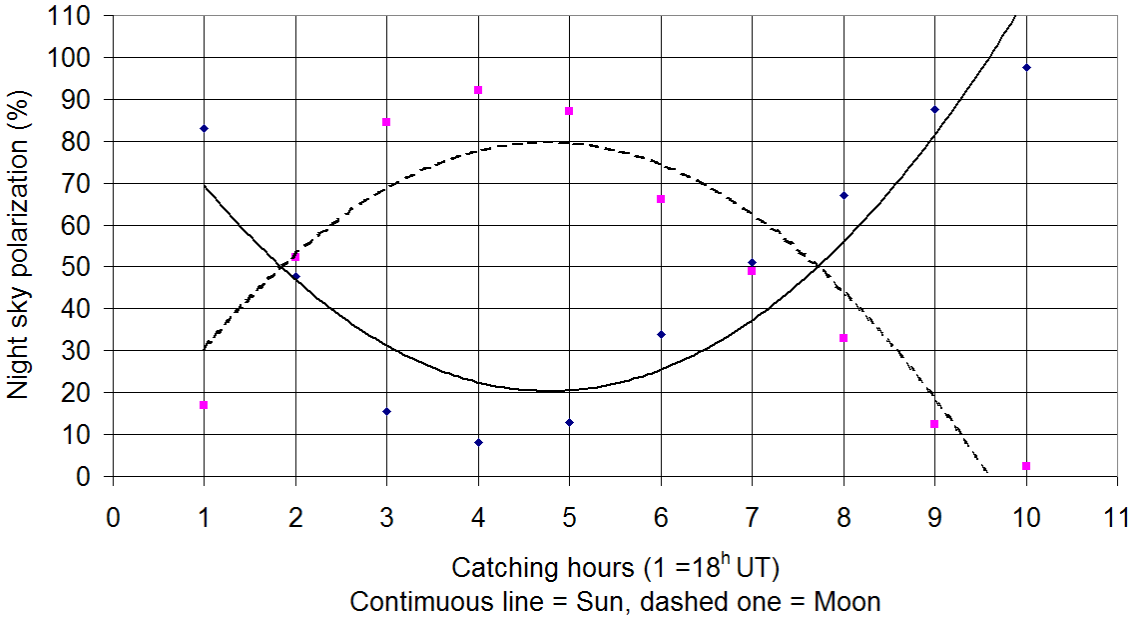
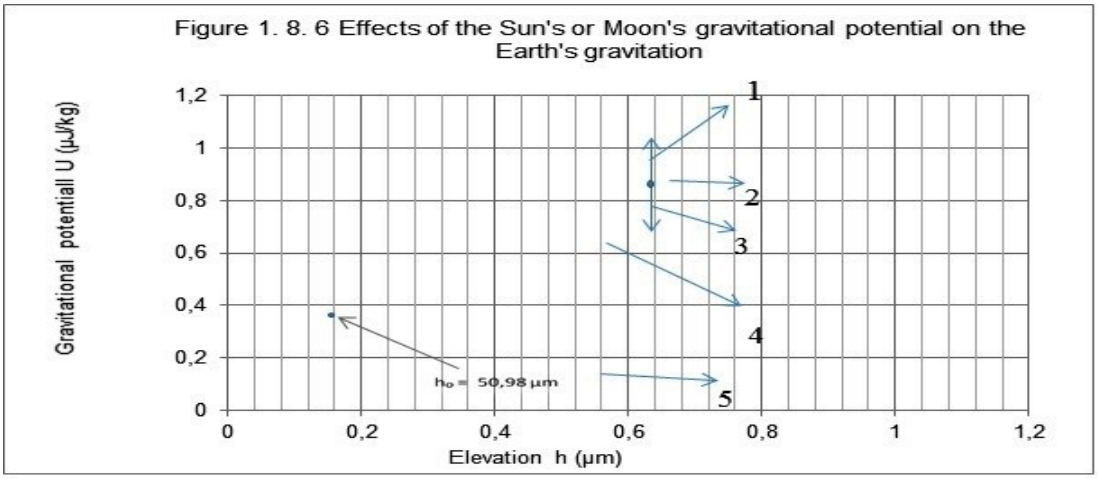


Figure 1. 8. 4 The neutral points of Moon in connection of altitude of Moon above horizon

Figure 5 Night sky polarization originated by the Sun and Moon in connection with the catching hours





1 Gravitational potential of the celestial bodies are positive sign (e.g. +500 µJ/kg). They increase the gravitational potential of the Earth.
2 Gravitational potential of the Earth = h*g (µJ/kg)
3 Gravitational potential of the celestial bodies are negative sign (e.g. -500 µJ/kg). They decrease the gravitational potential of the Earth.
4 Resultant of the celestial bodies (e.g. If the gravitational potential of the bodies = -500 µJ/kg)
5 Critical ascent height, here the resulting gravitational potential is zero. If $h<h_0$ the impact of a celestial body is dominated by suction, if $h> h_0$ the inhibitory effect of Earth.

CHAPTER 2
(Central Europe, Hungary)

Light-trap Catch of the Lepidoptera Species in Connection with the Sun's and Moon's Characteristics (Jermy-type Light-traps)

Nowinszky L., Kiss M., Puskás J., Barta A.

2. 1 Introduction

2. 1. 1 Moon phases and polarized moonlight

Great many studies in literature are devoted to the role of the Moon in modifying light-trapping catch. The conclusions are contradictory and up to this day a good many questions have remained unclarified. True, the authors usually collected differing species at the most different geographical locations and have not even registered the Moon phase in every case. Several researchers include moonlight in their list of factors that modify collecting, but owe us a detailed analysis of the workings of that influence (Jermy, 1974, Lödl, 1987).
Using a 125W mercury vapour lamp in North America, Hardwick (1972) did not find any difference between the cosine of the ordinal number of the days before and after a Full Moon and the logarithm of the number of owlet moth (Noctuidae) specimen caught.

Relatively few authors have observed increased light-trap catch in the vicinity of a Full Moon. Despite strong moonlight, Papp and Vojnits (1976) collected quite a lot of moths in Korea using 125W and 250W mercury vapour lamps. According to Járfás and Viola (1981), Codling Moth (*Cydia pomonella* L.) flew to a Járfás-type fractionating light-trap in masses on clear moonlit nights. An interesting observation at and closely after a Full Moon: Malgay (epistolary comment) collected specimens of 113 species at light on August 2nd, 2007 at a Full Moon. According to some observations, the presence of the Moon above the horizon induces lengthened flight activity (Heikinheimo, 1971).

The efficiency of collecting is different in the waning and in the waxing half of lunation

Several authors share the view that the efficiency of light-trapping is not the same in the waxing (from a New to a Full Moon) and the waning (from a Full Moon to a New Moon) period of lunation. In these cases, the catch minimum is usually at a Full Moon.
Persson (1976) was catching owlet moths (Noctuidae) in Australia using a light-trap equipped with a 400W mercury vapour lamp. In the Last Quarter, after a Full Moon, collecting was more successful than in the First Quarter when the Moon was above the horizon in the evenings. Garcia (1977) collected Hawkmoths (Sphingidae) by use of a 250 W mercury vapour light-trap in Venezuela. He caught the highest amount in the waning, the lowest in the waxing period of lunation. Vaishampayan and Verma (1982 and 1983) were collecting Scarce Bordered Straw (*Helicoverpa armigera* Hbn.) in India with the help of a Pennsylvania-type

trap operating with a 250 W mercury vapour lamp. Collecting was more successful in the waning than in the waxing period. They presume that the response of moths is weaker to the stimulus of the light-trap in the vicinity of a Full Moon. Sekhar et al. (1996) and subsequently Nath and Rai (2000) reported similar results from India, using 160W mercury vapour light-traps: their catch of Scarce Bordered Straw (*Helicoverpa armigera* Hbn.) was higher in the waning than in the waxing period of lunation. Using a Pennsylvania-type trap equipped with a 200W fluorescent bulb, Shrivastava et al. (1987) were collecting specimens of the Egyptian Cotton Leafworm (*Spodoptera littoralis* Fabr.) in India. The catch was higher in the waning than in the waxing period. They explain this by a reduced collecting distance. As opposed to the studies mentioned above, operating a 250W mercury vapour lamp in India, Vaishampayan and Shrivastava (1978) had a higher catch of Egyptian Cotton Leafworm (*Spodoptera littoralis* Fabr.) in the waxing than in the waning phase of lunation. In the ±3 day, vicinity of a New Moon the catch was more than ten times higher than in the ±3 day vicinity of a Full Moon. Steinbauer (2003) found the light-trap catch rate for *Mnesampela privata* (Lepidoptera: Geometridae) generally declined with increasing moon age until a few days after the Full Moon and generally rose again thereafter until two or three days prior to the New Moon. Stradling et al. (1983) found the monthly variation in catch was found to correspond with the cycle of lunar illumination, being significantly depressed with increasing brightness. Interspecific differences in the response to moonlight were also detected.

Light-trap efficiency goes down at a Full Moon

Most of the authors experienced a drop in the efficiency of trapping as a result of moonlight. Leinonen et al. (1998) find this so evident that they do not even operate a light-trap on moonlit nights. Taylor (1986) wrote that the catches of all nine species of noctuid and sphingid moths were reduced by moonlight, but not equally.

Williams (1936) have published fundamental studies in this field. According to his statements, three times more Noctuidae specimen would fly to light on a clear night at a New Moon than at a Full Moon. In cloudy weather, this ratio is 2:1, while with clouds disregarded, the ratio of insects caught at a New Moon and at a Full Moon is 2.7:1. In his later works, Williams (1940) extended his investigations to several orders of insects. Considering all insects, he collected the maximum number of specimen on the 20th day of lunation and the minimum on the 1st day, at a Full Moon.

According to Williams (1936), Williams et al. (1956) and El-Ziady (1957), the reasons for a smaller catch at a Full Moon might be as follows:

Moonlight reduces the activity of insects and so the active population accessible for the light-trap is smaller,

The light of the lamp collects moths from a smaller area in moonlit environment,

It has a direct impact on the actual number of specimen of the population,

Impact on flight activity. It is possible that insects like to fly rather at shady places than at clear areas, and probably in higher altitudes at a Full Moon.

No scientist could give a probable answer to this question in recent decades, most have not even tried. Some authors find an explanation by accepting the theory of the impact of a collecting distance, others refer to decreased activity.
Hosny (1955) operated UV light-traps in an open field and in a forest at the Rothamsted research station. In the open area, they caught twice as many Macrolepidoptera species at a New than at a Full Moon. Using a light-trap equipped with a 100W normal bulb, Wéber (1957) collected four times more insects at a New Moon than at a Full Moon. Brénière et al. (1962) observed a strong decrease in the light-trap catch of African White Stemborer (*Maliarpha separatella* Rag., Lepidoptera: Pyralidae) at a Full Moon in Madagascar.
Using a 125W mercury vapour lamp in New South Wales, Morton et al. (1981) examined the impact of moonlight on the catch of Scarce Bordered Straw (*Helicoverpa armigera* Hbn.). They recorded a 49% decrease as compared to the theoretical maximum value established by Austin et al. (1976). On the other hand, there was no significant decrease in the catch of the Native Budworm (*Heliothis punctigera* Wallengren). Aliniazee (1983) trapped more of the Filbertworm (*Melissopus latiferreanus* Welsingham, Tortricidae, Lepidoptera) on dark nights than at a Full Moon. Tucker (1983) observed the high light-trap catch of *Sopdoptera exempta* Walker (Lepidoptera: Noctuidae) more often around a New Moon than at a Full Moon. On May 13th 1979, Rézbányai-Reser (1989) collected during a total lunar eclipse near Luzern. First, when light was strong, flight activity was scarce, but during the eclipse insects flew to light more and more often as if the Moon had been obscured by clouds. Flight activity subsided with the Moon fully visible again. Yela and Holyoak (1997) detected a decrease in the catch in growing moonlight by using a modified Heatly-type UV trap in Southern Spain. However, cloudy skies usually made the catch rise. Operating a UV trap in Australia, Steinbauer (2003) successfully collected Autumn Gum Moth (*Mnesampela privata* Guenèe, Lepidoptera: Geometridae) a few days after a New Moon and in the 2 days before and after the First Quarter. Murugesan et al. (2005) were catching cotton pests, *Spodoptera litura* Fabr., *Helicoverpa armigera* Hbn., *Earias* spp., *Pectinophora gossypiella* Saunders (Lepidoptera: Gelechiidae) with light-traps with 100W yellow and blue bulbs in India. They collected more specimens at a New Moon than in the other quarters. According to Jeyakumar et al. (2007), the diel average of the number of Scarce Bordered Straw (*Helicoverpa armigera* Hbn.) specimen collected with a light-trap in India in the four quarters of lunation were as follows: Full Moon: 22,05, Last Quarter: 26,75, New Moon: 50,35 and First Quarter: 16,80. Sanyal et al. (2013) examined whether the moon phase has any significant effect on catch success, a light-trap was run on daily basis for one-month period in the month of April at an altitude of 1440m between 8 p.m. and 12 p.m. period. Most species as well as individuals were attracted in and around no moon nights and declined as the ambient moon light started to increase and came to a minimum around Full Moon nights when the ambient moon light was at its best.

Moonlight decreases the distance of collecting

Before we start to discuss the different views in scientific literature regarding the role of the collecting distance as a modifying factor, it is important to define and distinguish the concepts of a theoretical and a true collecting distance. By collecting distance, we mean the radius of the circle in the centre of which the trap is located and along the perimeter of which the

illumination caused by the artificial light source equals the illumination of the environment (theoretical collecting distance).

The size of the theoretical collecting distance depends on:

Luminous intensity of the artificial light source (candela), which is theoretically constant, but the change of voltage may modify the parameters of light (lifespan, luminous flux, total power input, and luminous efficacy). The continuously changing illumination of the environment (time and span of twilights, the periodical changes of the Moon, light pollution) that may be different depending on geographical position, the season of the year or during one night.

Theoretical collecting distance has been calculated by several authors, for different light-trap types and lunar phases. According to calculations by Dufay (1964), the collecting distance of a 125 WHPL light source is 70 m at a Full Moon and 830 m at a New Moon. Studies by Bowden (1973a, 1973b, Bowden and Church, 1973) discuss in detail the decline of luminous intensity between civil and astronomical twilight as a function of the lunar phases. He summarized in tables the illuminance from the Moon in all lunar phases also considering atmospheric absorption, classified by zones in the vicinity of the equator. They determined collecting distances for 125W mercury vapour lamp: 35m at a Full Moon, 518 m at a New Moon (Bowden and Morris, 1975). He described (Bowden, 1982) the collecting radius of three different lamps with the same illuminance: a 125 W mercury vapour lamp, in the UV range 57 m at a Full Moon,736 m at a New Moon, 160 wolfram heater filament mercury vapour lamp 41 m at a Full Moon, 531 m at a New Moon, 200 W wolfram heater filament lamp 30 m at a Full Moon, 385 m at a New Moon. He also recorded correction values for the codes of the 10 categories of cloud types in tables, according to which the catch rises under more clouded skies. Bowden and Morris (1975) corrected daily catch results by an index calculated from the collecting distance. They established the index in the following way: They determined the collecting distance for all hours of all the nights of the lunation. Taking the value at a New Moon as an index unit (10), they expressed all the index values belonging to the different phase angles as a percentage of this. After this correction, the catch of more taxa Bostrychidae (Isoptera and *Spodoptera triturata* Wlk.) reached its maximum at the time of a Full Moon. In the view of Mukhopadhyay (1991), the collecting distance of a 100 W wolfram heater filament light-trap is 245.2 m at a New Moon and 16.7 m at a Full Moon. Earlier Williams (1936) developed a correction method for excluding the influence of lunation. For this he considered the averages and the positive and negative deviations at a New Moon and at a Full Moon as well as the fact, that the difference between these is the smallest in June and the largest in October; the deviation in the asymmetry of the correction in the months before and after June.

In our earlier work (Nowinszky et al., 1979), we determined these distances as 18m and 298 m for the Jermy-type trap working with a 100W normal bulb. Based on the collecting distances we also calculated the corrections for the Turnip Moth (*Agrotis segetum* Den. et Schiff.) and the Greek Character (*Agrotis ipsilon* Hfn.). The results showed the catch maximums at a Full Moon (Nowinszky and Tóth, 1990). However, today we think that the correction based on collecting distances is only acceptable, if the reason for the detected low catch at a Full Moon was – in the case of all species – the minimal collecting distance at that

time. In addition, the collecting distance calculated for a New Moon and a Full Moon has shown little difference at the heavily light-polluted areas since the time these papers were written (Nowinszky, 2008).

Nag and Nath (1991) collected in India with a 160 W mercury vapour lamp. The catch of the Greek Character (*Agrotis ipsilon* Hfn.) was smaller at Full Moon. They explain the results by a shorter collecting distance. In the view of Bowden and Church (1973), Vaishampayan and Shrivastava (1978), Vaishampayan and Verma (1982) and Shrivastava et al. (1987) the smaller catches of light-traps at a Full Moon is in connection with the stronger and brighter light of the Moon and smaller collecting area, and is therefore a clearly physical phenomenon. The authors cited above did not as yet have to consider light pollution.

By light pollution, we mean a change in natural nocturnal light conditions caused by anthropogenic activity. Cinzano et al. (2001) discussed the nocturnal state of the sky in several studies. They published a world atlas listing the most important data by countries. In this work, the authors consider artificial illumination above 10% of the natural background illuminance as light pollution. Light pollution has a harmful effect on the life of animal species, darkness by nigh provides them with a feeling of security. In the recent decades, several works were published on the harmful effects of light pollution on the life of different animal species. On the other hand, only few studies cover the relationship between light pollution and light-trapping. Artificial background illuminance alters the contrast between the trap and the environment as well as the luring stimulus, in the same way as moonlight does (Reinert, 1989). The relationship between light pollution and the theoretical collecting distance of light-traps is discussed in our recent studies (Nowinszky, 2008).

Moonlight inhibits flight activity

Győrfi (1948) attributes the much smaller amount of insects flying to light at a Full Moon to decreased activity. According to Edwards (1961), an estimate of the activity depends on two factors. One is the proportion of the population in an active phase and the other the amount of time spent in flight by this specimen. Agee et al. (1972) reported on few Corn Earworm (*Heliothis zea* Boddie) and other noctuids being active at a Full Moon, but on many being active before the rise of the Moon and after its set. Using 15W fluorescent UV lamps in Texas, Nemec (1971) collected Corn Earworm (*Heliothis zea* Boddie) in highest numbers at a New Moon and in lowest at a Full Moon. He is of the view that moths are having an inactive period at a Full Moon. By reason of their studies, Baker and Sadovy, (1978), Baker (1979) and Sotthibandhu and Baker (1979) believe that moonlight cannot have an influence on the collecting distance. Thus, in their point of view, increased light intensity moderates flight activity. McGeachie (1989) is of the view that the change of moonlight influences behaviour rather than the efficiency of the trap.

With his light-trap equipped with two 5W fluorescent UV tubes, Brehm (2002) collected geometrid moths (Geometridae) in Equador. He is of the view that the catch represents activity rather than abundance.

The following observations by Dufay (1964) contradict the theory of moonlight inhibiting activity:

Nocturnal moths can be seen in the light of car lights also on moonlit nights,

At a Full Moon collecting decreases but does not stop,

In case of lunar eclipses, the catch is high when the Moon is obscured, although closely before and after it is low. This observation is quite demonstrative, as the eyes of nocturnal insects adapt to darkness only 5-9 minutes after it sets in.

The position of the Moon above the horizon, the colour temperature of moonlight

Only a few works discuss the efficiency of light-traps in the context of the position of the Moon above the horizon. In addition to his ultrasound experiments, Agee (1969) also collected with UV traps. He found that only a few Corn Earworm (*Heliothis zea* Boddie) specimen and other noctuids were active when the Moon was 10° or more above the horizon.
Scheibe (2000) operated two types of light-traps (OSRAM HQL 125W and PHILIPS SON 70W). When the position of the Moon was high above the horizon, he recorded a very low catch of several taxa:

The polarized moonlight

In our earlier work (Nowinszky et al., 1979) we recorded three catch peaks in the summarized light-trap catch data of 7 species throughout lunation. However, instead of finding a peak at a Full Moon we observed a smaller catch maximum at a New Moon. The high catch recorded in the First and the Last Quarter may be explained by the high ratio of polarized light, while that in the vicinity of a New Moon – when there is no moonlight at all – by maximal collecting distance, an attribute of this period (Nowinszky et al., 1979).
Danthanarayana and Dashper (1986) examined insect behaviour in response to polarized light by using three Pennsylvania type light-traps. The traps ran on 12 V Toshiba LF 6 W fluorescent light tubes emitting cold white light. They were placed outside an equilateral triangle with 10 metres sides and their position was altered every day. One of the traps emitted polarized light in the horizontal plane, the other emitted polarized light in the vertical plane and the third emitted non-polarized light. Beetles (Coleoptera), moths (Lepidoptera) and membrane-winged insects (Hymenoptera) flew to non-polarized light in greater numbers. Dermatoptera species can be trapped more successfully with light polarized in the vertical plane, while caddis flies (Trichoptera) and flies (Diptera), including in the first place non-biting midges (Chironomidae) can be best attracted to light polarized in the horizontal plane. It is quite remarkable that the result pertaining to moths contradicts an earlier finding by Kovarov and Monchadskiy (1963) who claim that species of that order fly in masses to polarized light. However, the two researchers used 1 000 W mercury vapour lamps to collect insects. Szentkirályi et al. (2005) used horizontally polarized and unpolarized light-traps for collecting ground beetles (Carabidae). 8 of the 115 species caught occurred more frequently in the traps emitting polarized light. Of these the specimen number of ground beetles *Bembidion varium* Ol. and *Bembidion minimum* Fabr. was consequently and significantly higher in the polarized light-trap than in the unpolarized one. Several species were proven to be able to perceive polarized light.
Danthanarayana (1976) and Steinbauer (2003) related trap catches of their study species to individual days within the lunar cycle. They study found that certain orthopterans and lepidopterans exhibit non-linear relationships with the fraction of the Moon surface illuminated.

Illuminated fraction of the Moon's surface

Steinbauer (2003) found in 2-years light-trap data for the geometrid moth, *Mnesampela privata* Guenée that catch rate generally declined with increasing moon age until a few days after Full Moon and generally rose again thereafter up to 2-3 days prior to the New Moon. Steinbauer et al. (2012) wrote the fraction of the Moon surface illuminated explained significant variation in the catches of three species (*Lepidogryllus* Otte & Alexander, *Aiolopus thalassinus* Fabricius (Acrididae: Acridinae) and *Pycnostictus seriatus* Saussure).

Our own research results are reported in the following studies:

A brief summary of our own research on this topic:

Based on our knowledge originating from the research work of other scientists and our own findings described above, we summarize the effect of the Moon and moonlight influencing light-trap collecting in a book edited by Nowinszky (2008):

Lunar phases and the efficiency of light-trapping

Lunar phases affect catch results on the different days of lunation considering all light-trap types and all species under examination,

Deviations may vary by species, the behaviour of the different species may be similar or different,

The catch of certain species may be different or similar when the volume of catch at two distant periods of time is compared,

The catch of the same species might be different in the same period of time and geographical locality, when different types of light-traps are used. However, the collecting efficiency of some light-traps is almost the same,

In the case of light-trap types and all the species under examination a minimum is recorded in the catch in the vicinity of a Full Moon,

Maximum catches rarely occur exactly at a New Moon, rather in the First and/or the Last Quarter, or in the phase angle divisions between a New Moon and the Quarters. This might be explained by the joint effect of an already relatively large collecting distance and the high ratio of polarized moonlight characteristic for this period. Consequently, the effect of high polarization that intensifies activity is added to the effect of the collecting distance in increasing the catch,

The influence of the lunar phases in modifying the catch may be detected not only during moonlit hours, but also in those without moonlight. This seems to prove a statement by Danthanarayana (1986) claiming that lunar influence is independent from the visibility of the Moon,

Thus, we have to distinguish lunar influence and the influence of moonlight.

Collecting distance and the efficiency of light-trapping

We have to draw a line of distinction between the concept of a theoretical and that of an actual collecting distance. The actual collecting distance is, in most cases, much shorter than the theoretical one calculated on the basis of the level of illumination in the environment,

The constant change of the theoretical and actual collecting distance used to play an important, but not exclusive role in the efficiency of collecting,

Due to light pollution the difference between the theoretical and actual collecting distance has become basically balanced out. Consequently, the catch of certain species is practically equal at a Full Moon and at a New Moon,

The actual collecting distance – just like the theoretical one – varies by light-trap types and taxa, but in the case of 100W normal bulb traps it was approx. 90 m for many species,

If a catch minimum can be detected at a Full Moon also in the catch data of recent years, the reason for this should be found in other lunar influences,

We find the correction of catch results - applied earlier by more authors - acceptable, even in case of data dating back several decades, only if it happens based on an actual collecting distance. We find a similar correction of recent data perilous.

The position of the Moon above the horizon and the efficiency of light-trapping

Although the position of the Moon above the horizon affects collecting, we do not think this is a determining factor

Illumination from the Moon and the activity of insects

Generally, illumination by the Moon does not hamper the flight activity of insects. Besides the points made by Dufay (1964), the following facts prove this theory. It is a justified fact, that certain insects use polarized moonlight for their orientation. It is unthinkable that the activity of these insects would decrease when polarized moonlight is present in a high ratio. Our investigations have also proved the catch to be higher in case of higher polarization,

In moonlit hours we observed a higher catch on more occasions than in hours without moonlight,

The relatively strong illumination by the Moon can not be the reason for a catch minimums recorded at a Full Moon. Most insects start to fly in some kind of twilight and illumination at twilight is stronger by orders of magnitude than illumination by moonlight,

Suction trap studies by Danthanarayana (1986) have not justified the decrease observable with light-traps at a Full Moon,

Observation claiming that insects spend less time in flight during a Full Moon should be completed with similar observations for a New Moon. High standard scientific investigation is needed to study both periods.

Not even on the basis of the relative brightness of the Moon do we find a correction of the catch data acceptable, as this method does not consider the role of polarized moonlight and it is not effective throughout the whole lunar month.

The certainty of the orientation of insects

Based on the work by Jermy (1972), we presumed in our earlier studies that moderate catch results recorded at a Full Moon may be explained by the better orientation of insects. This hypothesis attributes low catch results to negative polarization typical for the period immediately before and after a Full Moon, possibly enabling insects to distinguish the light of the lamp from moonlight and thus avoid the trap.

Nowinszky (2003) had already assumed that light-traps in the environment of Full Moon would collect only few insects due to the vertically polarized moonlight. In the first and last quarters, much more is collected due to the horizontally polarized moonlight.

2. 1. 2 The night sky polarization and the Sun's and Moon's neutral points in sky

It has been well known for almost for half a century that the polarized light of the sky plays an important role in the orientation of certain insects. Researches, however, has been as yet concentrated primarily on insects flying in daytime or at dusk and entomologists have paid less attention to species active at night.

It has been known ever since the beginning of the 19th century that the light of the sky is partly polarized. This is because the light from the Sun gets scattered by the molecules and aerosol particles of the atmosphere (Rayleigh scattering, Mie effect). The degree of polarization is characterized by the quotient of the quantity of polarized and non-polarized light. The existing state of polarization is always determined by a combination of the geographical location, the season of the year, the angle of incidence of the Sun's radiation, the aerosol saturation of the atmosphere and several microclimatic factors. A clear sky always generates less polarized light than a clouded or especially a completely overcast sky. As the Rayleleigh scattering is inversely proportional to the fourth power of the wavelength of the light, the extent of polarization is also strongly dependent on the spectral range of the light involved. The degree of polarization is also influenced by the topocentric location (zenith distance and azimuth) of the Sun from the point of view of the observer. Measuring is usually carried out at the zenith or somewhere close to it. In the latter case, it is not indifferent if the measurements are made in the direction of the Sun or in other directions. According to Lipsky and Bondarenko (1970) maximum polarization appears in an area some 85° from the direction of the Sun.

The light of the sky at sunset and daybreak is strongly polarized. In some places, however, neutral spots can be observed in areas of a few arc-square grades where polarization is practically zero (Rozenberg, 1966, McCartney, 1976). Their location in the sky always depends on the given position of the Sun. At a distance of 15-20° from the Sun but always preceding it, Brewster's point can only be observed by daylight. Babinet's point follows the Sun on its virtual trajectory by 15-25° in the evening and precedes it by the same value at daybreak, so it is observable at twilight. In an opposite direction to the Sun and always at a distance of 180° from the above two, there are two more neutral points, namely, Arago's point, as a counter-point to Brewster's point and the so-called 'anti-Babinet's point' (has no accepted name in professional writing) that can be detected only from higher altitudes. Gál et al. (2001) measured, using 180° field of view (full-sky) imaging polarimetry, the patterns of the degree and angle of polarization of the moonlit clear night sky in every half an hour throughout the night at full Moon. The patterns were compared with those of the sunlit sky. The observed patterns including the positions of the Arago and Babinet neutral points of the moonlit night sky and sunlit day sky are practically identical if the zenith angle of the Moon is the same as that of the Sun. The possible biological relevance of the polarization pattern of the moonlit night sky in the polarization vision and orientation of night-active insects is briefly discussed

Horváth et al. (2002) reports on the first observation of this neutral point from a hot air balloon.

The same considerations apply to the neutral points on the Moon.

The neutral points are presumably perceived by insects as discontinuities in a sky emitting a continuity of polarized light. Therefore, we assume that these points might have a role to play in their orientation. Sun's Arago Point and Moon's Babinet Point may be of significance in the periods of evening and dawn twilight.

The fact that the polarized light of the sky has a role to play in the orientation of some insects has been known for about fifty years. However, research so far has been concentrating first of all on insects flying at daytime or at twilight. Entomologists have devoted a small amount of attention to the species active by night. Studies of basic importance of the past decades on the role of the polarized light of the sky in the orientation of bees and ants were published by Wehner (1976), Wehner and Rossel (1983), Brines and Gould (1982) and Horváth and Wehner (1999). Wellington (1974) studied in the context of zenith polarization the changes in the activity of mosquitoes at evening and early morning twilight. He found that these insects became inactive as soon as the Sun got covered in thick cloud or encircled by a bright halo free of polarization. The role of polarized light reflected from water surfaces in the orientation of water insects has been studied by Schwind and Horváth (1993), Horváth (1995a and 1995b), Horváth and Gál (1997) and Horváth and Varjú (2004).

Kyba et al. (2011) wrote that in the bright moonlit nights in a highly polarized light bands stretching from the sky at 90 degrees to the Moon, and has recently shown that the nocturnal organisms are able to navigate it. Unfortunately, it is very difficult to experimentally verify this, particularly for the case of flying insects, and further research into this area is warranted.

Further literature references on the relationship between sky polarization and aquatic insects are provided in Chapter 4. 1.

We have not come across any publication in professional literature discussing light-trapping efficiency in an interrelationship with the position of neutral points.

Therefore, we can only refer to our own studies on the following topics:

Lunar periodicity of light-trap catches and flight activity of the turnip moth (Nowinszky & Tóth, 1990)

Vertical distribution related with migration and moon phases of Macrolepidoptera species collected by light-traps (Nowinszky et al., 1991).

The relationship between lunar phases and the emergence of the adult brood insects (Nowinszky et al., 2010a).

Light-trapping as a dependent of moonlight and clouds (Nowinszky et al., 2010b).

Light-trap catch of European Corn Borer (*Ostrinia nubilalis* Hbn.) depending on the moonlight (Nowinszky & Puskás, 2009)

Possible reasons for reduced light-trap catches at a Full Moon (Nowinszky & Puskás, 2010)

Light-trapping of *Helicoverpa armigera* in India and Hungary in relation with moon phases (Nowinszky & Puskás, 2011)

The influence of polarized moonlight and collecting distance on the catches of winter moth *Operophthera brumata* L. (Lepidoptera: Geometridae) by light-traps (Nowinszky et al., 2012)

The Influence of Moonlight on Forestry Plants Feeding Macrolepidoptera Species, Research Journals of Life Sciences (Nowinszky & Puskás, 2013a)

Light-trap catch of harmful Microlepidoptera species in connection with polarized moonlight and collecting distance (Nowinszky & Puskás, 2013b)

Light-trap catch of Lygus sp. (Heteroptera: Miridae) in connection with the polarized moonlight, the collecting distance and the staying of the Moon above horizon (Nowinszky & Puskás, 2014)

Light-trap Catch of European Corn-borer (*Ostrinia nubilalis* Hübner) in Connection with the Polarized Moonlight and Geomagnetic H-Index (Nowinszky & Puskás, 2015)

Light-Trap Catch of Turnip Moth (*Agrotis segetum* Denis et Schiffermüller, 1775) in Connection with the Night Sky Polarization Phenomena (Nowinszky et al., 2017a)

Light-trapping of Caught Macrolepidoptera Individuals and Species in Connection with Night Sky Polarization and Gravitational Potential of Sun (Nowinszky et al., 2017b)

Light-trap Catch of Microlepidoptera spec. indet. in Connection with the Gravitational Potential of Sun and Moon (Nowinszky et al., 2018)

New Results in Researching the Relationship between Light-trapping of *Ostrinia nubilalis* Hbn. and Some Features of Night Sky and the Moon in Hungary and USA (Nowinszky et al., 2019)

2. 2 Material

The light-trap network with the same Jermy-type light-traps has been operating continuously in Hungary since 1958. About 130 light-traps operated for six decades and provided invaluable data for scientific research. The studies of Hungarian researchers enriched the literature with many valuable new scientific results.

The light source of the Jermy-type light-trap is a 100W normal electric bulb and the killing agent is chloroform (Jermy, 1961). It consists of a frame, a truss, a cover, a light source, a funnel and a killing device. All the components are painted black, except for the funnel, which is white. The frame is fixed to a pile dug into the ground. Before operation cotton wool pads are placed at the bottom to reduce the risk of injury to the collected insect material. The captured insects are often unsuitable for the species definition because the killing effect of chloroform does not prevail immediately, and in particular small insects are still often damaged

Lepidoptera (Macro- and Microlepidoptera) is the best-processed group. Until now, however, no studies were published on the most injured moths. The reason for this is that the unidentified specimens were recorded as “Microlepidoptera spec. indet.”. Because they were not known by species, it was not possible for further investigations. However, if we consider that there is a huge amount of collection data, we could see a possibility for this research. For our investigations, all Microlepidoptera spec. indet. data were used from 49 traps of the light trap network in 1962, 1963, 1964, 1966, 1967, 1968 and 1969. We did not have data from 1965, so we processed data for seven years. During 1,479 nights 590,139 Microlepidoptera moths were caught. However, because many light-traps worked during each night, we 21,761 catching nights of data. See also Chapter 1. 2

Table 2. 2. 1 The catching data of Macrolepidoptera species in Hungary

Species	Number of Years	Moths	Data
DREPANIDAE, THYATIRINAE			
Thethea or Denis & Schiffermüller, 1776	9	3,505	622
GEOMETRIDAE, STERRHINAE			
Idea rusticata Denis & Schiffermüller, 1775	9	21,922	470
Idea dimidiata Hufnagel, 1767	9	1,890	755
Idea deversaria Herrich-Schäffer, 1847	8	8,169	256
Scopula virgulata Denis & Schiffermüller, 1775	9	5,556	557
Scopula marginepunctata Goeze, 1781	9	2,090	562
Cyclophora punctaria Linnaeus, 1758	9	10,545	1,395
Cyclophora linearia Hübner, 1799	6	5,698	476

Rhodostrophia vibicaria Clerck, 1759	9	3,218	743
GEOMETRIDAE, LARENTIINAE			
Xantorrhoe ferrugata	4	1,454	463
Operophtera brumata Linnaeus, 1758	9	33,880	1,433
GEOMETRIDAE, ENNOMINAE			
Lomaspilis marginata Linnaeus, 1758	2	211	111
Ligdia adustata Denis & Schiffermüller, 1775	9	1,874	711
Macaria alternata Denis & Schiffermüller, 1775	9	26,473	1,176
Chiasmi clathrata Linnaeus, 1758	9	2,749	909
Biston betularia Linnaeus, 1758	8	1,779	396
Hypomecis punctaria Scopoli, 1763	9	15,231	1,174
Hypomecis danieli Wehrli, 1932	9	6,888	788
Ectropis crepuscularia Den. & Schiff., 1775	9	15,706	1,238
Ascotis selenaria Denis & Schiffermüller, 1775	3	538	217
Heliomata glarearia Den. & Schiff., 1775	9	1,454	552
Tephrina arenacearia Den. & Schiff., 1775	6	944	265
NOTODONTIDAE, PYGAERINAE			
Clostera curtula Linnaeus, 1758	9	1,320	375
Clostera pigra Hufnagel, 1766	2	274	137
EREBIDAE, RIVULINAE			
Rivula sericealis Scopoli, 1763	9	8,250	1,281
EREBIDAE, HYPENINAE			
Hypena proboscidalis Linnaeus, 1758	2	199	66
EREBIDAE, LYMANTRIINAE			
Caalliteara pudibunda Linnaeus, 1758	9	1,096	216
EREBIDAE, ARCTIINAE			
Phragmatobia fuliginosa Linnaeus, 1758	3	1,610	470
Dysauxes ancilla Linnaeus, 1758	9	9,312	433
Miltochrista miniata Forster, 1771	4	1,592	325
Pelosia muscerda Hufnagel, 1766	8	2,019	552
Eilema lurideola Zincken, 1817	4	1,248	119
Eilema complana Linnaeus, 1758	9	3,123	477
REBIDAE, HERMINIINAE			
Herminia derivalis Hübner, 1796	3	11,316	333
Zanclognatha lunalis Scopoli, 1763	9	37,128	680
Polypogon tentacularia Linnaeus, 1758	3	1,150	278
EREBIDAE, BOLETOBIINAE			
Colobochyla salicalis Den. & Schiff., 1775	9	2,254	653
NOCTUIDAE, EUSTROTIINAE			
Deltote pygarga Hufnagel, 1766	8	8,131	649
NOCTUIDAE, ACONTIINAE			
Acontia trabealis Scopoli, 1763	8	1,852	496
NOCTUIDAE, XYLENINAE			
Pseudeustrotia candidula Den. & Schiff., 1775	3	776	217
Elaphria venustula Hübner, 1790	8	2,120	415
Cosmia trapezina Linnaeus, 1758	8	2,107	285
NOCTUIDAE, HADENINAE			
Orthosia cruda Denis & Schiffermüller, 1775	3	635	50
Anarta trifolii Hufnagel, 1766	9	1,433	460
Mythimna turca Linnaeus, 1761	9	2,743	739
Mythimna pallens Linnaeus, 1758	2	294	124
Athetis furvula Hübner, 1808	9	52,892	509
Athetis gluteosa Treitschke, 1835	9	3,400	571
Platyperigea terrea Freyer, 1840	8	2,611	287

Episema glaucina Esper, 1789	6	17,737	456
NOCTUIDAE, NOCTUINAE			
Agrotis exclamationis Linnaeus, 1758	9	864	414
Agrotis segetum Denis & Schiffermüller, 1775	4	20,690	4,205
Xestia c-nigrum Linnaeus, 1758	9	3,903	894

2. 3 Methods

The Methods are written in Chapter 1. 3.

2. 4 Results and Discussion

The results are presented in Figures 1-22.

Figure 2. 4. 1 Light-trap catch of Microlepidoptera sp. indet. in connection with the night sky polarization originated by Sun

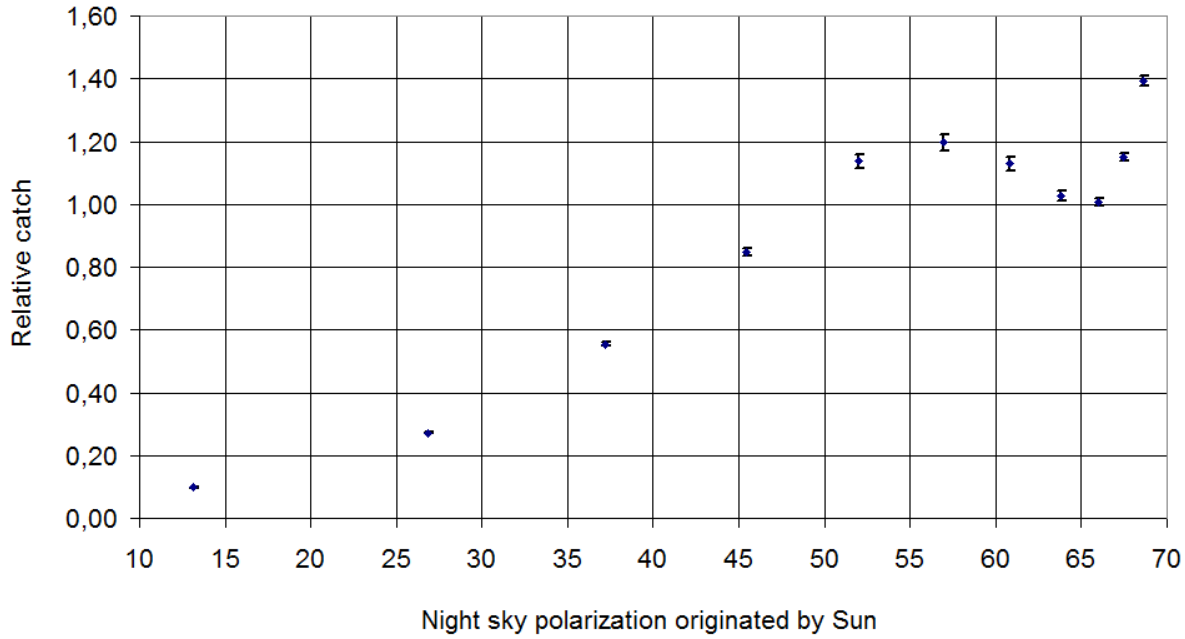


Figure 2. 4. 2 Light-trap catch of Microlepidoptera sp. indet. in connection with the night sky polarization originated by Moon

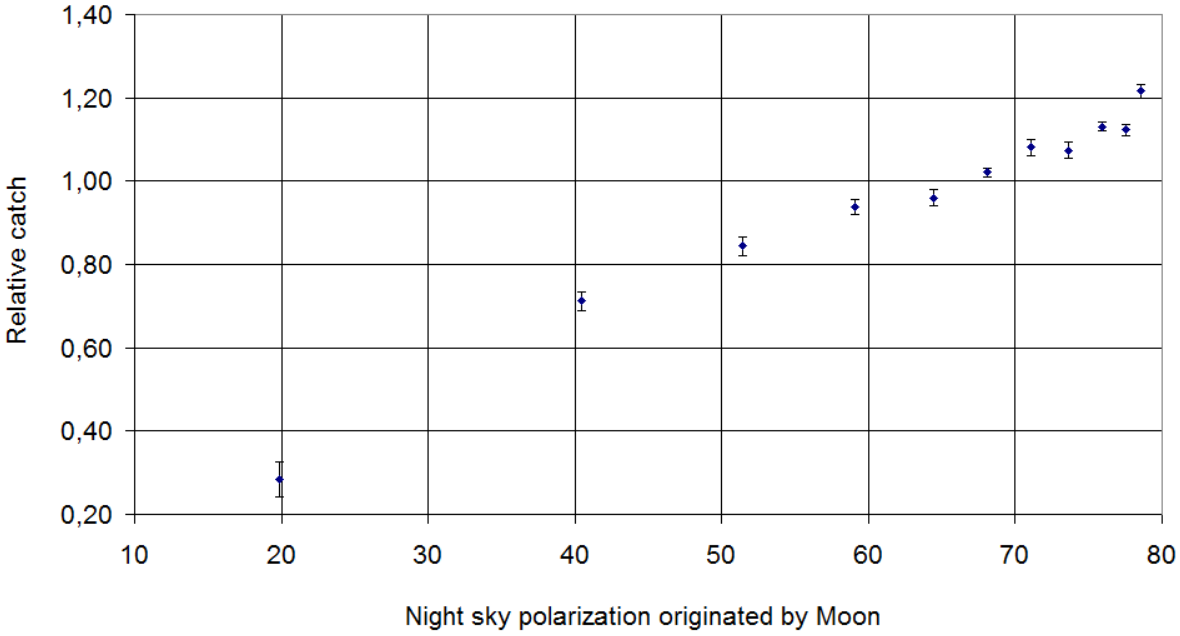


Figure 2. 4. 3 Light-trap catch of Microlepidoptera sp. indet. in connection with the gravitational potential of Sun

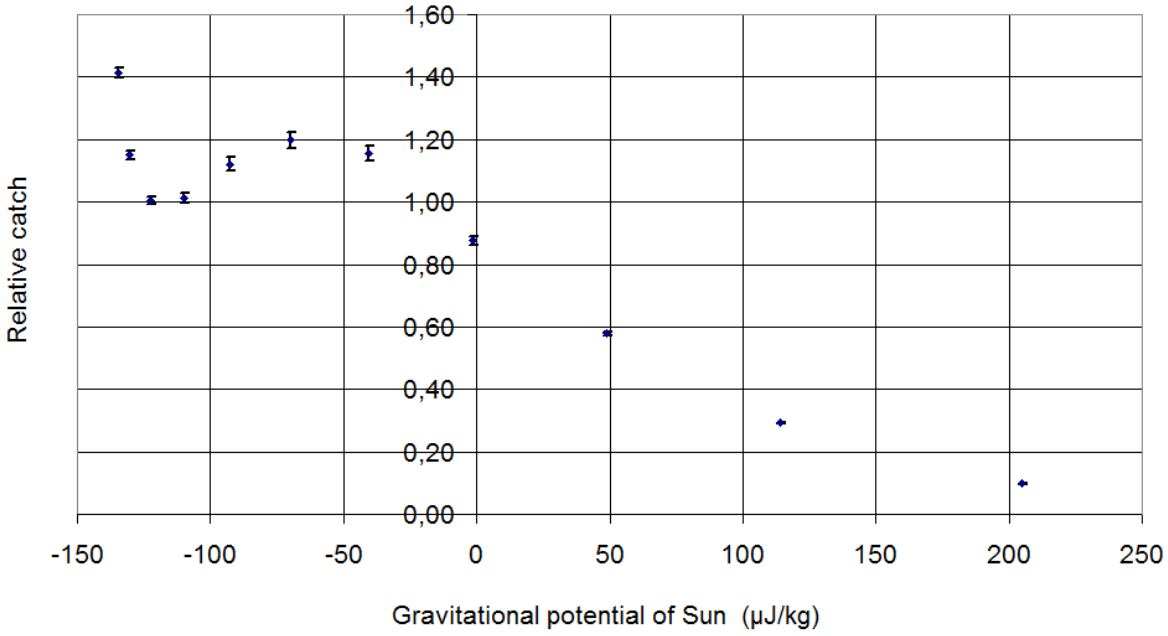


Figure 2. 4. 4 Light-trap catch of Microlepidoptera sp. indet. in connection with the gravitational potential of Moon

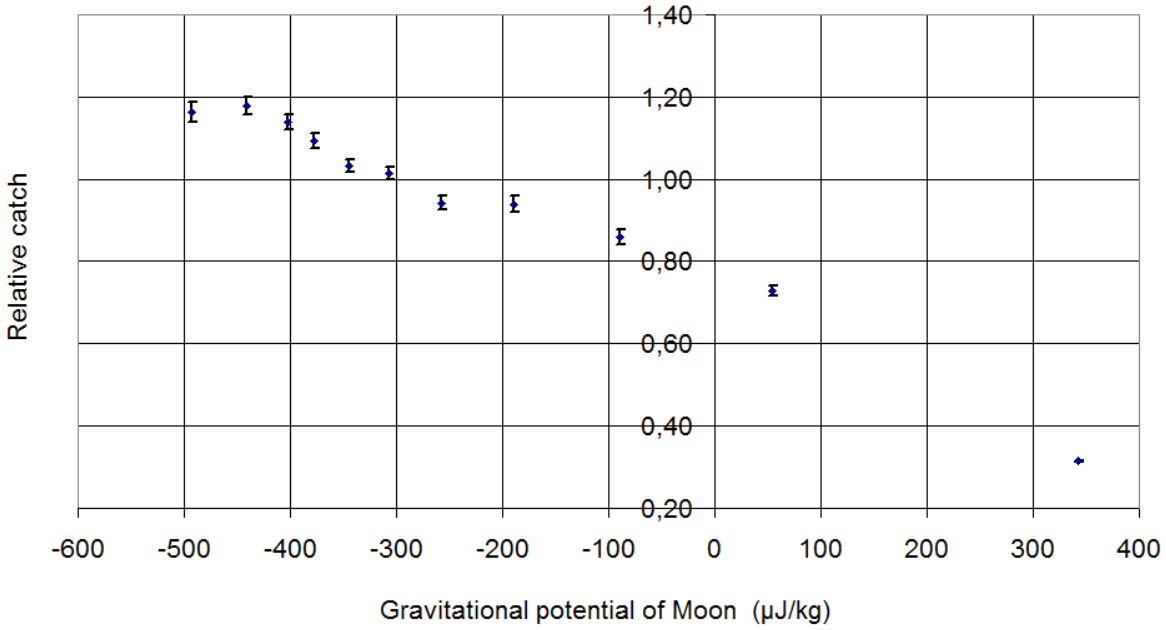


Figure 2. 4. 5 Light-trap catch of Microlepidoptera sp. indet. in connection with the gravitational potential of Sun+Moon

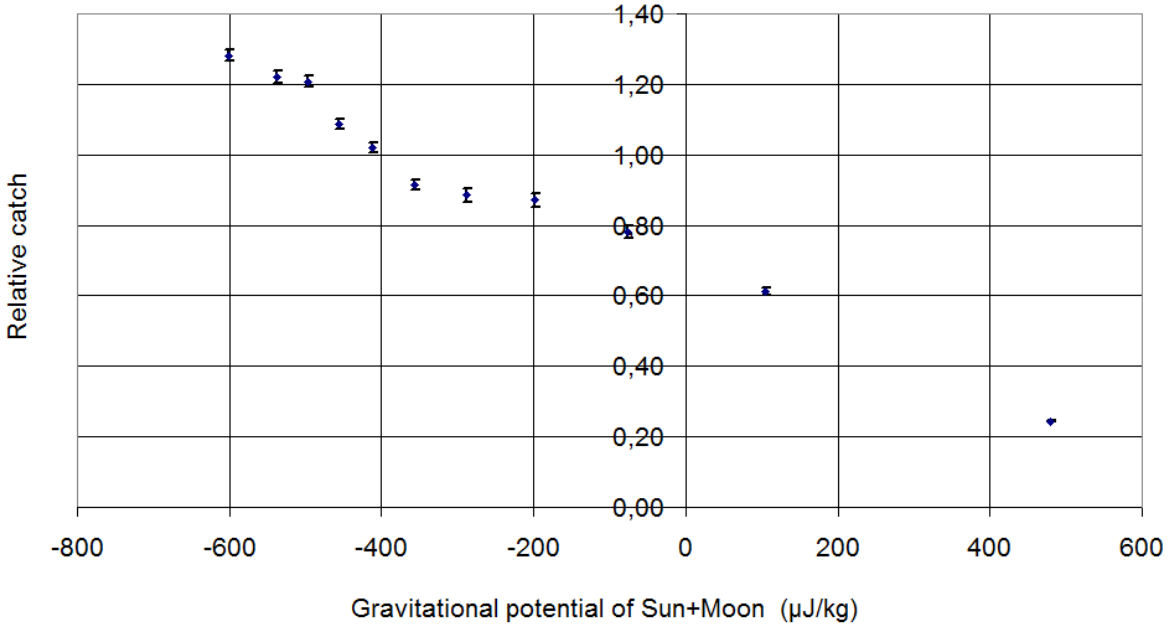


Figure 2. 4. 6 Light-trap catch of Microlepidoptera sp. indet. in connection with altitude of Sun's Arago point

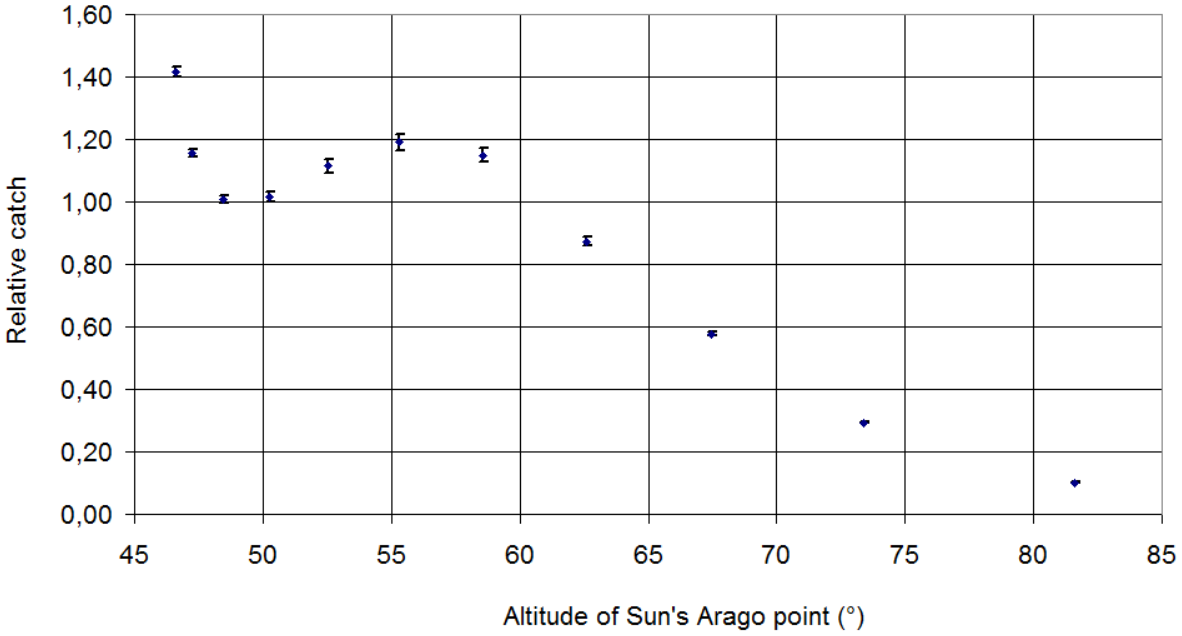


Figure 2. 4. 7 Light-trap catch of Microlepidoptera sp. indet. in connection with the altitude of Moon's Babinet point

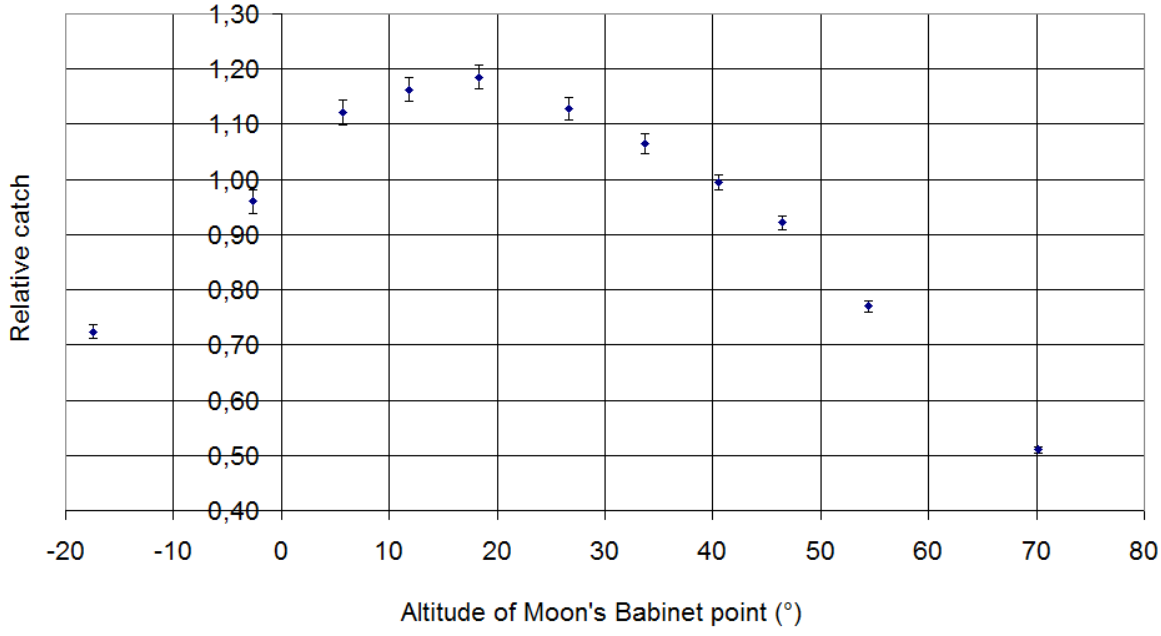


Figure 2. 4. 8 Light-trap catch of Microlepidoptera sp. indet. in connection with the phase angles of Moon (0=New Moon, 180=Full Moon)

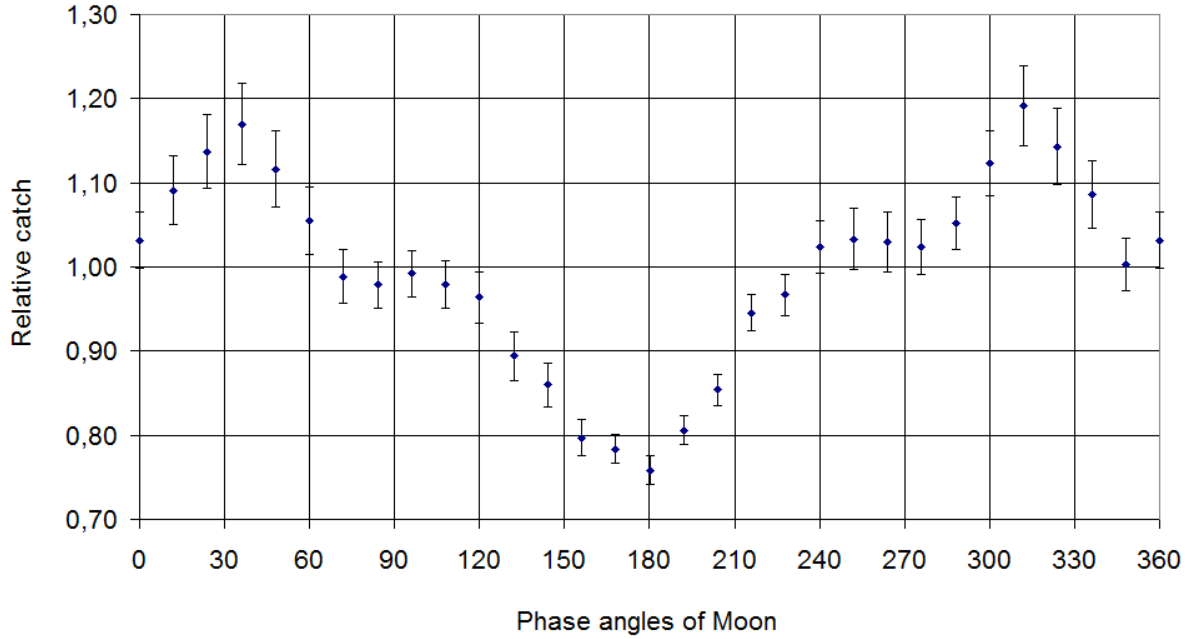


Figure 2. 4. 9 Light-trap catch of Microlepidoptera sp. indet. in connection with the apparent magnitude of Moon

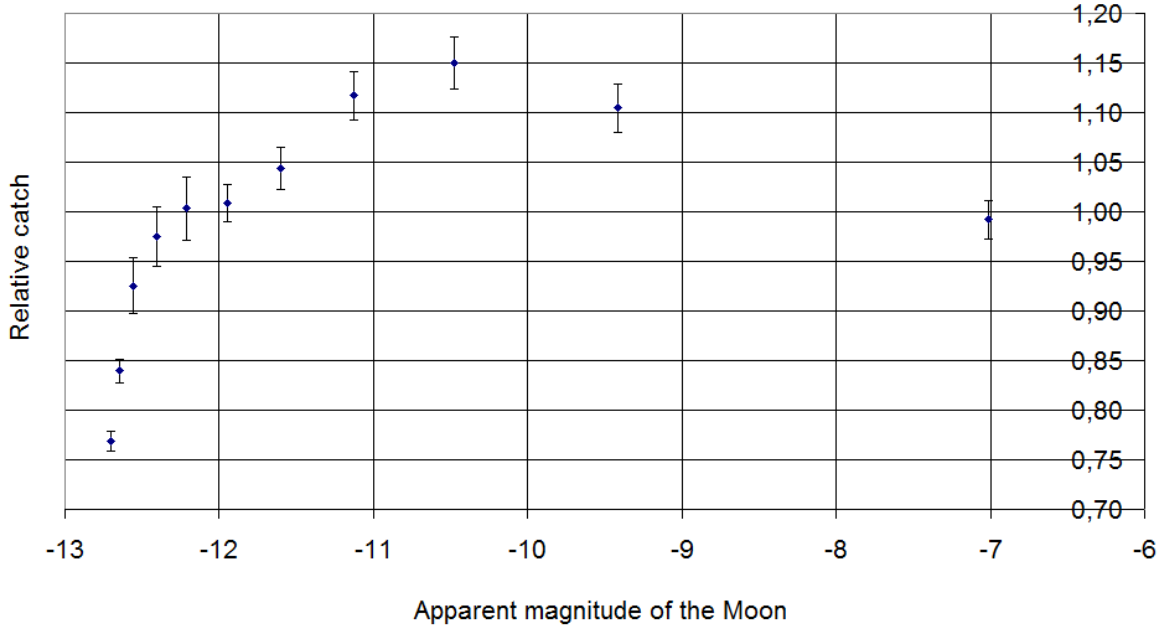


Figure 2. 4. 10 Light-trap catch of Microlepidoptera sp. indet. in connection with the illuminated fraction of Moon

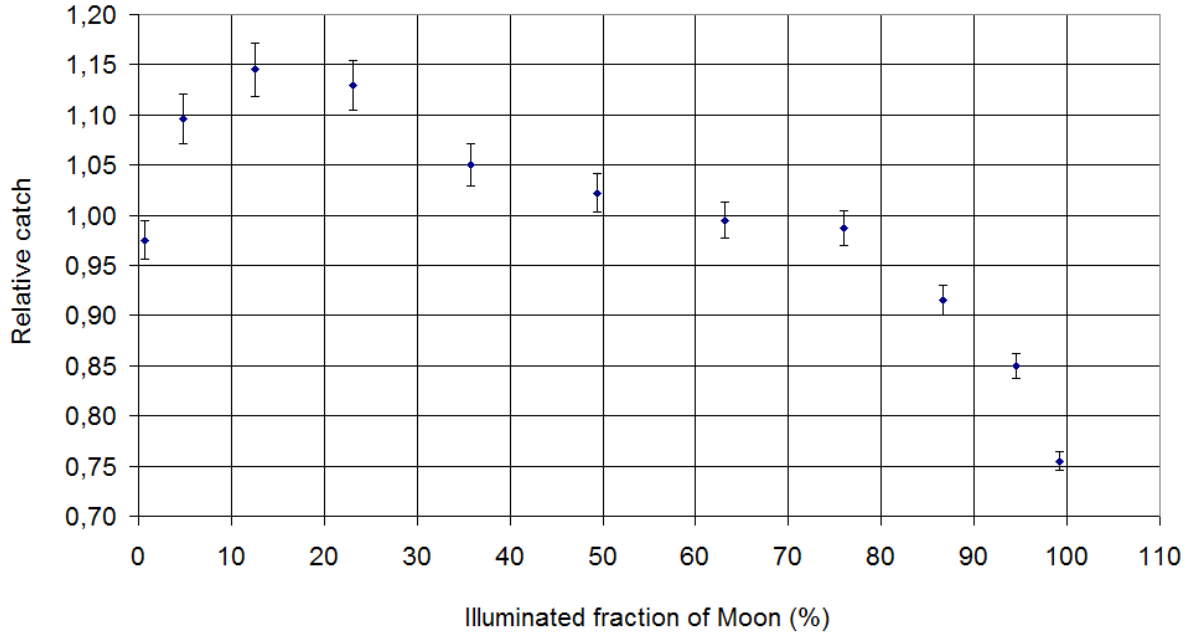


Figure 2. 4. 11 Light-trap catch of Microlepidoptera sp. indet. in connection with the moonlight

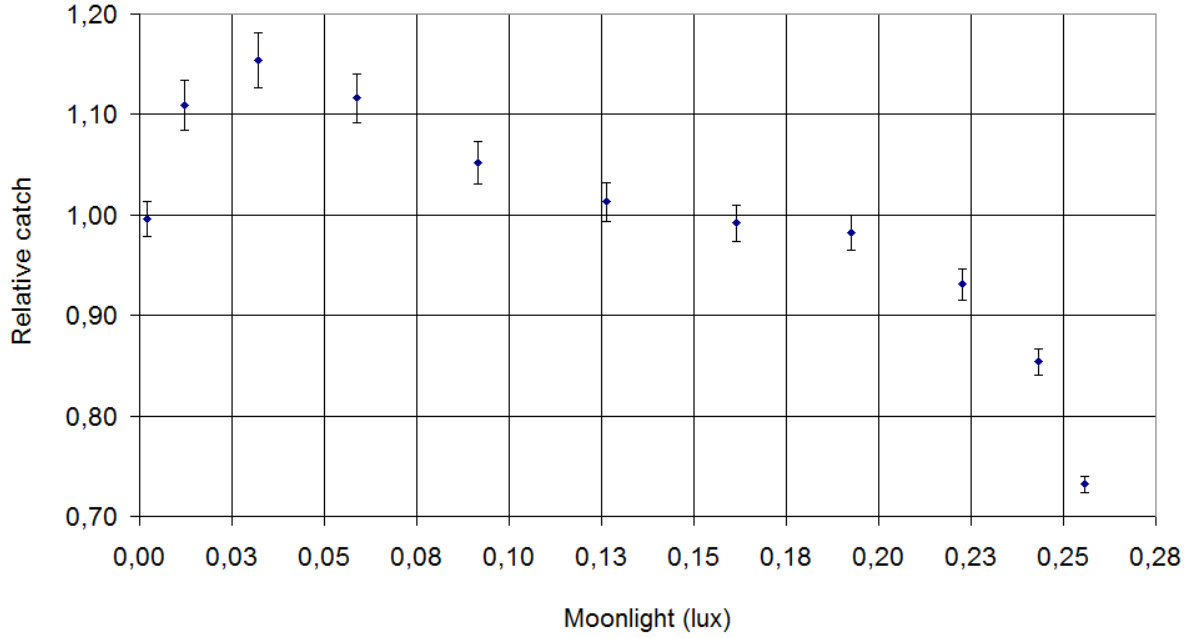


Figure 2. 4. 12 Light-trap catch of Macrolepidoptera sp. complex in connection with the night sky polarization originated by the Sun (Early and late-summer aspects)

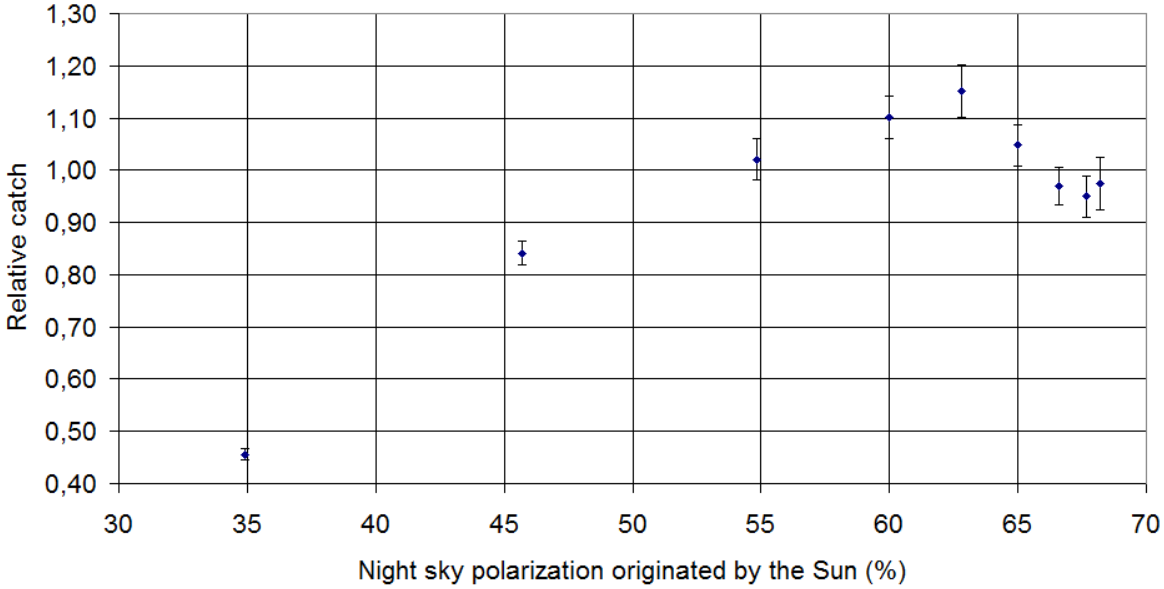


Figure 2. 4. 13 Light-trap catch of Macrolepidoptera sp. complex in connection with the night sky polarization originated by the Moon (Early and late-summer aspects)

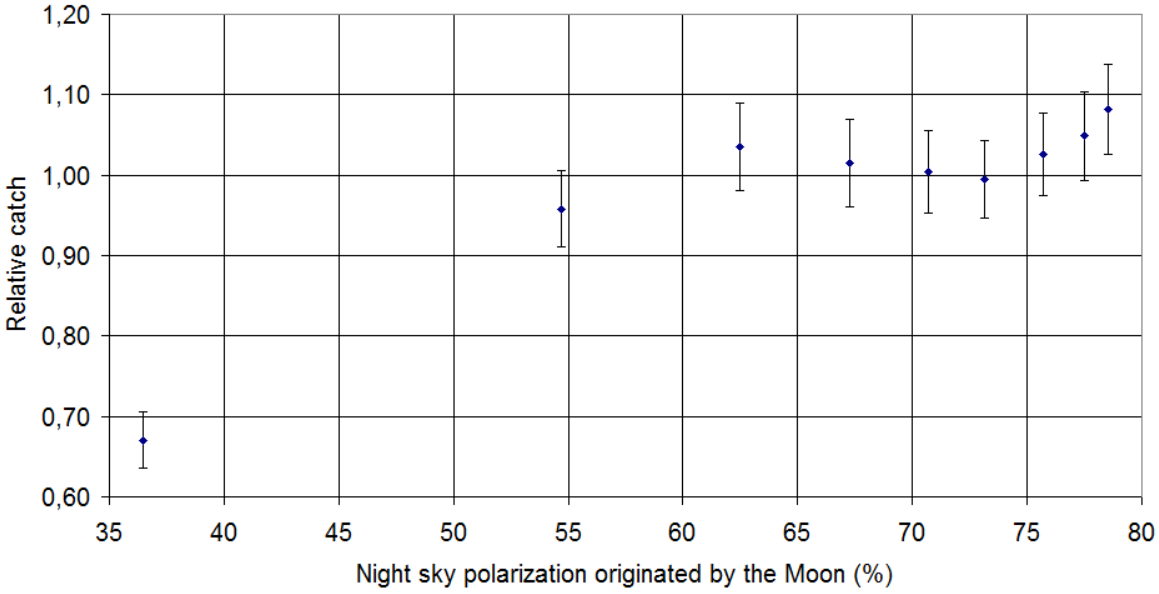


Figure 2. 4. 14 Light-trap catch of Macrolepidoptera sp. complex in connection with the gravitational potential of the Sun (Early and late-summer aspects)

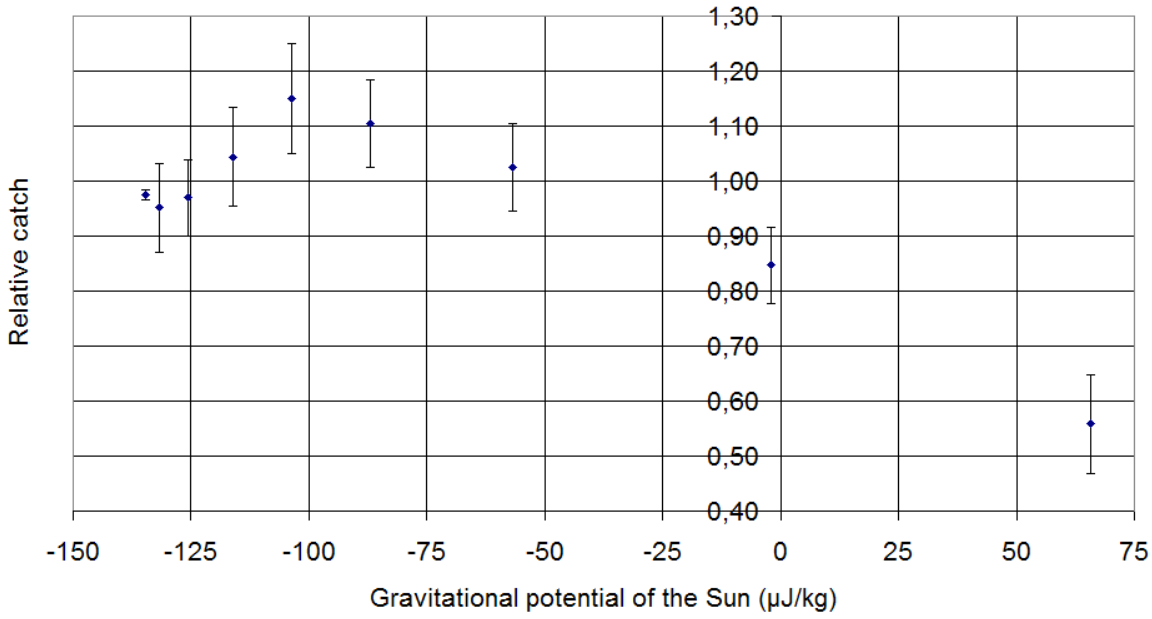


Figure 2. 4 15 Light-trap catch of Macrolepidoptera sp. complex in connection with the gravitational potential of the Moon (Early and late-summer aspects)

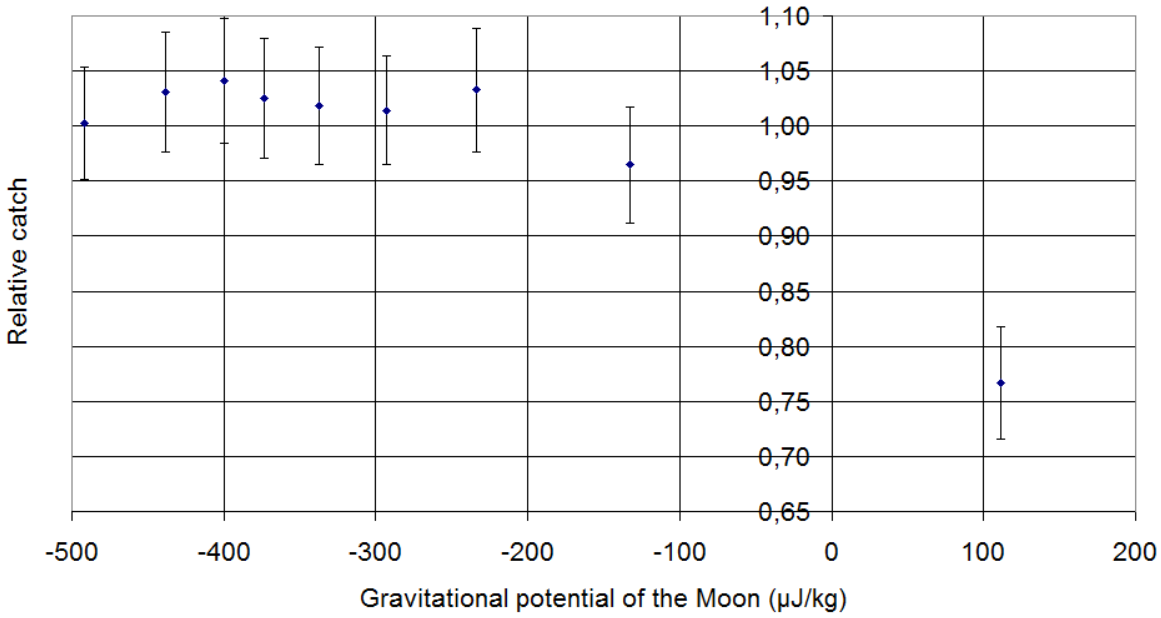


Figure 2. 4. 16 Light-trap catch of Macrolepidoptera sp. complex in connection with the gravitational potential of the Sun+Moon (Early and late-summer aspects)

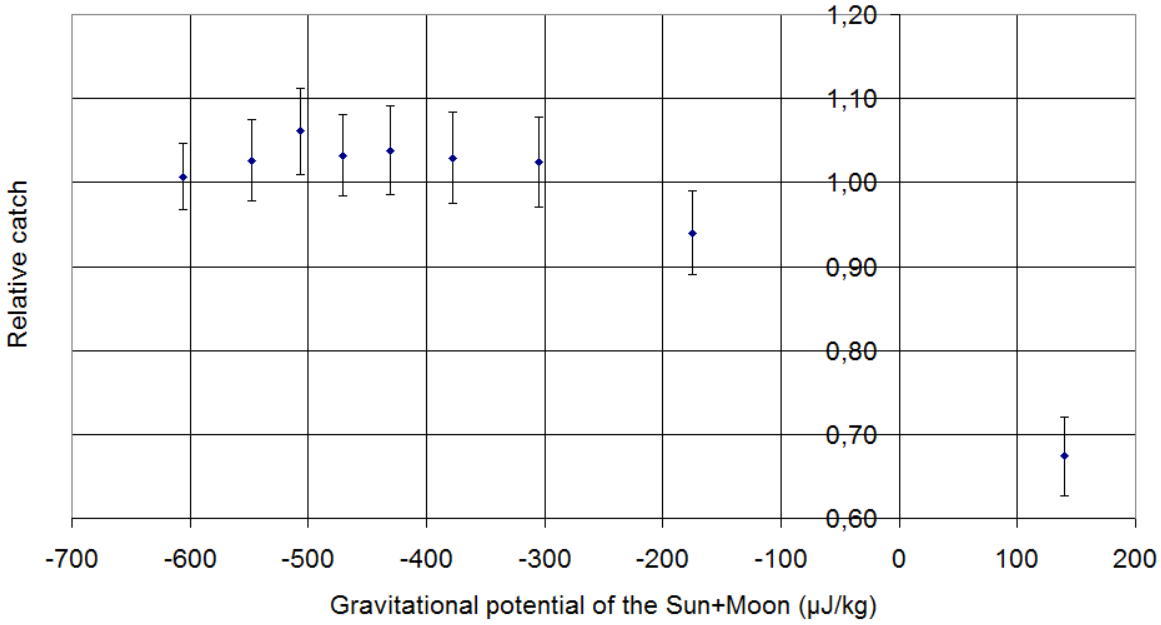


Figure 2. 4. 17 Light-trap catch of Macrolepidoptera sp. complex in connection with the altitude of Sun's Arago point (Early and late-summer aspects)

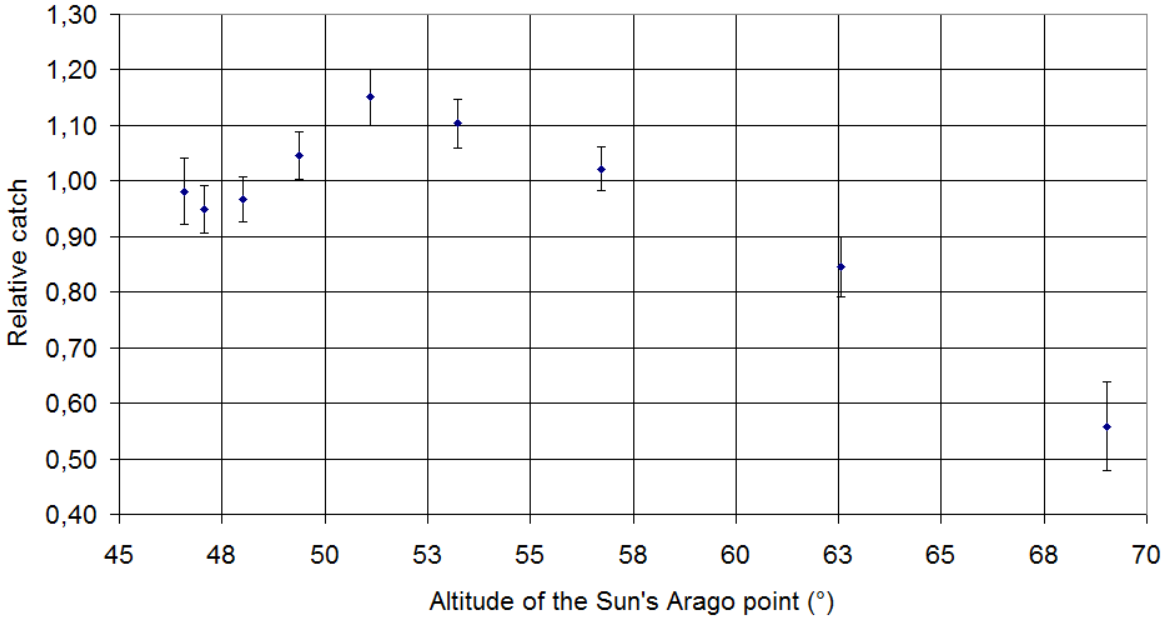


Figure 2. 4. 18 Light-trap catch of Macrolepidoptera sp. complex in connection with the altitude of Moon's Babinet point (Early and late-summer aspects)

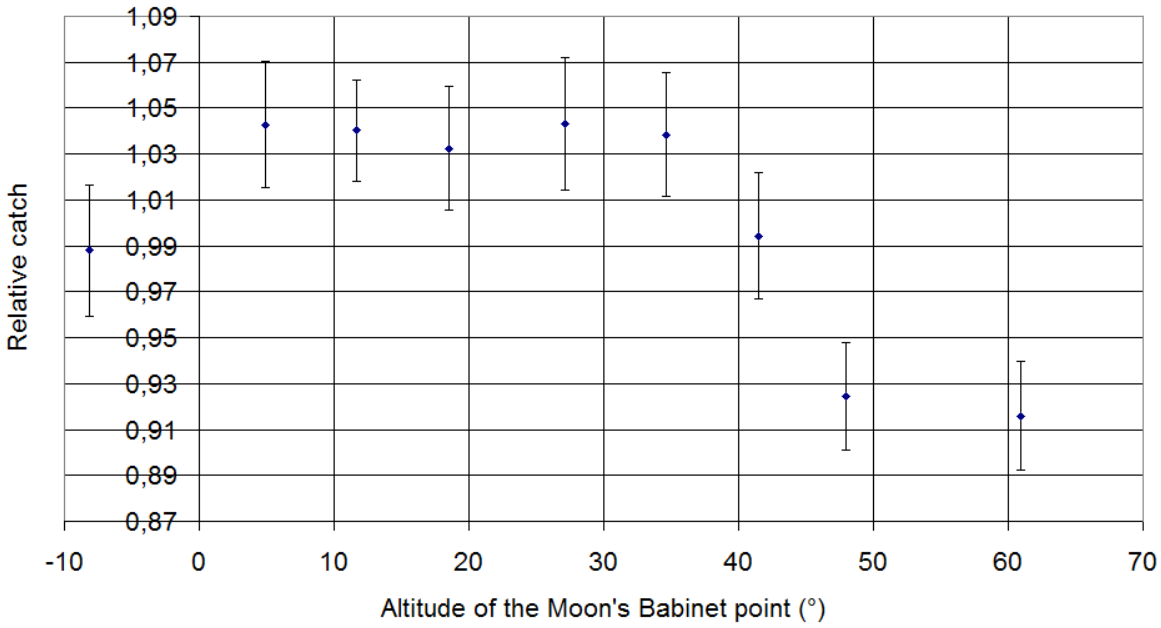


Figure 2. 4. 19 Light-trap catch of Macrolepidoptera sp. complex in connection with the phase angle of the Moon (Early and late-summer aspects)

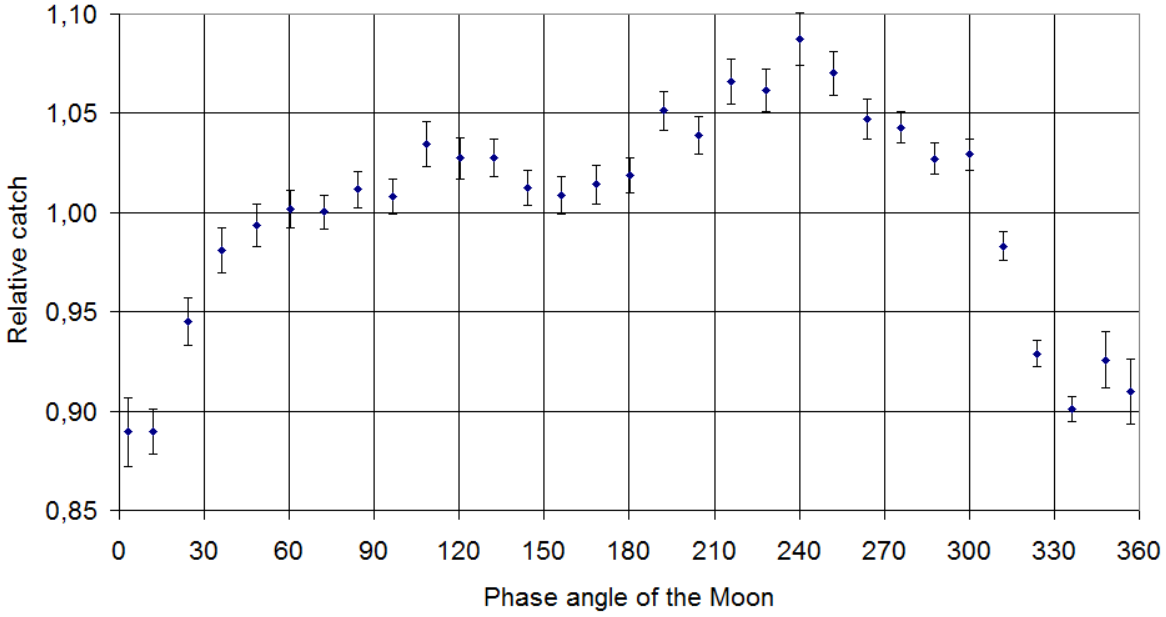


Figure 2. 4. 20 Light-trap catch of Macrolepidoptera sp. complex in connection with the apparent magnitude of the Moon (Early and late-summer aspects)

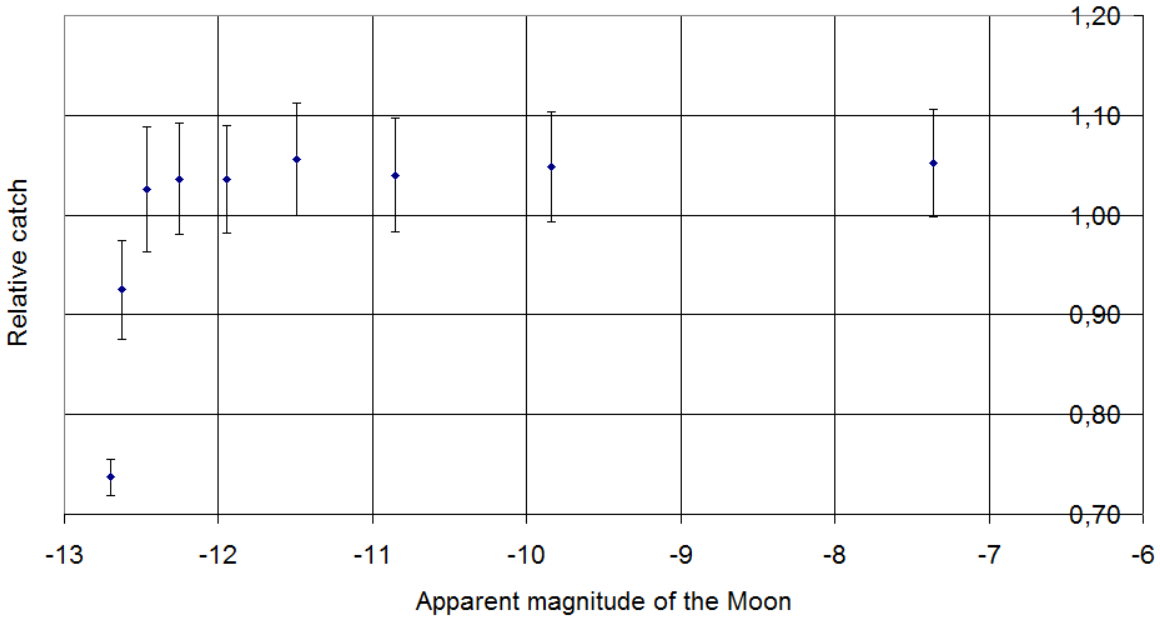


Figure 2. 4. 21 Light-trap catch of Macrolepidoptera sp. complex in connection with the illuminated fraction of the Moon (Early and late-summer aspects)

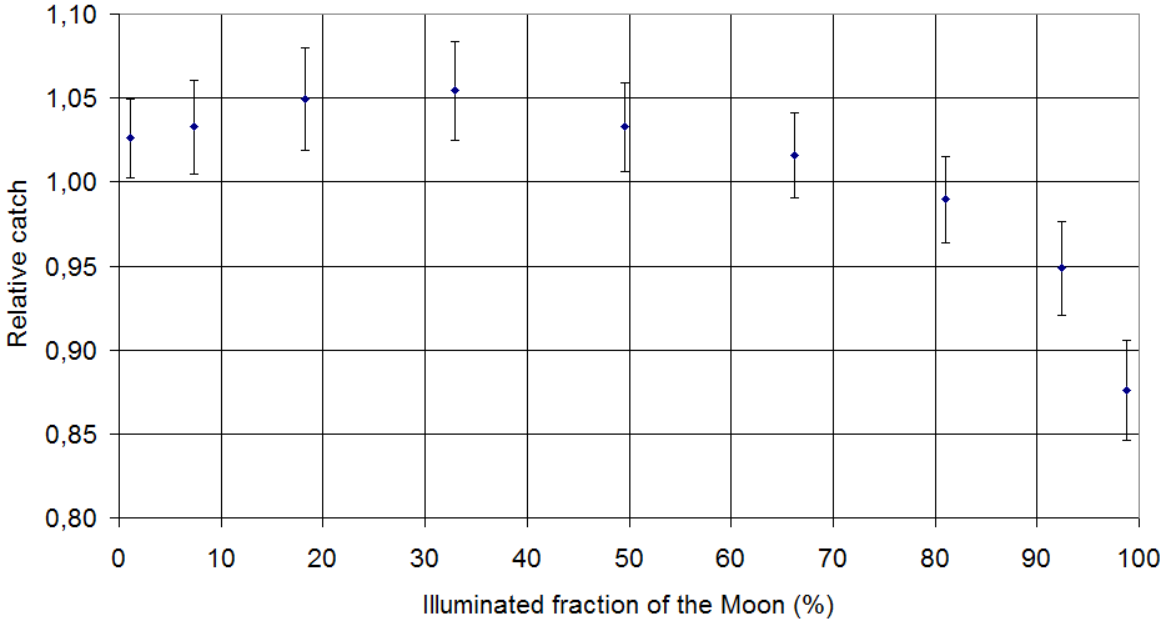
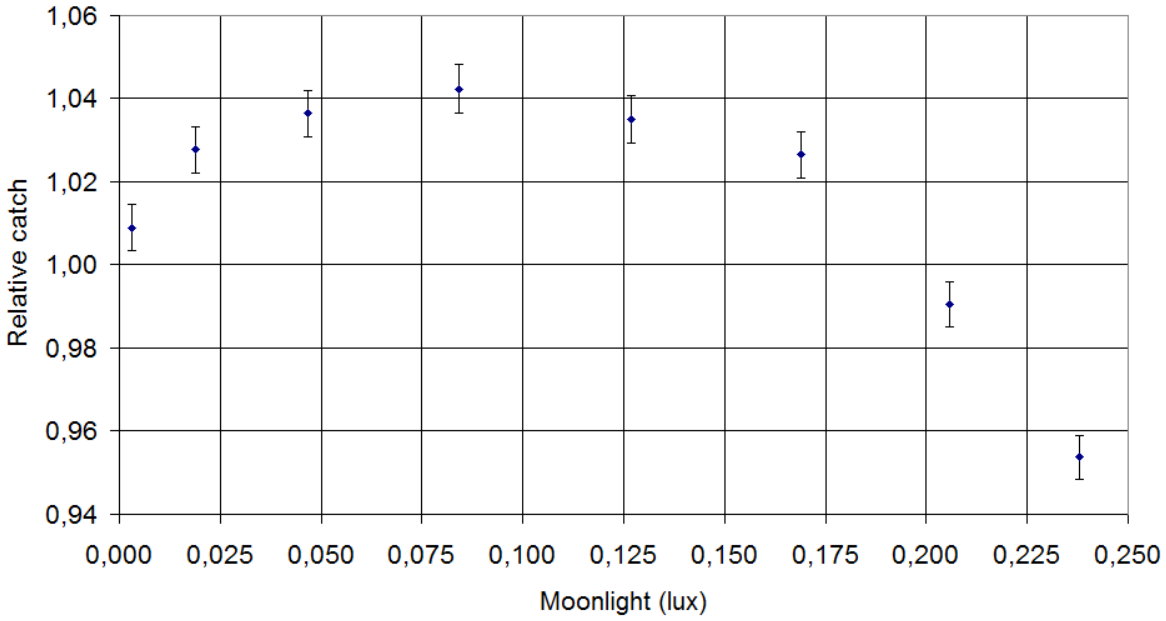


Figure 2. 4. 22 Light-trap catch of Macrolepidoptera sp. complex in connection with the moonlight (Early and late-summer aspects)



Our results show that the influence of the Sun's and Moon's characteristics on the catch of Microlepidoptera and Macrolepidoptera species is almost the same. There is only a significant difference between the lunar phases, as catch of Microlepidoptera species are most successful near New Moon, while Macrolepidoptera species are most successful in the last quarter. The reason for this should be investigated later. Light-trap catch of Lepidoptera species, trapped in Central Europe, is successful at higher values of celestial polarization, than in Australia and the two USA states. The reason is probably due to the different geographical conditions.

See also Chapter 1 Conclusion

Once again, it has been proven that if we are working on high-mass data from many species, we can aggregate their collection data. It is not advisable to do the same if we have data for only a few species.

See also Chapter 1 Conclusion.

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CHAPTER 3
(Central Europe, Hungary)

Light-trap Catch of the Coleoptera Species in Connection with the Sun's and Moon's Characteristics (Jermy-type Light-traps)

Puskás J., Kiss M., Nowinszky L., Bürgés Gy., Barta A.

3. 1 Introduction

Researchers worldwide collect many beetle (Coleoptera) species with light-traps for various research purposes. We cannot comment on these works in detail in this study, but some foreign and Hungarian research papers are quoted. Edwards (1961) and Hosking (1979) in New Zealand, Hanna (1964) in Egypt collected beetles using light-rap. Using a 15W fluorescent UV light trap in South Carolina, USA, Day and Reid (1969) compared the catch results of the Southern Potato Wireworm (*Conoderus falli* Lane, Coleoptera: Elateridae) in periods when the Moon was not above the horizon. Karpova & Matalin (1991), Matalin (1994, 1996, 1997, 1998) deal with Carabidae. Nabli et al. (1999) found the moon phases did not significantly affect light trap catches of the beneficial ladybird beetles (Coleoptera: Coccinellidae). Working with Pilani-type light traps equipped with 100W bulbs in India, Banerjee et al. (1981) collected specimen of the carabid beetle *Clivina helferi* Putzeys during 12 lunations. The number of specimen caught at a New Moon was more than 3 times the amount caught at a Full Moon. They explain the results by reduced flying activity.
Mészáros et al. (1976) report that they collected 93 beetle (Coleoptera) species with a new type light-trap in 1971 in Macedonia (geographical coordinates: 41°20'47" N and 21°33'16" E). Kádár & Lővei (1987), Kádár & Szél (1989) and Kádár & Szentkirályi (1997) also collected Carabidae species in Hungary with light-trap. Tóth (1973) investigated the frequency of beetle (Coleoptera) species from the collection data of the National Forestry Light-trap Network. Vig (2003): Review posted the historical background and perspectives of leaf beetle (Chrysomelidae) fauna of the Carpathian Basin.
Dacke et al. (2003) notifies that many animals use the solar polarization pattern of the sky for their orientation, but the *Scarabeus zambesianus* Péringuey, 1901 is the first insect, who is able to use for this purpose in the moonlight.
Garcia-López et al. (2010) found the differences of flight activity of scarab beetle species in Costa-Rica. They are more active in the first five hours of the night than in the last five hours. The ultraviolet lamp was more effective than the mercury-vapour and white lamps. The best period of the night to carry out the sampling also depends on the taxonomic group because it is influenced by the flying behaviour of the species and must be determined in each case.
Cave (2001) reports that the Chrysina species (Coleoptera: Scarabeaidae) collected with mercury vapour lamps in the area of the Cusuco National Park (Honduras) flew to light in masses, almost covering the stars. The wings of the beetles were marked by tiny holes of the size of a needle point to indicate the date and place of collecting. The beetles marked were seen again on some nights, but entirely new groups were also observed. The beetles released passed into the hand that freed them practically every time before taking to the air.
Bhandari et al. (2017) found that among the insect orders, Coleopterans were mostly trapped in black light trap followed by Lepidopteron and Hemipterans in Nepal.

Khalaf et al. (2017) demonstrated the impact of moon phases on the number of *Oryctes* spp. adults caught by light-trap and the existence of an inverse relation between moon light and flight activity of adults.
According to Dacke et al. (2003) many animals are able to use the solar polarization pattern of the sky for their orientation, but the *Scarabeus zambesianus* Péringuey, 1901 is the first insect, who is able to use for this purpose in the moonlight million fold less, than the brightness of the solar polarization.
These important new findings are confirmed in subsequent studies. They show the relative role of the moon in orientation. They conclude that the moon is not a primary tool for orientation. The polarization pattern around the moon is a more reliable cue for orientation (Dacke et al., (2014). Dacke et al. (2013) and Dacke (2014) found that the Bogong Moths (*Agrotis infusa* Boisduval, 1832) could use several types of celestial compasses that run along straight tracks. These are the Sun, the Moon, the polarized light pattern, and even the Milky Way, which is far more prominent than a single star. It is extremely important to state of Dacke et al. (2011) that celestial orientation is as precise during First and Last Quarters of Moon as it is during Full Moon. Moreover, this orientation precision is equal to that measured for diurnal species that orient under the 100 million times brighter polarization pattern formed around the Sun. This indicates that, in nocturnal species, the sensitivity of the optical polarization compass can be greatly increased without any loss of precision.

We quote Hungarian authors for the species studied in our present study.
Tóth (1975) found that *Serica brunnea* L. is the prevalent species everywhere in the Carpathian Basin, but the damage made by it is significant only in some regions.
Homonnay (1977) and Járfás & Tóth (1977) dealt with the light trapping of the *Melolontha* species. Sifter (1971), Bürgés (1972 & 1982), Bürgés & Gál (1980, 1981a, 1981b & 1982), Bürgés et al., (1976) discussed the factors influencing Sifter (1971), Bürgés (1972, 1982), Bürgés et al., 1976, Eke et al. (1977)) discussed the influencing factors of light trapping of the Chestnut Beetle (*Curculio elephas* Gyll.) and its forecasting. Szentkirályi et al. (2005) used horizontally polarized and unpolarized light traps for collecting ground beetles (Carabidae).
Nowinszky & Puskás (2011) stated that the flying activity of the Common Cockchafer (*Melolontha melolontha* L.) increases when the ozone concentration of air is high. Ladányi et al. (2012) light trapped the April Beetle (*Rhizotrogus aequinoctialis* Herbst) at 21 sites between 2005 and 2011. It shows a definite increase if the ozone content of the air exceeds 80 $\mu g/m^3$.
In an earlier study (Puskás et al., 2015) we examined the beginning of swarming of 93 Coleoptera species of a Becse-type light-trap in Prilep (Macedonia) from 1971 in connection with the lunar phases. The beginning of swarming of Coleoptera species were in connection with lunar phases. The most frequent case is the connection with Last Quarter of Moon.
This beetle is a serious wood-boring pest that is a major threat to the phytosanitary condition of forests and orchards. Puskás and Nowinszky (2018) found that the light-trap catch of the *Hymenalia rufipes* is positively correlated with retention time of the Moon above horizon.

In the literature however we have not found any studies that deal with our present topic.

3. 2 Material

The light-trap data of examined species except the *Curculio elephas* Gyllenhaal were taken from the data basis of Hungarian Light-trap Network. The catching data of *Curculio elephas* Gyllenhaal are Bürgés's own trapping results.

The catching data of caught species can be seen in Table 3. 2. 1.

Table 3. 2. 1 The name of families, species, years, number of individuals and nights

Families and Species	Years	Number of Traps	Moths	Data
Scarabaeidae				
Brown Chafer *Serica brunnea* Linnaeus, 1758	1969-1974	6	7,700	499
April Beetle *Rhizotrogus aequinoctialis* Herbst, 1790	2004-2011	2	1,924	272
Rhizotrogus aestivus Olivier, 1789	1967-1974	2	1,953	160
Summer Chafer *Amphimallon solstitialis* Linnaeus, 1758	1987-2000	4	1,282	340
Common Chockchafer *Melolontha melolontha* Linnaeus, 1758	1966-1975	45	11,133	1,024
Curculionidae				
Chestnut Beetle *Curculio elephas* Gyllenhaal, 1836	1973-1974, 1977, 1979	3	3,093	150

3. 3 Methods

We computed the Sun's and Moon's features for 11 p.m. (UT) for the active species all night, and 6 p.m. (UT) for active species only in the evening.

The methods are described in detail in Chapter 1. 1. 3.

3. 4 Results and Discussion

Our results can be seen in Figures 3. 4. 1 – 3. 4. 11. The illustrated Figures show that the catching results of the Coleoptera species complex are significantly in connection with the Sun's and Moon's features.

The effect of the polarized moonlight is not discussed in this chapter because earlier (Nowinszky et al., 1979). We have already reported that the Brown Chafer (*Serica brunnea* L.) and the Common Cockchafer (*Melolontha melolontha* L.) are light trapped successfully in the both First Quarter and Last Quarter of the (Nowinszky et al., 1979).

It is striking that the light trapping of all six species is more strongly modified by the Sun's gravitational potential and the night sky polarization than of the Moon.

The two peaks are due to the fact that *Melolontha melolontha* L. is caught between April and May, when the polarization of the sun is measured between 55 and 65 degrees. The other species studied will fly to later months and the polarization will now be higher, near 68 degrees. The higher polarization issues a higher catches of the summer flying species than the lower polarization of the spring flying species.

This fact can be experienced despite that the Moon's gravity is much stronger than the Sun's one, and the Moon's sky polarization is higher except the twilight and early hours. However, the Moon's movement is one of the most complicated issues of celestial mechanics, its presence or absence varies according to complex periods. Therefore, the Sun represents more information than the Moon for the insects.

Figure 3. 4. 1 Light-trap catch of the Coleoptera sp. complex in connection with the night sky polarization originated by the Sun

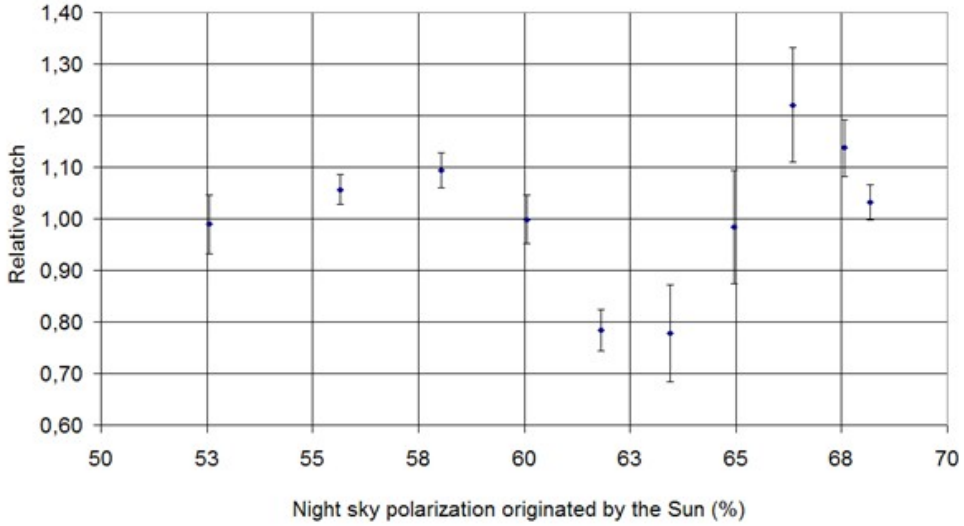


Figure 3. 4. 2 Light-trap catch of the Coleoptera sp. complex in connection with the night sky polarization originated by the Moon

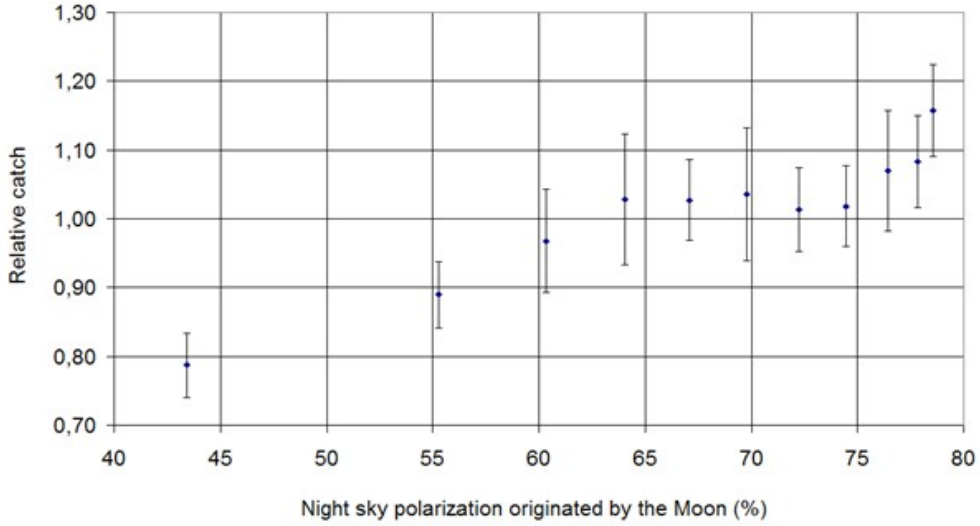


Figure 3. 4. 3 Light-trap catch of the Coleoptera sp. complex in connection with the gravitational potential of the Sun

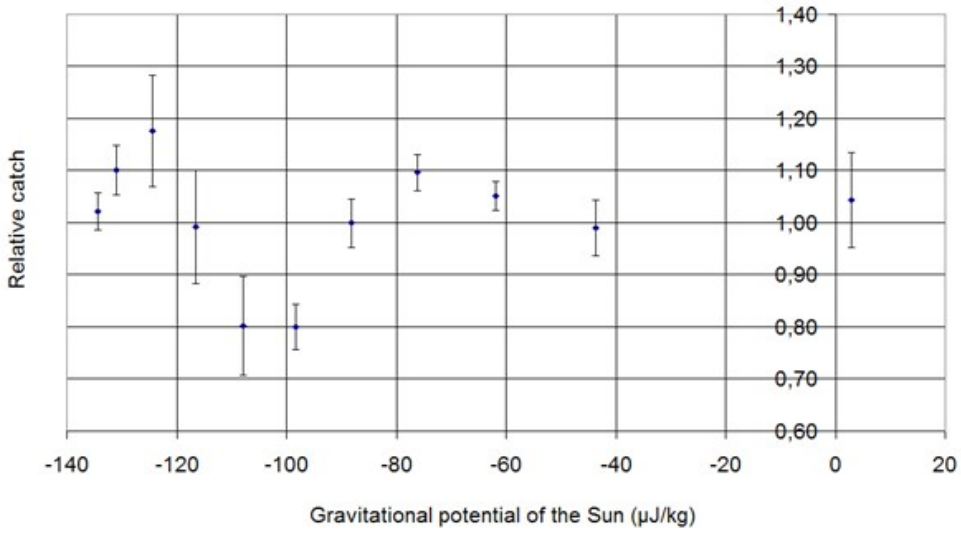


Figure 3. 4. 4 Light-trap catch of the Coleoptera sp. complex in connection with the gravitational potential of the Moon

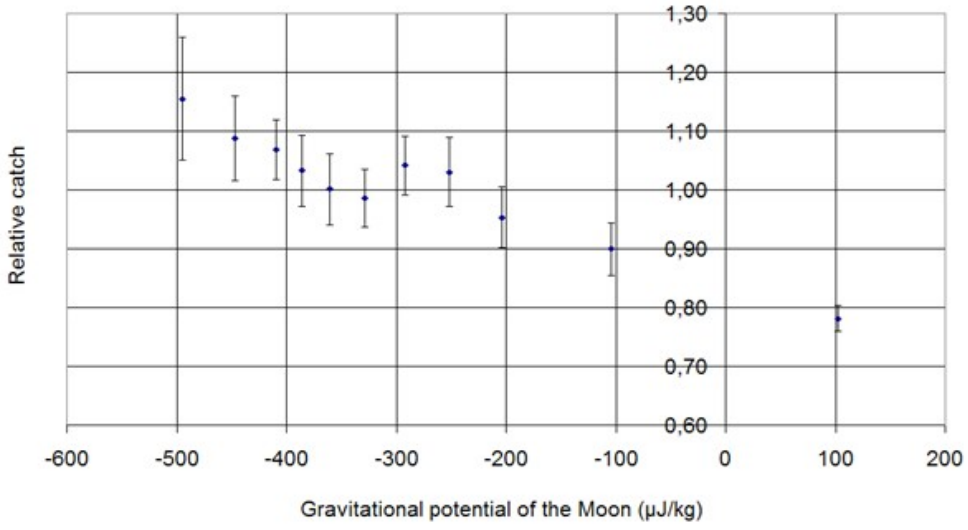


Figure 3. 4. 5 Light-trap catch of the Coleoptera sp. complex in connection with the gravitational potential of the Sun+Moon

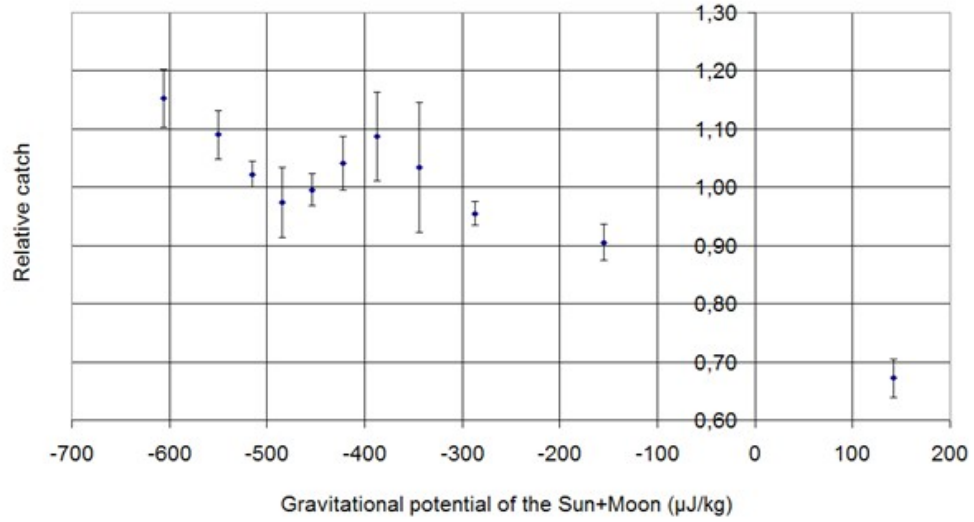


Figure 3. 4. 6 Light-trap catch of the Coleoptera sp. complex in connection with the altitude of the Sun's Arago point

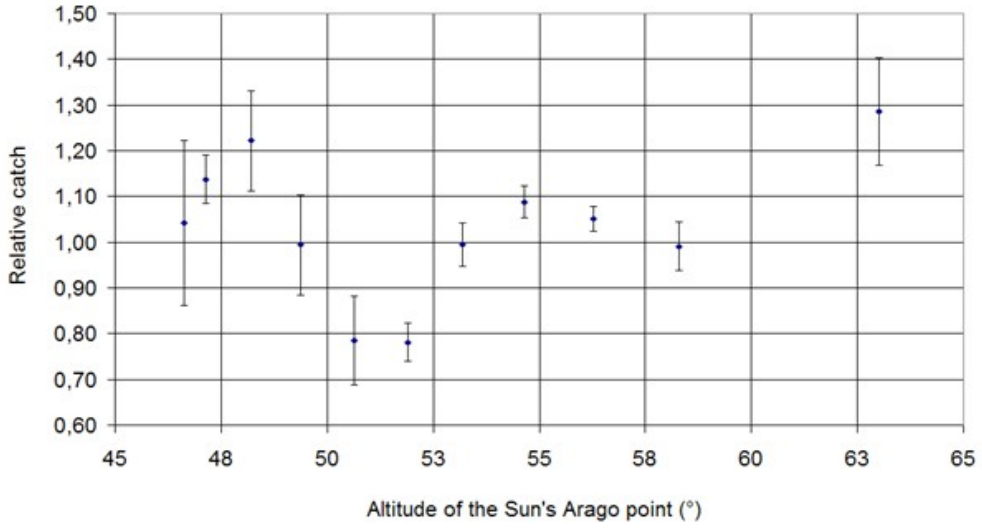


Figure 3. 4. 7 Light-trap catch of the Coleoptera sp. complex in connection with the altitude of the Moon's Babinet point

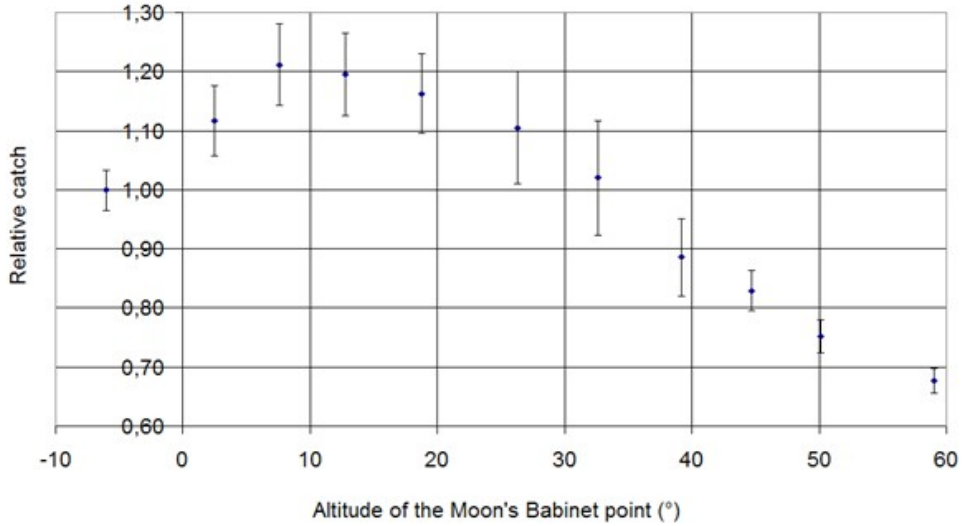


Figure 3. 4. 8 Light-trap catch of the Coleoptera sp. complex in connection with the phase angle groups of the Moon

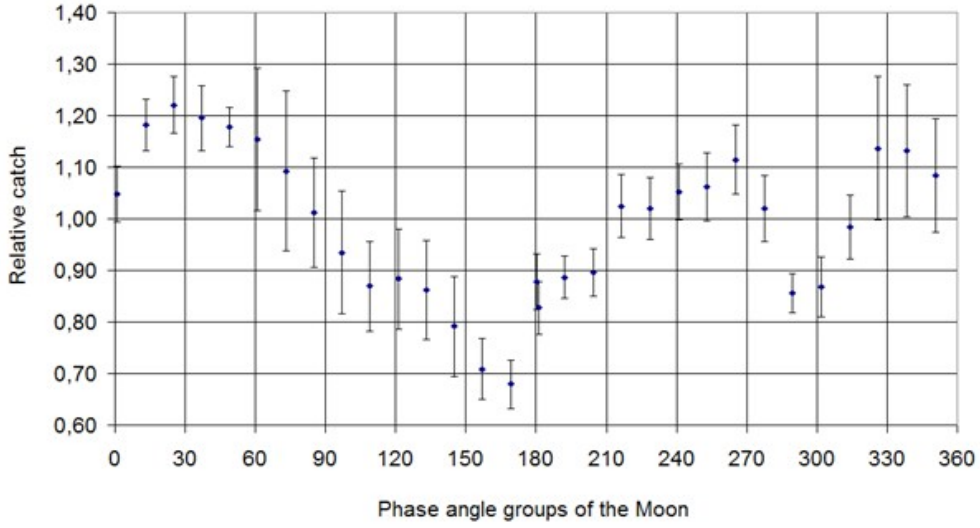


Figure 3. 4. 9 Light-trap catch of the Coleoptera sp. complex in connection with the apparent magnitude of the Moon

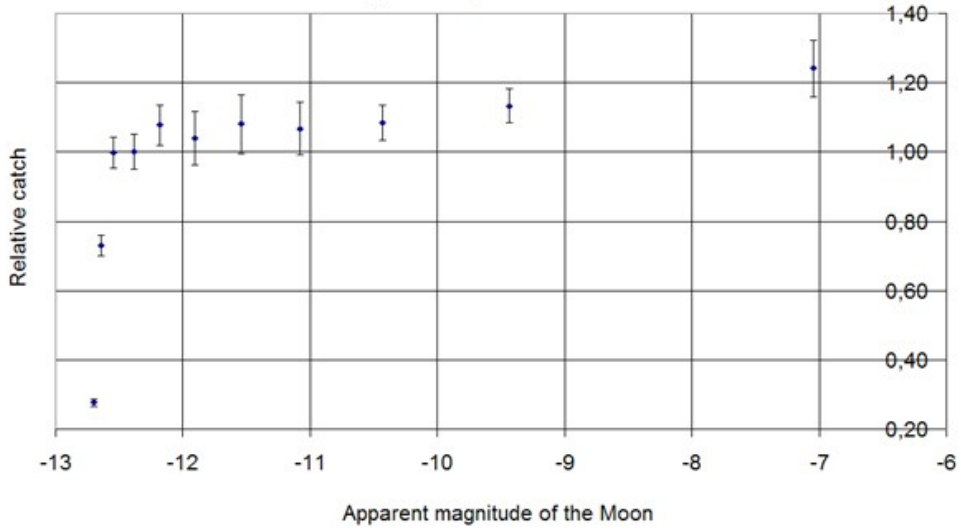


Figure 3. 4. 10 Light-trap catch of the Coleoptera sp. complex in connection with the illuminated fraction of the Moon

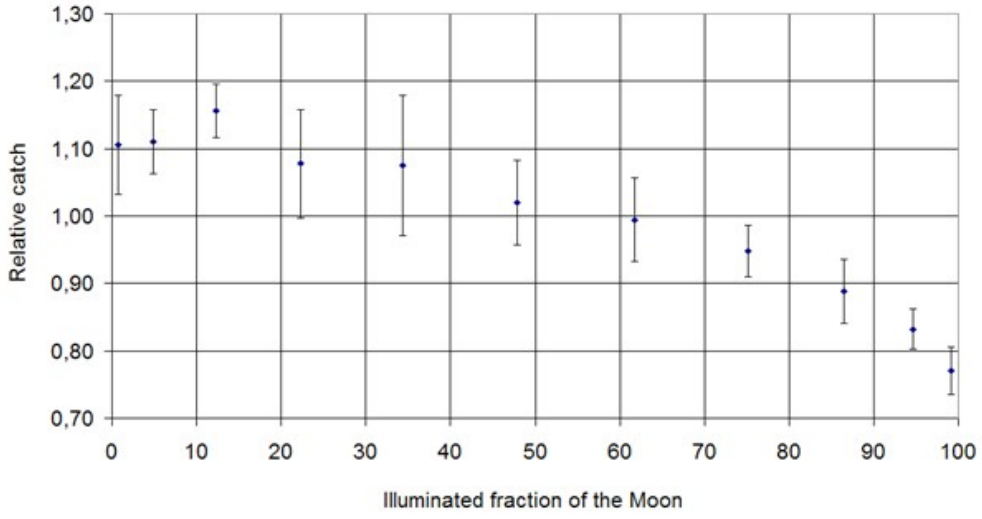
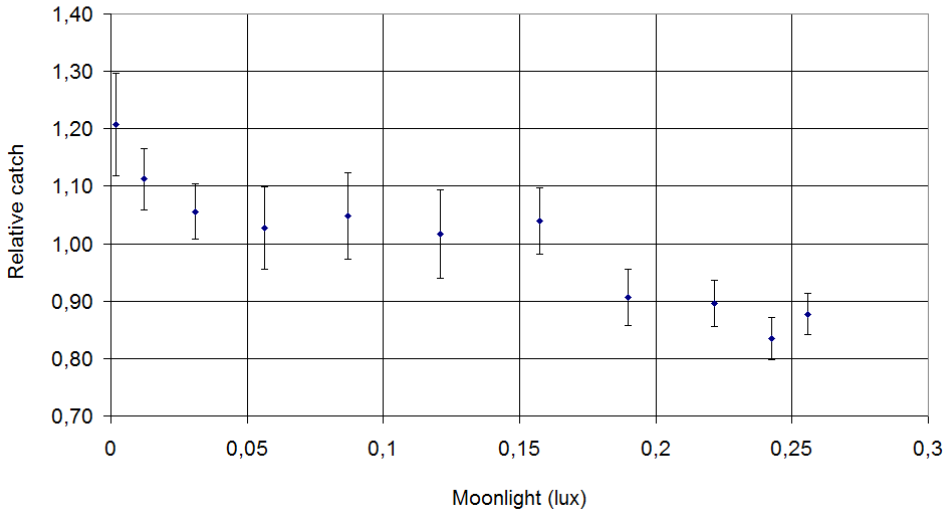


Figure 3. 4. 11 Light-trap catch of the Coleoptera sp. complex in connection with the moonlight



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CHAPTER 4

Light-trap Catch of the Trichoptera Species in Connection with the Sun's and Moon's Characteristics (Jermy-type Light-traps)

Kiss O., Kiss M., Puskás J., Nowinszky L., Barta A.

4. 1 Introduction

As confirmed by ancient observations and records ever since Aristotle nocturnal insects are attracted to artificial light (Kovács 1962). The researchers used the light trap at night editing the attraction of flying insects for artificial light sources.
The caddisflies (Trichoptera) in one of the most important group of aquatic insects, the seasonal activity is therefore essential to understanding the ecological investigations (Kiss, 2003).
The caddisflies species are mostly active at night and fly well in artificial light. Therefore, according to Kiss (2003) and Malicky (1980) the light trapping is one of the most suitable methods in knowledge of their swarming time and abundance. Use of light-trap is suitable in order to monitor the seasonal activity species tested by the distribution of flight time, the beginning and end, and the length of the peak of activity. The collection of results, however, many environmental factors change.
The caddisfly (Trichoptera) species fly en masse to the artificial light sources. Many studies can be found in the literature where researchers report their results of light-trap collections for various purposes. We cannot describe these works in detail, but we refer to some of the researchers whose works were important for our research: Crichton (1978), Malicky (1987), Waringer (1991), Ujvárosi (1999), Graf et al. (2008), Müller-Peddinghaus (2011), Rychla & Buczyńska (2013), Buczyńska et al. (2014, 2016), Nowinszky et al. (2016).
Kiss (1982-83, 1983, 1984, 2002, 2005, 2008, 2012, Kiss et al. 1995, 1999) caught lot of caddisfly species and individuals from the mountain streams and Danube and Tisza rivers.
The night sky polarization is particularly important for aquatic insects because they find their habitats on this basis. Many researchers dealt with the relationship between the polarization of the sky and the orientation of aquatic insects (Horváth & Varjú, 2004), Hegedűs et al. (2007), Gál et al. (2001), Csabai et al. (2006), but they did not work on light-trap catch data.
The degree of polarization also depends on the atmospheric conditions. However, the direction of polarization pattern is very robust, the typical 8-shaped pattern as well as the axis of symmetry is well recognizable.
Aquatic insects detect water by means of the horizontal polarization of light reflected from the water surface (Bernáth et al., 2004). These polarotactic insects can be attracted to surfaces reflecting horizontally polarized light, such as dry asphalt roads (Kriska et al. 1998), oil surfaces (Bernáth et al., 2001; Horváth et al. 1998; Horváth & Zeil, 1996), black plastic sheets (Bernáth et al., 2001) and car-bodies (Kriska et al. 2006), for example.
Farkas et al. (2010) suggest in both mayfly species (*Ephoron virgo* Olivier and *Caenis robusta* Eaton) unpolarized light induces positive phototaxis, horizontally polarized light elicits positive photo- and polarotaxis, horizontally polarized light is much more attractive than unpolarised light, and vertically polarized light is the least attractive if the stimulus intensities and spectra are the same.

Kriska et al. (2008) document here that every year in April and May, the caddis fly *Hydropsyche pellucidula* (Curtis 1834) emerges from the river Danube in Budapest (Hungary) and is attracted en masse to the vertical glass surfaces of buildings standing on the river bank Horváth et al. (2010) found the buildings with glass surfaces can reflect horizontally polarized light so strongly that they appear to aquatic insects such as Ephemeroptera and Trichoptera to be bodies of water. Insects that lay eggs in water are especially attracted to such structures because these insects use horizontal polarization of light off bodies of water to find egg-laying sites.
The influence of lunar phases has been found in several our studies on several species of Trichoptera (Nowinszky et al. 2010, 2012, 2014).
Recently, the influence of the night sky polarization and gravitational potential of the Sun and the Moon have also been found on four species of Trichoptera (Kiss et al. 2017).

4. 2 Material

Jermy-type light-traps were used to catch caddisflies. The light-trap consists of a 125 W mercury lamp and a saving lid with a diameter of 1 metre. There was a collecting funnel under the lamp. Its diameter was 40 cm and this collector drove into a container. We used clear chloroform as killing material. Our light-trap operated in all years and on all settlements between 1st April and 31st October on all nights.
The determination of the specimens was made by Otto Kiss. In this study we used the data from the most frequently captured 11 species.
The families, species, number of specimen and catching nights of examined caddisflies are shown in Table 1.

Table 4. 2. 1 Catching data of fluvial Trichoptera species

Families – Species	River Danube (Göd, 1999) Number of		River Tisza (Szolnok, 2000) Number of	
	Specimen	Nights	Specimen	Nights
Hydroptilidae				
Agraylea sexmaculata Curtis, 1834			1,725	127
Ecnomidae				
Ecnomus tenellus Rambur, 1842			2,193	103
Polycentropodidae				
Neureclipsis bimaculata Linnaeus, 1758	4,619	167	1,593	95
Hydropsychidae				
Hydropsyche contubernalis Mc Lachlan, 1865	21,467	191	12,302	179
Hydropsyche bulgaromanorum Malicky, 1977	16,832	172	22,500	94
Brachycentridae				
Brachycentrus subnubilus Curtis, 1834	4,004	129		
Lepidostomatidae				
Lepidostoma hirtum Fabricius, 1775	2,434	107		
Limnephilidae				
Limnephilus affinis Curtis, 1834			723	104
Halesus digitatus Schrank, 1781			1,238	105
Leptoceridae				
Athripsodes albifrons Linnaeus, 1758			814	115
Ceraclea dissimilis Stephens, 1836			929	100
Setodes punctatus Fabricius, 1759	4,705	145	1,848	87

The collection site, they geographical coordinates and the year of collection are as follow:

Duna River at Göd (47°41′70″N; 19°08′23″E) in year 1999.
Tisza River at Szolnok (47°10′76″N; 20°11′25″E) in year 2000.

4. 3 Methods

The Methods are described in Chapter 1. 3.

Our results are depicted coming from the features of celestial bodies and the catching data. Figures also show thee confidence intervals.

4. 4 Results and Discussion

It is striking that the light trapping of all four species is more strongly modified by the Sun's gravitational potential and the night sky polarization than of the Moon. This occurs despite the Moon's gravity being much stronger than the Sun's gravity, and the Moon's sky polarization being higher except in the twilight and early hours. However, the Moon's movement is one of the most complicated issues of celestial mechanics, its presence or absence varies according to complex periods. Therefore, the Sun represents more information than the Moon for the insects. The Discussion can be seen also in Chapter 1. 4.

The results can be seen in Figures 4. 4. 1 – 4. 4. 10.

Figure 4. 4. 1 Light-trap catch of fluvial Trichoptera sp. complex in connection with the night sky polarization originated by the Sun

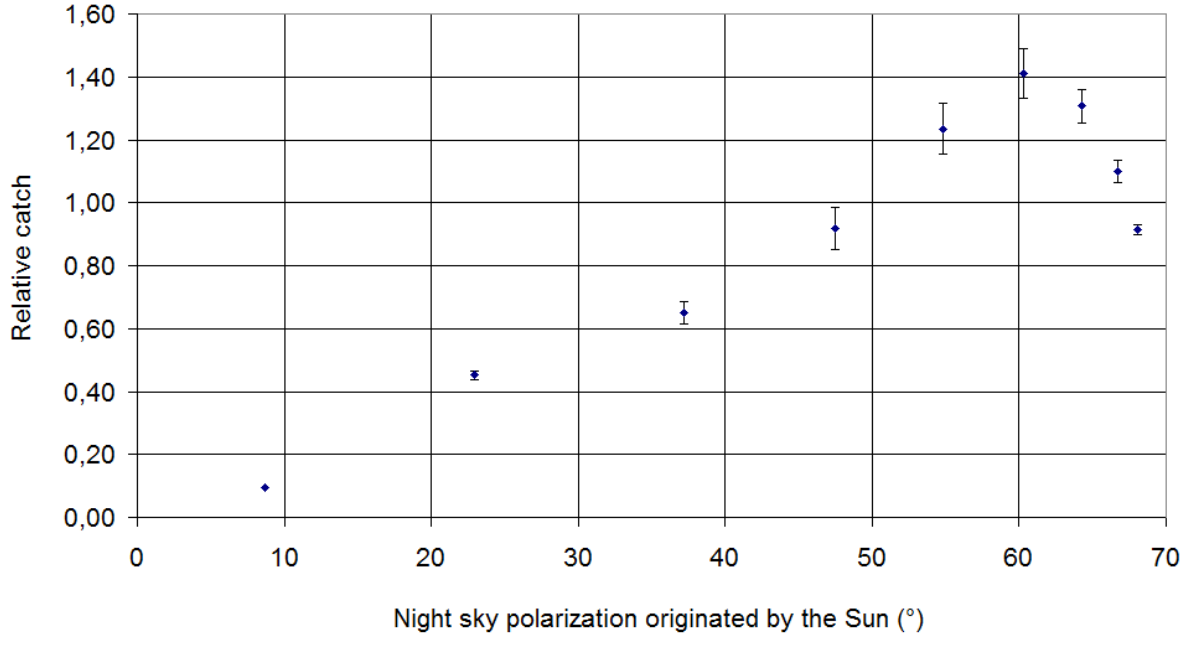


Figure 4. 4. 2 Light-trap catch of fluvial Trichopptera spec. complex in connection with the night sky polarization originated by the Moon

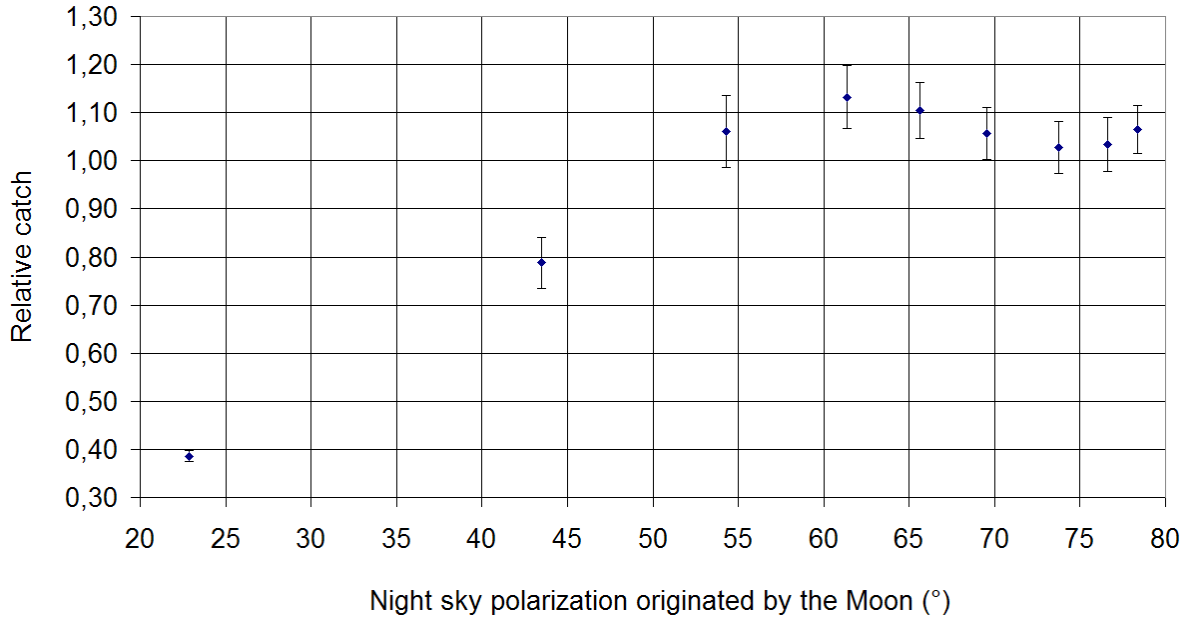


Figure 4. 4. 3 Light-trap catch of fluvial Trichoptera sp. complex in connection with the gravitational potential of the Sun

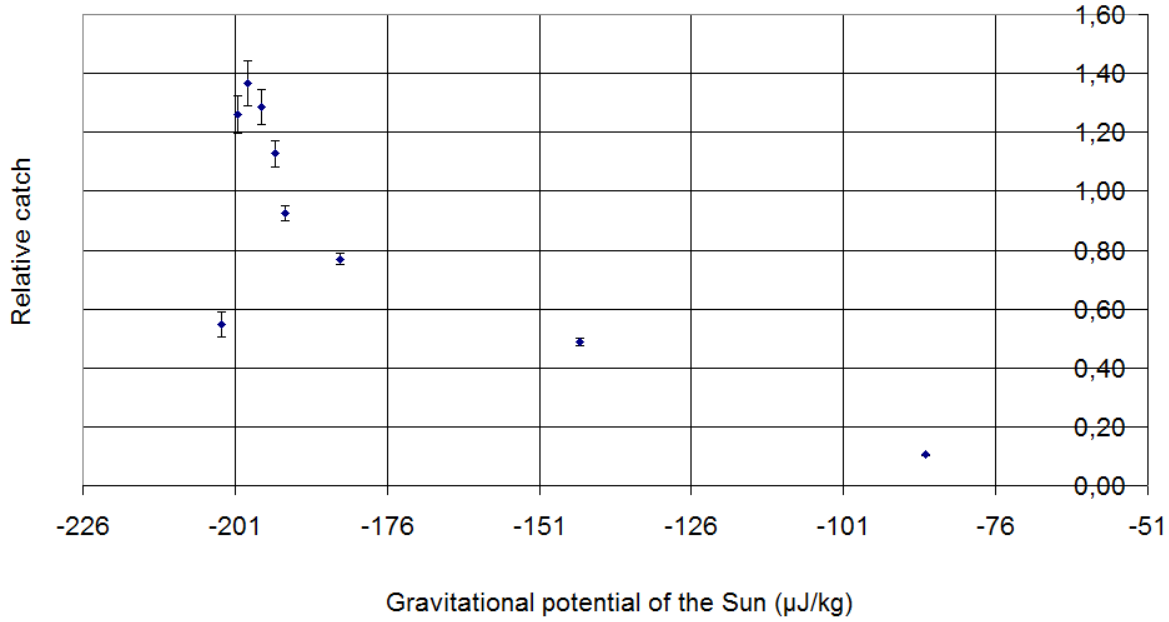


Figure 4. 4. 4 Light-trap catch of fluvial Trichoptera sp. complex in connection with the gravitational potential of the Moon

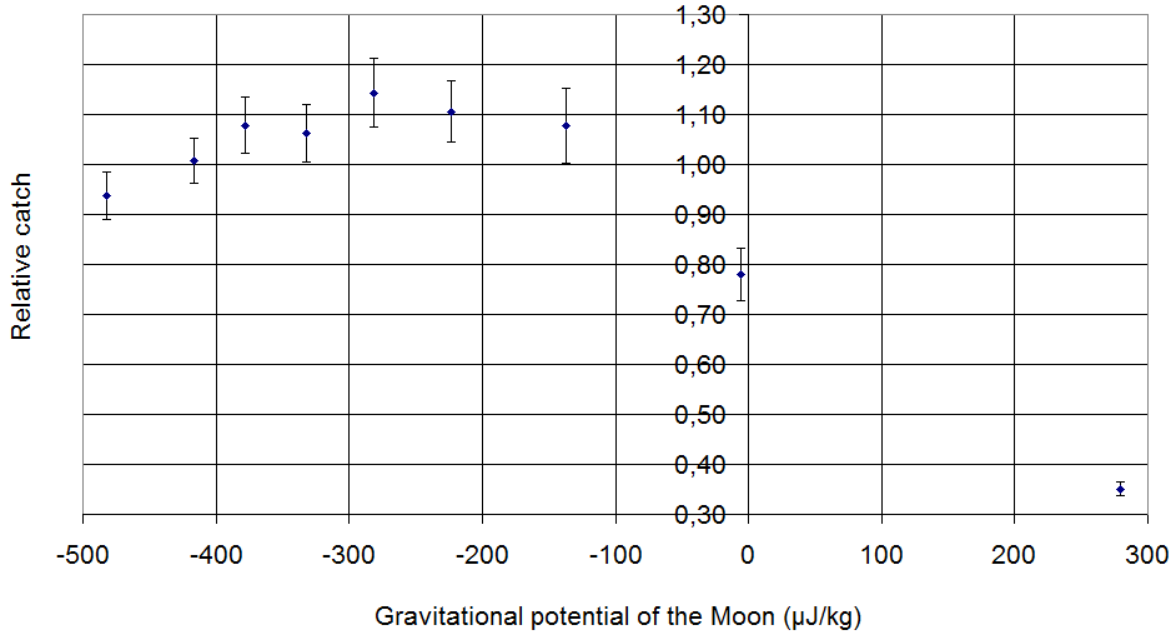


Figure 4. 4. 5 Light-trap catch of fluvial Trichoptera sp. complex in connection with the gravitational potential of the Sun+Moon

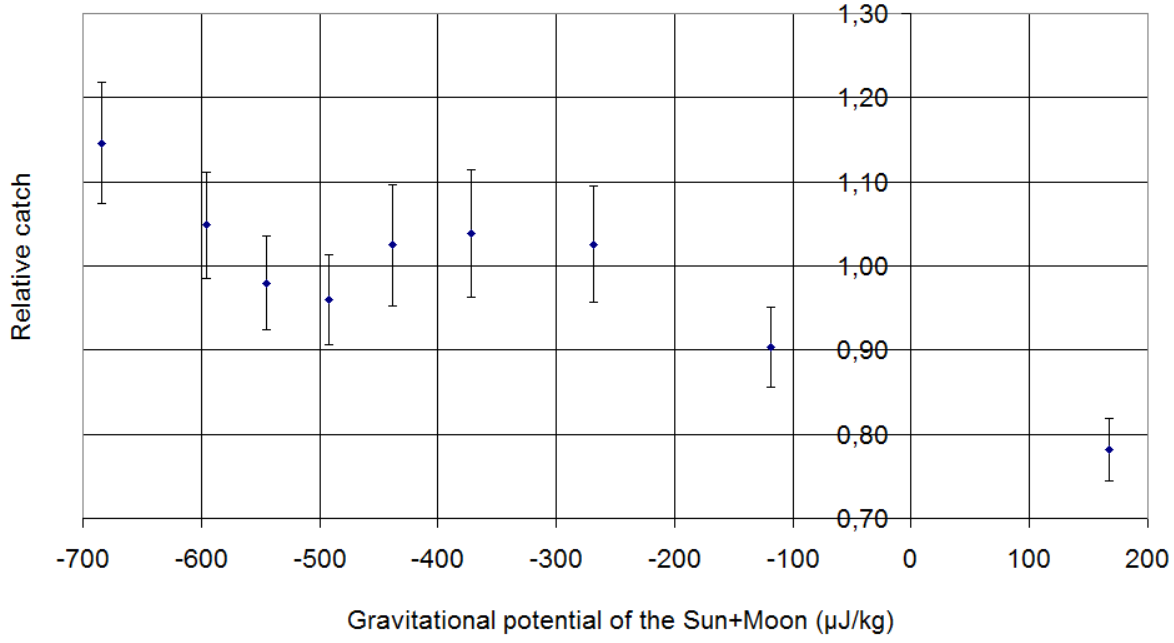


Figure 4. 4. 6 Light-trap catch of fluvial Trichoptera sp. complex in connection with altitude of Sun's Arago point

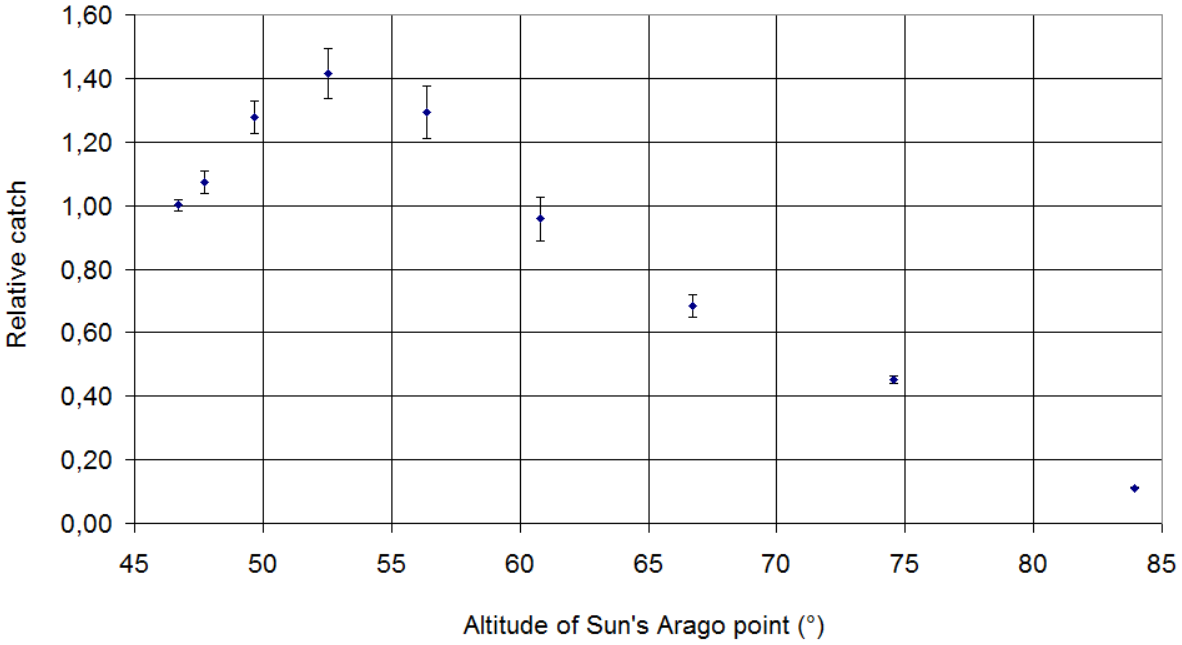


Figure 4. 4. 7 Light-trap catch of fluvial Tichoptera sp. complex in connection with altitude of Moon's Babinet point

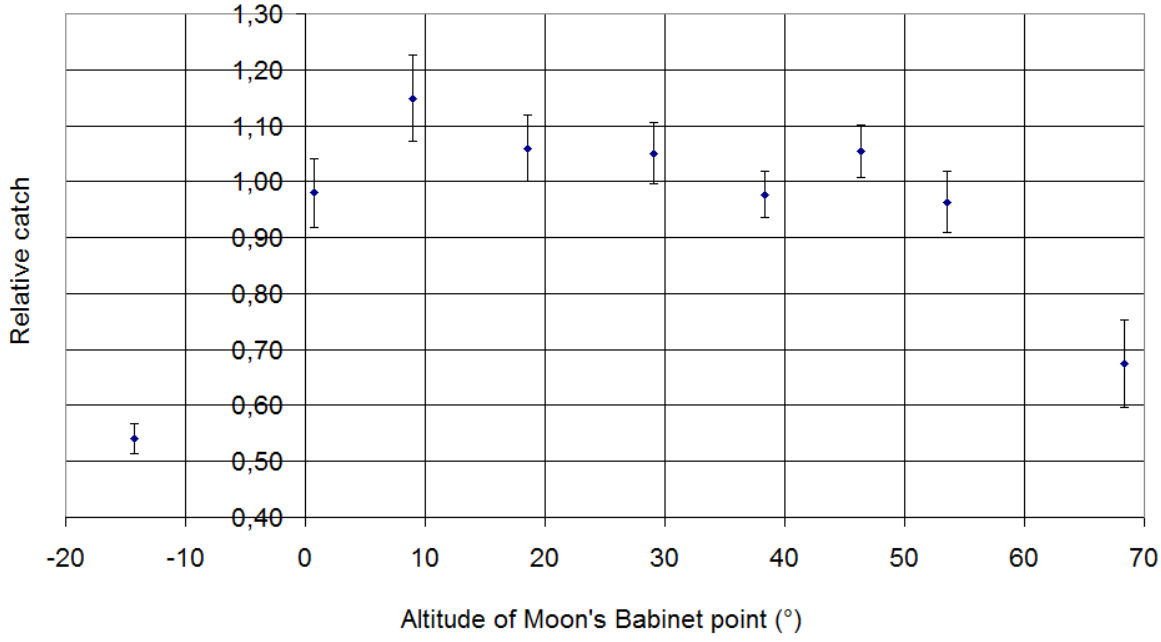


Figure 4. 4. 8 Light-trap catch of fluvial Trichoptera sp. complex in connection with apparent magnitude of the Moon

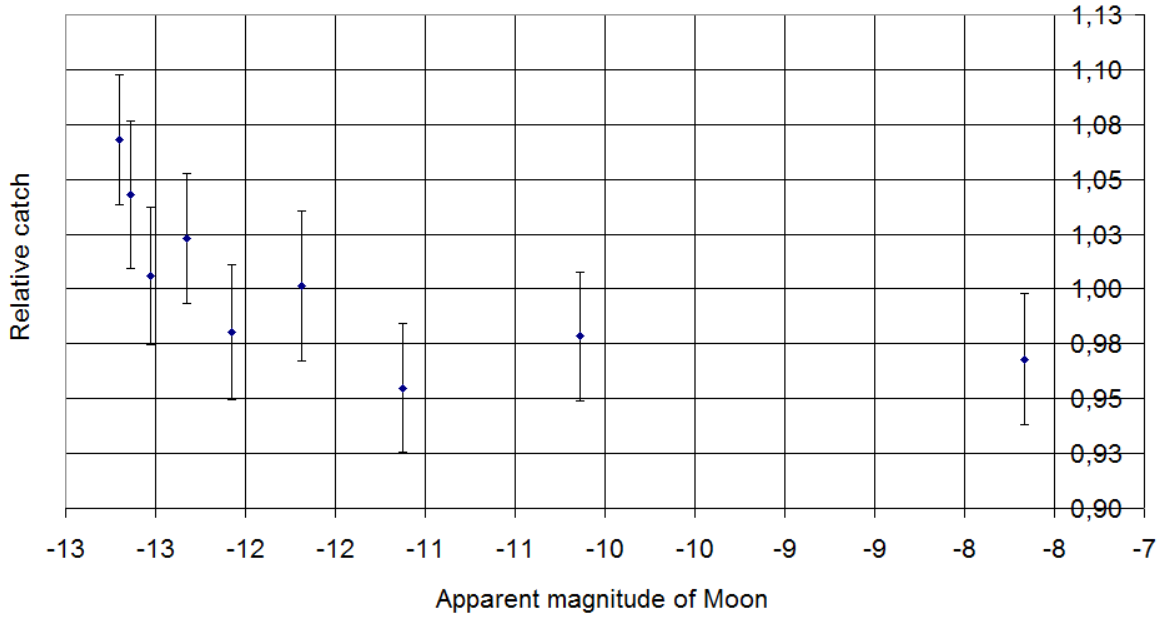


Figure 4. 4. 9 Light-trap catch of fluvial Trichoptera sp. complex in connection with the illuminated fraction of the Moon

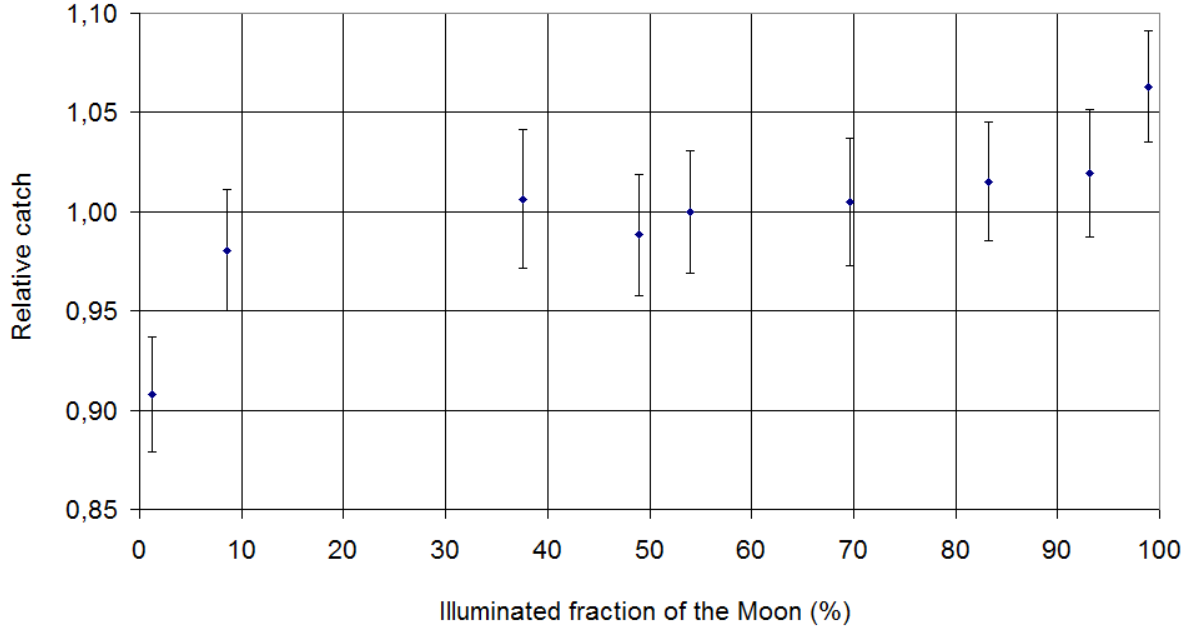
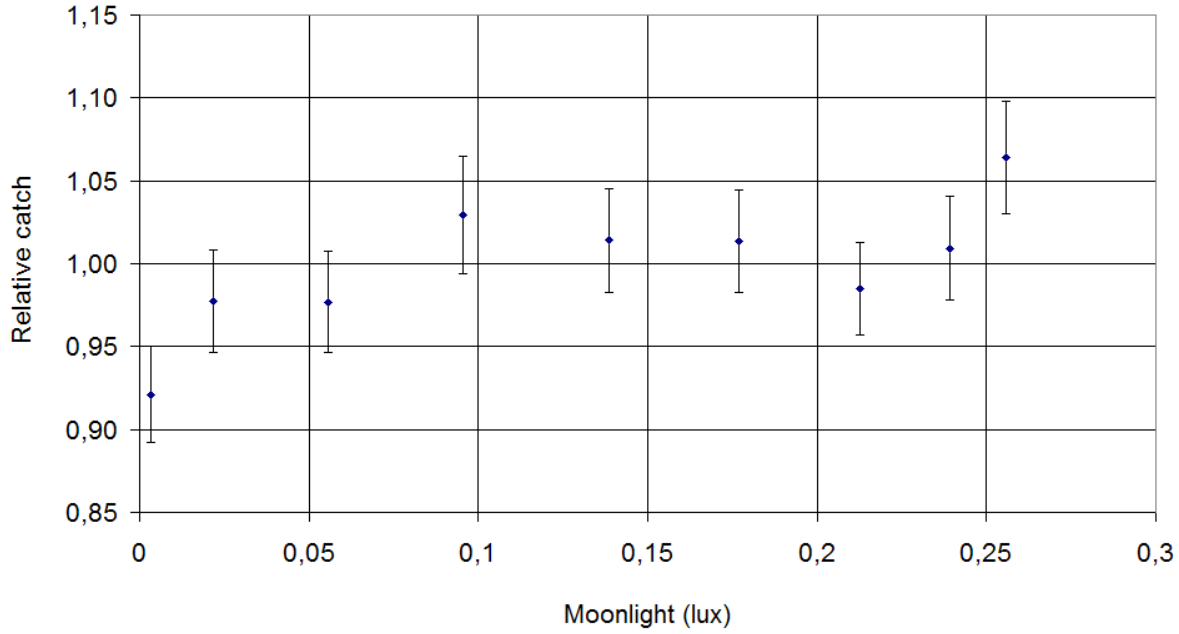


Figure 4. 4. 10 Light-trap catch of fluvial Trichoptera sp. complex in connection with the moonlight



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CHAPTER 5
(Central Europe, Serbia)

Light-trap Catch of the Lepidoptera Species in Connection with the Sun's and Moon's Characteristics (Becse-type Light-trap)

Kiss M., Nowinszky L., Puskás J., Barta A., † Mészáros Z.

5. 1 Introduction

Although the efficiency of Jermy-type light traps, which is commonly used in Hungary, is constantly changing, a relatively small proportion of insects are trapped which approach the light source. The concept of efficiency is interpreted differently by different authors.

According to Malicky (1987) collecting by light-trap has three aspects. One is "catchability" (Fangbarkeit), the degree of willingness to fly to an artificial source of light. This is not to be mixed up with the concept of phototropism or phototaxis. The second is flight distance (Anflugdistanz), the distance between the light-trap and the place where the insect was hatched or released. The third is the distance of attraction (Anlockdistanz), the distance from which the light-trap can exert its power of attraction.

As it appears to Brehm (2002) the light-trap samples reflect activity rather than abundance in the habitat.

According to Nowinszky (2003) approaching the light-trap has three phases.

In the first phase the insect is at a distance from the trap where it remains unaffected by its light. However, during its migration or vagrancy it may reach the so-called "collecting distance" where it perceives the light from natural sources and that of a lamp to be of equal intensity and, provided it is guided by light stimuli in its orientation, there will be an equal probability of choosing one or the other to get oriented in space. Once in the collecting distance, the light of the lamp will appear brighter. If the insect chooses the lamp, it will leave its original course and in line with Buddenbrook's (1937) theory, it will approach the lamp along a logarithmic spiral or some other way. Approaching the collecting distance is typical of the vagile species and can be of a definite direction or incidental.

The second phase starts when the insect arrives within the "collecting distance". The "collecting distance" continuously changes as light conditions change in the environment and in the case of the less vagile species it is conceivable that the individual will never reach the light-trap if this distance is bigger than what it can or is willing to cover in the course of a night. On the other hand, individuals of the more mobile species reach the distance (3-17 m) from which, according to Baker and Sadovy (1978), they will directly react to the light of a lamp.

The fate of the insect will be decided in the third phase, in the direct vicinity of the lamp. It flies into the light and is trapped, or in some way avoids being trapped. It flies away from the vicinity of the lamp, or lands and calms down somewhere near the trap. It is of this phase that

we know the least and it is also the one where our knowledge is the most uncertain. We don't know why one specimen is trapped while on the same night another specimen of the same species avoids the trap.

The efficiency of this third phase can be improved by the Becse-type light trap, which was developed and successfully used by Varga and Mészáros (1973b).

In some of our previous studies, we have already used catch data from this trap that captures a lot of insects.

Puskás et al. (2014) found most species are collected in connection with the increasing the height of the tropopause, but decrease was observed only in case of three species.

The results of Nowinszky et al. (2015) proved that the daily catches were significantly modified by the Q-index (It is the index-number of the solar activity), expressing the different lengths and intensities of the solar flares. The different form of behaviour, however, is not linked to the taxonomic position.

Puskás et al. (2015) examined the beginning of swarming of 21 Microlepidoptera species catching in Bečej (Serbia) and 93 Coleoptera species catching in Prilep (North Macedonia) in connection with the lunar phases. The beginning of swarming is in connection with phase of the Moon at least with one part of Macrolepidoptera and Coleoptera species. The most frequent case is the connection with Last Quarter.

5. 2 Material and Methods

The light-trap was operated by Varga & Mészáros (1973a & 1973b) between 1969 and 1973 on the territory of the Agricultural and Industrial Combine in Bečej, Serbia (Geographical coordinates are: 45°37'05"N and 20°02'05"E) and collected many more insects than the Hungarian Jermy-type traps. The light source of the trap is an IPR WTF 220V, 250W mercury vapour lamp 2 meters above the ground. There is a large collecting cage under the funnel of the trap. The cage contains two perpendicular separation walls made of plastic haircloth dividing the cage into four equal parts. This solution ensured that the tougher bodied and livelier beetles staying at the bottom of the cage couldn't damage the moths and other fragile insects that have climbed up on the separation walls. In the morning the cage was placed in a chest in which a few millilitres of carbon bisulphide had been burnt. The gases thus generated killed the insects quickly and effectively. The light-trap worked every night in the breeding season even in bad weather. Several of this type of traps collecting huge masses of insect material of good quality has been operating in Yugoslavia. Regarded to be dangerous, the use of this type of trap has not been permitted in Hungary.

The moth data of Becse-type light trap were processed and published (Vojnits et al., 1971, Mészáros et al. 1971). This light-trap operated in Bečej Agricultural and Industrial Combine in the years 1969-1973. We process 8 Microlepidoptera and 26 Macrolepidoptera species from the total catching data. The names of the species, the years of collecting and the number of individuals are shown in Table 5. 2. 1.

Table 5. 2. 1 Data of caught species

Species	Number of Moths	Data	Years
Geometridae, Sterrhinae			
Timandra comae Schmidt, 1931 Blood-vein	4,273	190	3
Geometridae, Ennominae			
Chiasmia clathrata Linnaeus, 1758 Latticed Heat	2,658	218	4
Ascotis selenaria Denis & Schiffermüller, 1775 Giant Looper	2,162	162	4
Tephrina arenacearia Denis & Schiffermüller, 1775	4,461	231	4
Erebidae, Lymantriinae			
Leucoma salicis Linnaeus, 1758 White Satin Moth	2,342	231	4
Erebidae, Arctiinae			
Spilosoma lubricipeda Linnaeus, 1758 White Ermine	2,644	84	2
Spilosoma urticae Esper, 1789 Water Ermine	4,457	115	3
Hyphantria cunea Drury, 1773 Autumn Webworm	4,514	255	4
Phragmatobia fuliginosa Linnaeus, 1758 Ruby Tiger	10,170	335	4
Noctuidae, Plusiinae			
Autographa gamma Linnaeus, 1758 Silver Y	7,045	383	4
Noctuidae, Acontiinae			
Acontia trabealis Scopoli, 1763 Spotted Sulphur	18,678	312	4
Noctuidae, Heliothinae			
Helothis maritima Boursin, 1964 Shoulder-striped Cover	3,563	215	4
Anarta trifolii Hufnagel, 1766 The Nutmeg	7,285	317	4
Lacanobia suasa Denis & Schiffermüller, 1775 Dog's Thoot	4,595	206	4
Lacanobia oleracea Linnaeus, 1758 Bright-line Brown-eye	7,616	203	4
Mamestra brassicae Linnaeus, 1758 Cabbage Moth	4,194	95	3
Mythimna pallens Linnaeus, 1758 Common Wainscot	3,400	175	3
Mythimna vitellina Hübner, 1808 The Delicate	3,590	181	4
Noctuidae, Nocruinae			
Agrotis exclamationis Linnaeus, 1758 Heart & Dart	2,073	182	4
Agrotis segetum Denis & Schiffermüller, 1775 Turnip Moth	5,956	318	4
Axylia putris Linnaeus, 1761 The Flame	2,673	156	4
Noctua pronuba Linnaeus, 1758 Large Yellow Underwing	1,839	209	4
Xestia c-nigrum Linnaeus, 1758 Setaceous Hebrew Character	20,715	346	4

The Methods are written in Chapter 1. 3.

5. 3 Results and Discussion

The results are shown in Figures 1-11.

Figure 5. 3.1 Light-trap catch of Macrolepidoptera sp. complex in connection with the night sky polarization originated by the Sun (Bečej, Serbia)

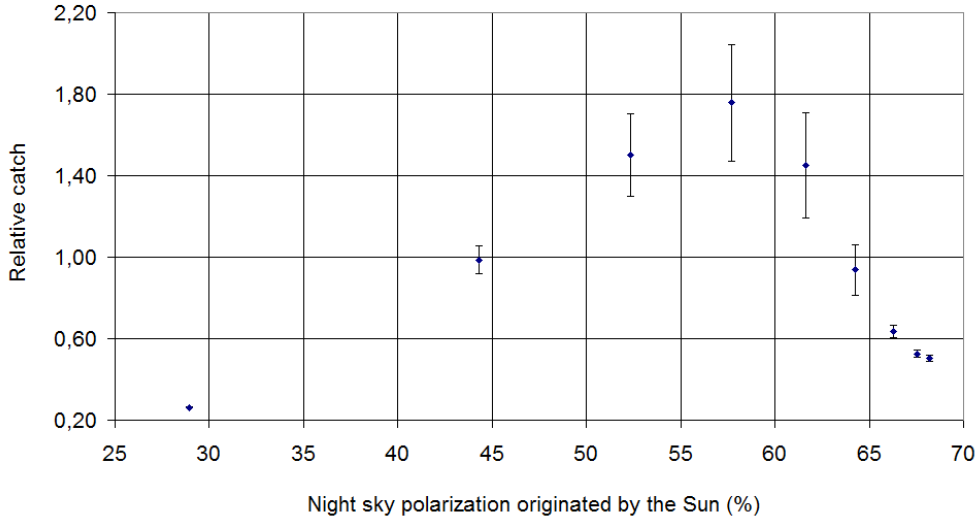


Figure 5. 3. 2 Light-trap catch of Macrolepidoptera sp. complex in connection with the gravitational potential of the Sun (Bečej, Serbia)

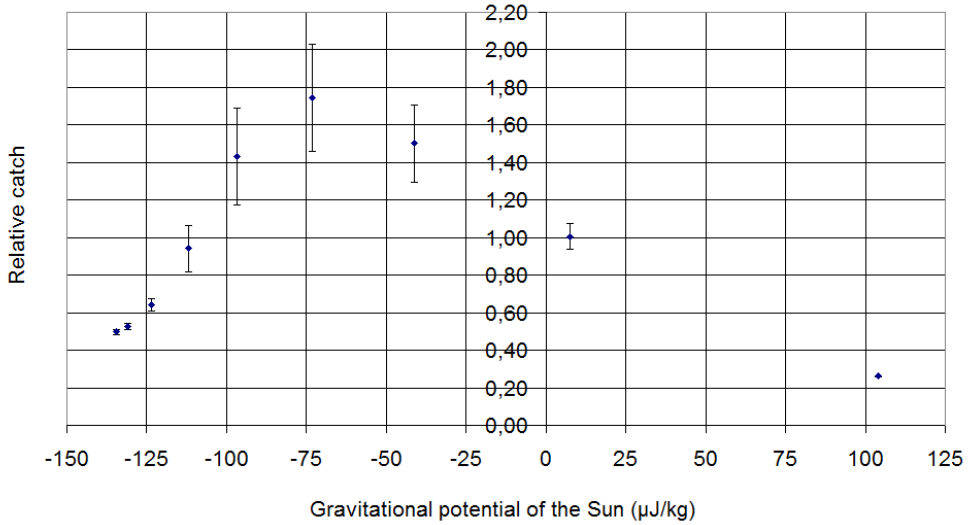


Figure 5. 3. 3 Light-trap catch of Macrolepidoptera sp. complex in connection with the night sky polarization originated by the Moon (Bečej, Serbia)

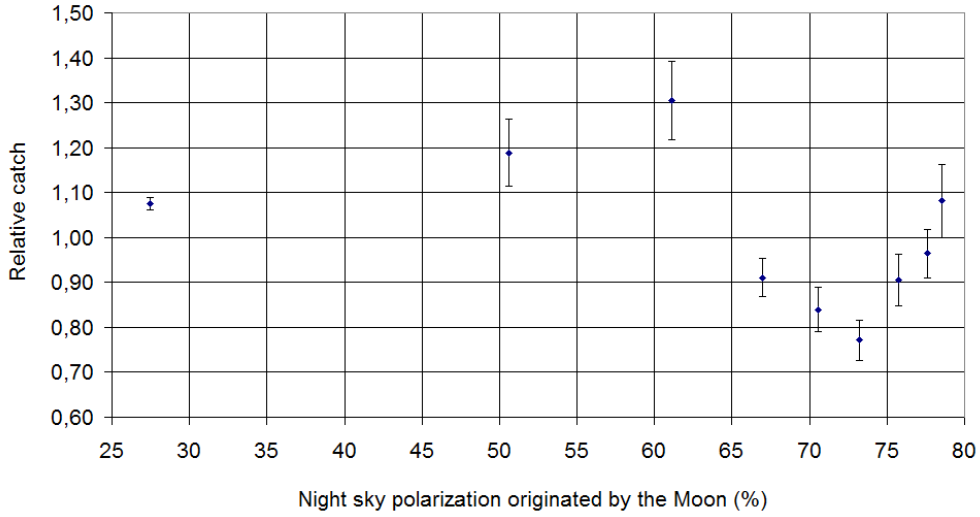


Figure 5. 3. 4 Light-trap catch of Macrolepidoptera sp. complex in connection with the gravitational potential of the Moon (Bečej, Serbia)

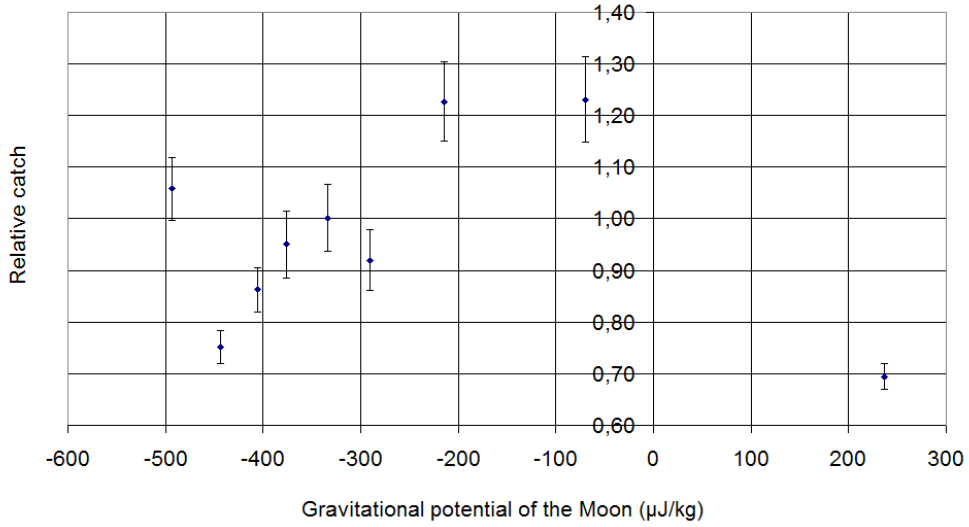


Figure 5, 3. 5 Light-trap catch of Macrolepidoptera sp. complex in connection with the gravitational potential of the Sun+Moon (Bečej, Serbia)

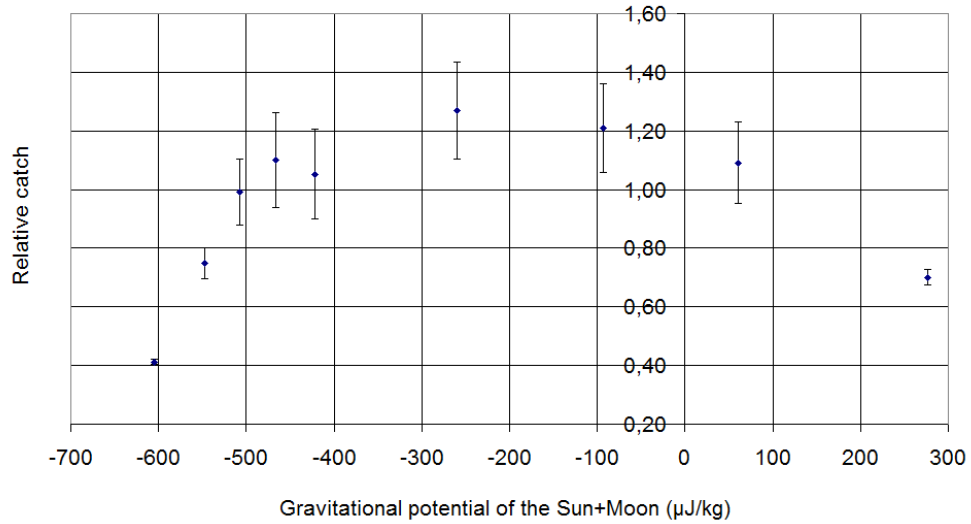


Figure 5. 3. 6 Light-trap catch of Macrolepidoptera sp. complex in connection with the altitude of Sun's Arago point (Bečej, Serbia)

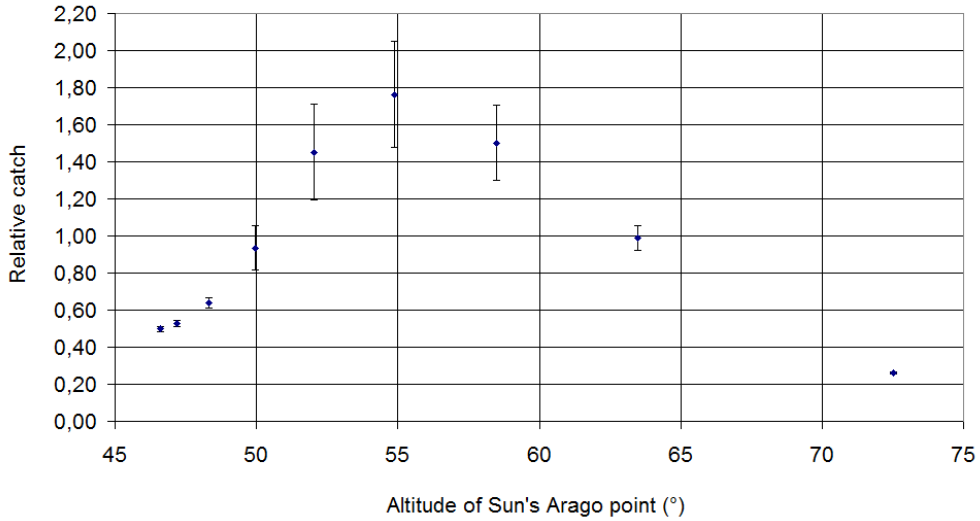


Figure 5. 3. 7 Light-trap catch of Macrolepidoptera sp. complex in connection with the altitude of the Moon's Babinet point (Bečej, Serbia)

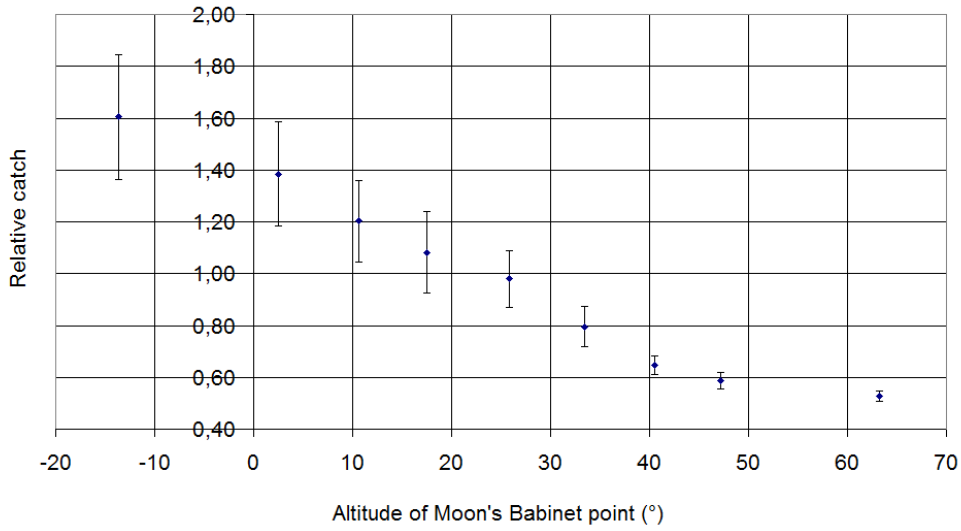


Figure 5. 3. 8 Light-trap catch of Macrolepidoptera spec. complex in connection with the phase angle groups of the Moon (Bečej, Serbia)

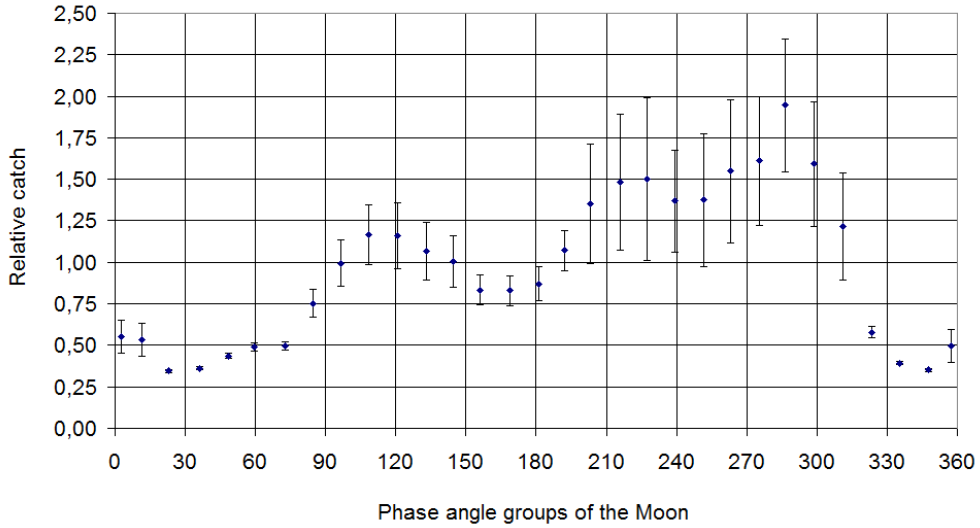


Figure 5. 3. 9 Light-trap catch of Macrolepidoptera spec. complex in connection with the apparent magnitude of the Moon (Bečej, Serbia)

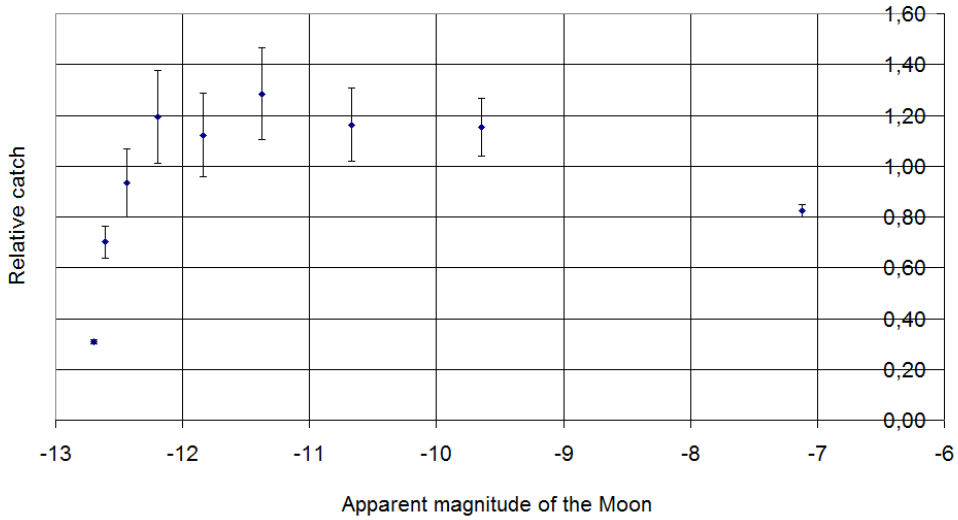


Figure 5. 3. 10 Light-trap catch of Macrolepidoptera spec. complex in connection with the illuminated fraction of the Moon (Bečej, Serbia)

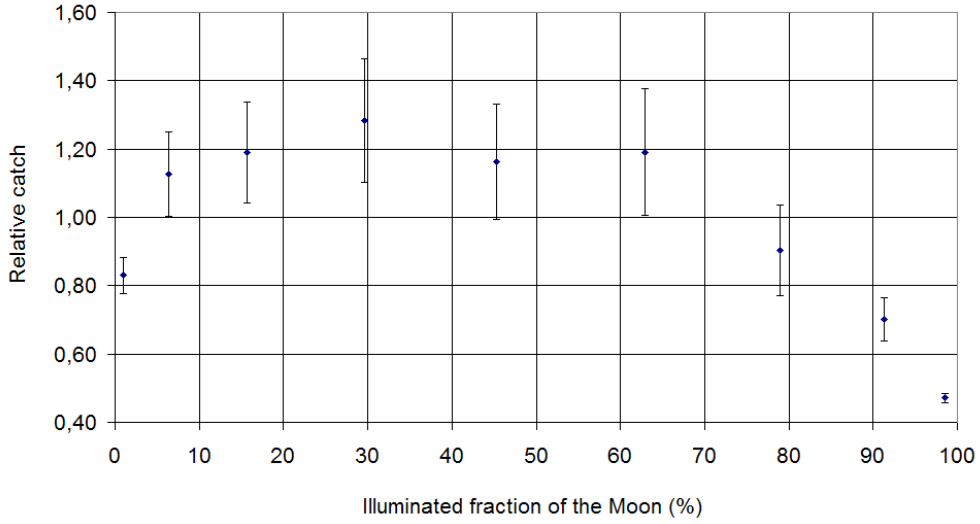
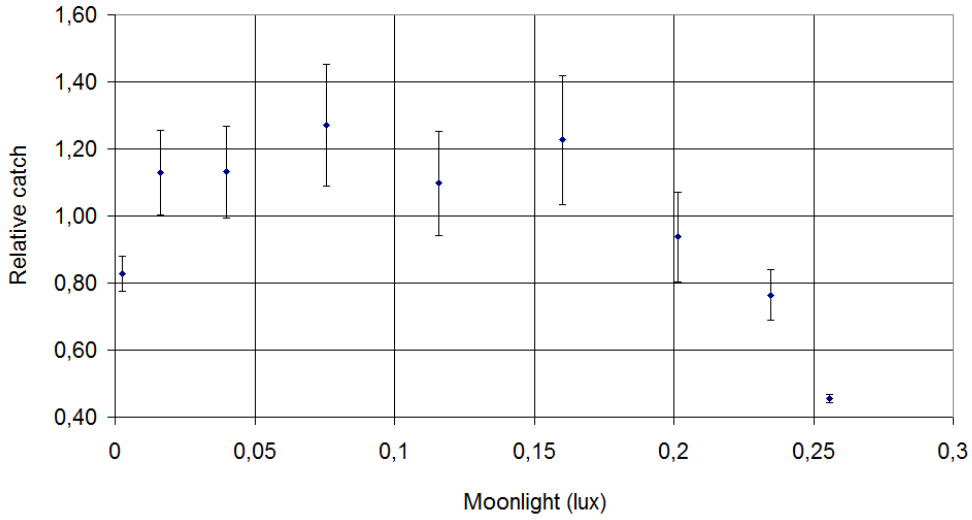


Figure 5. 3. 11 Light-trap catch of Macrolepidoptera spec. complex in connection with the moonlight (Bečej, Serbia)



The results are similar to those coming from the catch data of Jermy-type light-traps in Hungary. A significant difference relates to the position of the Moon Babinet Point above the horizon. According to both Hungarian and Serbian results, catches increase significantly when the Moon Babinet Point appears above the horizon. However, the catch of the Becse-type trap will then begin to decrease, while the catch of the Jermy-type trap will remain consistently high.

5. 4 References

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CHAPTER 6
Australia (Tasmania)

Light-trap Catch of the Lepidoptera Species in Connection with the Sun's and Moon's Characteristics (160 W Mercury Vapour Light-trap)

Hill L., Nowinszky L., Kiss M., Puskás J., Barta A.

6. 1 Introduction

There are few long term light trap datasets from Australia. The Tasmanian light trap network grew from one trap in 1953 to five traps in the period 1983-88 and then declined to one trap after 1994 until 2019. Comparable traps on the mainland seem to have had shorter durations. Wilson (1983), Maelzer et al. (1996), Maelzer and Zalucki (2000) and others (Oertel et al. 1999) analysed *Helicoverpa* data from the longest of the mainland Australian datasets from Narrabri and Trangie in New South Wales and Turretfield in South Australia. These sets variously encompassed the period 1962 to 1987 but for only a few species. As summarized below, other authors drew on short term datasets from elsewhere for various analyses.

To date, analyses of light trap data in Australia have mostly examined the effects of weather and climate on pest abundance and migration but a few studies examined lunar influence. The latter include Gregg et al. (1993, 1994), Persson (1977), Danthanarayana (1976), Steinbauer (2003) and Steinbauer et al. 2012 as summarized below. No studies have examined gravitational factors.

Near Brisbane, Persson (1977) used light trap data of 18 months in combination with field-cage emergence data to deduce that substantial reinfestation by immigration occurred following short periods of local extinction of populations. Brown (1978) noted the presence of many migratory species among insects caught over two years in a light trap near Sydney. Farrow and McDonald (1987) reviewed migration strategies of noctuid pests in Australia including species in the genera *Agrotis*, *Chrysodeixis, Heliothis, Helicoverpa, Mythimna, Persectania* and *Spodoptera*. They proposed that migration enables these species to track host plants and erratic rainfall across a continent. This theme is strong in Australian agricultural entomology. In particular, Gregg et al. (1993) identified the potentially strong effect of migration on light trap catches of 4.5 years duration.

Studies including a lunar factor

In analysing 18 months' light trap data Persson (1976) found a lunar periodicity for several pest Noctuidae. This effect was low when temperature was low. Temperature and wind were each responsible for about one-fifth of the variance in catch and nocturnal illumination for about one-tenth. Twenty per cent of the variance in catch could not be ascribed to changes in local weather or illumination.

Danthanarayana (1976), Steinbauer (2003) and Steinbauer et al. (2012) found that light trap catches of certain Orthoptera and Lepidoptera had non-linear relationships with the illuminated fraction of the Moon. Steinbauer (2003) found in 2-years light trap data for the geometrid moth, *Mnesampela privata* that catch rate generally declined with increasing moon age until a few days after full moon and generally rose again thereafter up to 2-3 days prior to the new moon. His result contrasts with Danthanarayana's results for the tortricid moth, *Epiphyas postvittana* (1976). Steinbauer also found a negative correlation with wind speed but not temperature. Steinbauer et al. (2012) used short term light trap catches to investigate the influence of meteorological and lunar variables on catches of 104 species of Orthoptera and Lepidoptera. They found particular relationships of wind speed, direction, temperature or lunar phase with catches of 24 species.
Gregg et al. (1993) classified many species of Noctuidae and Sphingidae as long distance migrants based on their capture over 4.5 years in two elevated (40-50 m), upwardly directly light traps in elevated parts (1460-1560m) of New South Wales, Australia. This included 24 species not previously suspected as migrants. Their analysis included census and sampling of generally scarce local host plants and the reproductive status (mostly immature) of trapped moths (Coombs et al. 1993). They found considerable variability in the proportion of catch before versus after midnight. They found that 76% of catch was concentrated in 3% of trapping periods (45 migratory events) at one trap and 87% of catch was concentrated in 2% of periods (17 migratory events) at the other trap. Large catches (relative catch >5) were usually obtained over short periods of 0.5-2 nights supporting the notion that suitable mesoscale airflows and population dynamics of highly dispersive species would be a dominant influence on catch rates. Some such airflows resulted in large catches during high winds, up to 80 km/hour despite a generally negative effect of fast winds on catch size. Stepwise multiple regressions using temperature, relative humidity, rainfall and wind speed accounted for only about 25% of the variance, much lower than comparable studies with ground level light traps. This indicated that local weather was not a dominant factor. There was no association with maximum hourly temperature such that some large catches occurred at temperatures <10 °. Significant relationships occurred with wind direction or wind shifts greater than 90 ° and with meteorological troughs and depressions but not cold fronts. Correlation with rainfall was not significant and no correlations were obtained with a 6-category lunar phase (Gregg et al. 1994). They applied airflow back-trajectory analysis to explore the non-local origin of their catches.

Studies not including a lunar factor

Kehat and Wyndham (1973) used continuous suction traps supplemented by an intermittent combination ultra-violet light/suction trap to complement field sampling of the lygaeid bug, *Nysius vinitor* in South Australia to find that the suction traps caught a 1:1 sex ratio while the combined light/suction trap caught predominantly immature females. They also found that mass flights were detected by both types of trap when minimum nocturnal temperature was >14.4°C.
McDonald and Farrow (1988) showed that *N. vinitor* migrated on warm north-westerly airflows into southeast Australia. This bug appears erratically and sometimes abundantly in the Stony Rise light trap as a summer breeding migrant but the contribution of its overwintering population to local breeding in Tasmania is not quantified in relation to the impact of migratory individuals from mainland Australia.

Wilson (1983) related light-trap data for the noctuid moths, *Helicoverpa armigera* and *H. punctigera* to field observations of pupae, crop availability and populations of the preceding season. Spring and early summer catches of *H. punctigera* were nine times higher than catches of *H. armigera*. For both species over 8 years of trapping, variance ratios of monthly effects showed higher significance than did annual effects.
Maelzer et al. (1996) used long term light trap data for *H. punctigera* to positively correlate the size of generation 2 to generation 1. They improved regression coefficients by addition of negatively correlated spring rainfall. Subsequently Oertel et al. (1999) used the same light trap data to identify weak positive correlations of the size of generation 1 with winter rainfall in the core winter breeding area, which is in arid Australia north of 30 ºS latitude. Maelzer and Zalucki (2000) sought earlier prognosis by relating long-term light trap data for *H. armigera* and *H. punctigera* to the Southern Oscillation Index and Sea Surface Temperature.
Smith and McDonald (1986) compared ultraviolet traps to fermentation bait traps for prognosis of infestations of the noctuid pest, *Mythimna convecta*. They related catches to field observations and a phenological day degree model to find that catches in ultraviolet traps were influenced by the reproductive status of moths such that they were less reliable than fermentation bait traps. McDonald and Smith (1986) found that ultraviolet-light trap data indicated that two annual peaks of adult activity of the noctuid pest, *Persectania ewingii* occurred with the first peak coinciding with establishment of the warm-season generation in crops.
Drake et al. (1981) and Drake and Farrow (1985) did not analyse light-trap catches but used them to identify moths detected by radar studies that identified mesoscale airflows favouring migration of noctuid moths across Bass Strait from mainland Australia to Tasmania. They showed that the Noctuidae: *Persectania ewingii*, *Agrotis infusa*, *A. munda* and *Chrysodeixis argentifera* migrate to Tasmania and dominate Tasmanian light-trap catches in spring.

Studies from the Tasmanian data

The migratory list developed by Gregg et al. (1993) from tower-mounted, upwardly pointing light-traps included many Noctuidae and Sphingidae that were also caught in later years with varying frequencies far away in the Stony Rise light-trap in Tasmania on the south coast of Bass Strait. Hill (2007) noted that a large proportion of the biomass light-trapped at Stony Rise in spring are known, likely or suspect migrants as did Drake et al. (1981) for earlier Tasmanian light-traps.
Hill (1993) demonstrated the non-overwintering migratory status of *H. punctigera* in Tasmania using pale colour of adults in Tasmanian pheromone traps as an indicator of origin (eclosion from warm soil) in distant areas of Australia. In a series of publications Hill (2014, 2017) examined pest records of the state agricultural agency spanning many decades, in combination with light-trap data and airflow back trajectory, to demonstrate that several other species migrate annually to Tasmania from mainland Australia with: (a) only low levels of overwintering in Tasmania (*Persectania ewingii*, *Plutella xylostella*); (b) no overwintering in Tasmania (*Mythimna convecta*, *Agrotis infusa*, *A. munda*) or (c) no breeding even in summer including the frequent vagrants (guests) *Creontiades dilutus* and *Hellula hydralis* and less frequent guests: *Utethesia pulchelloides*, *Sceliodes cordalis*, *Spodoptera exigua*, *Earias perheugeliana*, *Earias parallela* and *Meyrickiella rutellus*.
An unpublished analysis of data for about a dozen lepidopteran species, including several pestiferous Noctuidae that are now known to be annual migrants, from several of the

Tasmanian light-traps spanning 1953-75 was undertaken by Wolda. This was one of many datasets from around the world underlying his study of variability in abundance of tropical and temperate insects (e.g. Wolda 1978). He used a similarity index that compared each year with the first year in the series. In a 1976 letter to DPIPWE entomologist, Ernie Martyn, Wolda wrote, 'In this comparison your data are strange in that the amount of change between years tend to be extraordinarily high. The "Annual Variability" is among the highest of all data that I have seen thus far. Wolda wrote in a subsequent letter to Martyn in 1981, 'Cressy, like other data sets I have, shows a slow decreasing trend in similarity, but for (*sic*) Ouse and especially Elliott are much more erratic.' The Stony Rise light trap commenced operation after Wolda's analysis but the trap site is most comparable to the earlier traps at Forthside (10 km west of Devonport) and Elliott (Hill, 2013b). Hence the Stony Rise dataset is likely to exhibit high variability.

Magnetic field experiment

Dreyer et al. (2018) used wild, tethered Bogong Moths or common cutworm moths *Agrotis infusa* in flight simulators to investigate influence of Earth's magnetic field and horizontal landmarks on flight direction. This species undertakes an unusual two-way migration, poleward to mountainous southeast Australia in spring and the reverse in autumn. Their flight simulators operated outdoors at night and included a rotatable, circular, UV-transmissive, diffuser roof bearing a 1 cm wide black stripe, which was described as a landmark secondary to the primary horizontal landmark on the walls of the cylindrical flight simulator. In addition, large parasols were deployed over flight simulators on nights when the moon was visible. The steering direction of Bogong Moths was concluded to be, 'the result of an interaction between visual landmarks and the earth's magnetic field.

Drake and Farrow (1988) found the long-distance migration in a particular region is an adaptation to both the seasonal variations of habitat favourability in the region and the availability of winds suitable for transporting migrants in the required directions. Migration systems therefore depend on particular topographical and climatic factors, and are unique to each region.

6. 2 Materials and methods

The Tasmanian data derive from decades of near-continuous (1992 - 2019) operation of a 160W Rothamsted-design light trap at Stony Rise in Tasmania, Australia. This trap was the last of several long-term Rothamsted-design traps operated at several sites from 1953 until various dates by the Tasmanian state agricultural agency, currently known as the Department of Primary Industries, Parks, Water and Environment (DPIPWE). A history of the Tasmanian program was published in Hill (2013a). This includes a list of many of the species enumerated at the Stony Rise trap.

The trap at Stony Rise was similar to the Rothamsted-design traps operated in the United Kingdom (RIS, 2012). It was located at the edge of the small city of Devonport, which is central on the north coast of Tasmania. The trap was at 41º11'29"S, 146°19'24"E (41.18 ºS 146.32 ºE), at a site 69 m above sea level and 5 km south of Bass Strait, which separates the island state of Tasmania from mainland Australia.

The Stony Rise trap included a clear glass, truncated pyramid of 52 cm square base, 22 cm height and 12 cm top aperture surrounding a square, glass funnel of slightly lesser

height with 20 cm top aperture and 4 cm bottom aperture. This was mounted on a wooden base-board about 1.3 m above ground under a ridged, steel roof. The bulb was suspended within the funnel from the ceiling of the roof cavity, in which a clock-switch was fitted. Clearance between the top aperture of the funnel and the ceiling of the roof was about 4 cm. The catch was collected into a 10 cm square glass jar with a plaster of Paris floor holding tetrachlorethane killing fluid and with a 9 cm orifice screwed to the underside of the baseboard. This jar contained a piece of crumpled paper towel to reduce rubbing of specimens. The trap had a 160 Watt mercury vapour bulb about 13 cm high (16 cm total length). In December 2015 the trap frame was rebuilt in stainless steel to the same dimensions and using the original collection pyramid and funnel. The clock switch was replaced by a light sensitive switch.

The trap environment was mostly mown lawn and single-storey buildings for a 150m radius but a hedge of diverse native trees, shrubs and low plants about 4m high persisted 10 m to the north and similarly around building peripheries about 20-50m away to the south and east. Beyond 150m there was a peri-urban mixture of pasture, *Eucalyptus* forest and an increasing number of domestic gardens. The trap site was at the western edge of Devonport, a city of 20,000 people. In broad terms the site was exposed, in the lee of a native hedge, on relatively high ground to long-distance migrants arriving from the northern sector and within a few kilometres of extensive pasture and vegetable cropping districts located in the other sectors.

The Stony Rise trap site experiences a maritime cool temperate climate with prevailing oceanic, cool, westerly airflows regularly interrupted by warm northerly airflows. Nocturnal temperature at the Stony Rise trap site is below 10 ℃ for considerable periods. Mean temperature for the coldest month, July is 8.25 ℃ (4.1-12.4 ℃) and for the warmest month, February is 17 ℃ (12.4-21.6 ℃) with mean monthly minimum and maximum in parentheses. Mean monthly temperature is below 10 ℃ for four months.

The light was typically operated every night from 1 January 1992, with all individuals of selected taxa counted. Sometimes the catch was emptied at longer intervals so that a single 'trapping event' represents variously 1-14 nights of trapping. There were 5433 trapping events covering 7897 nights including 4167 single-night events, 502 two-night events, 516 three-night events and 165 four-night events. The remaining 83 events were variously 5-14 nights' duration. There were 194 sporadic nights when the trap malfunctioned, which is about 2.5% of 7897 nights in the main trapping periods. The trap did not operate for extended periods (3-6 months) in early 1996, early 1998, all of 2007, 2008 and 2009, early 2010 and late 2015. Enumeration of catches ceased on 6 February 2019. A total of 222,146 specimens were identified and enumerated for the data set, which is available through Research Gate website (https://www.researchgate.net/project/Long-term-light-trap-data-for-insects-in-Tasmania-1992-2019). This dataset is also being formatted for open access via the Global Biodiversity Information Facility.

The initial focus of the trapping was on Noctuidae and insect species of economic importance for Tasmanian agriculture. The selected taxa grew from 104 taxa in 1992 to 273 taxa by 2019**.** Hill (2013a) includes a list of many of the species enumerated at the Stony Rise trap.

Over 9000 specimens collected from the light-trap are preserved in the Tasmanian Agricultural Insect Collection (https://collections.ala.org.au/public/show/co131) including a synoptic subset of several hundred voucher specimens for which images are available.

We investigated data for all species, when the total number of captured individuals reached one hundred. Thus, we processed data of 133 species in total. These were divided into three groups (Microlepidoptera 63 species, Macrolepidoptera 70 species and among them Migratory Species 11 species (4 Microlepidoptera and 7 Macrolepidoptera).

Table 6. 2. 1 Catching data from Stony Rise, for Lepidoptera species with total catch exceeding 100.

	Family/Species	Catching Start	Catching Finish	Approxi-mate days	Catch sum	Count of trap-ping events	Notes
	Authority, date in parentheses when current genus is not the original genus						
1	**Hepialidae**						
2	*Fraus simulans* (Walker, 1856)	1993.01.01	2019.01.28	7707	302	5184	
3	**Psychidae**						
4	*Lepidoscia arctiella* (Walker, 1860)	2013.01.01	2019.01.28	2113	173	1871	
5	**Plutellidae, Plutellinae**						
6	*Plutella xylostella* (Linnaeus, 1758)	1992.01.01	2019.01.28	8073	25294	5424	M
7	**Oecophoridae, Oecophorinae**						
8	*Wingia aurata* (Walker, 1864)	2013.01.01	2019.01.28	2113	127	1871	
9	*Philobota near nephelarcha (*Meyrick, 1884)	2012.06.11	2019.01.28	2317	337	1918	
10	*Philobota productella* (Walker, 1864)	2012.11.26	2019.01.28	2149	9779	1905	
11	*Eulechria melesella* (Newman, 1856)	2012.11.15	2019.01.28	2160	263	1911	
12	**Oecophoridae, Stathmopodinae**						
13	*Stathmopoda melanochra* (Meyrick 1897)	2014.06.02	2019.01.28	1596	1149	1502	
14	**Oecophoridae, Xyloryctinae**						
15	*Cryptophasa albacosta* (Lewin, 1805)	2001.01.01	2019.01.28	5212	120	4748	
16	**Gelechiidae Gelechiinae**						
17	*Phthorimaea operculella* (Zeller, 1873)	1992.01.01	2019.01.28	8073	614	5424	
18	**Lecithoceridae**						
19	*Lecithocera terrigena* (Meyrick, 1904)	2013.01.01	2019.01.28	2113	4506	1871	
20	**Coleophoridae**						
21	*Coleophora alcyonipennella* (Kollar, 1832)	2012.01.11	2019.01.28	2469	1872	1921	
22	**Pterophoridae, Pterophorinae**						

23	*Stenoptilia zophodactylus* (Duponchel, 1840)	2013.01.01	2019.01.28	2113	191	1871	
24	**Tortricidae, Tortricinae, Archipini s. lat.**						
25	Archipini sensu lato, indeterminate species of Constrictana group	2015.01.01	2019.01.28	1383	1975	1225	
26	**Tortricidae, incertae sedis**						
27	*Heliocosma incongruana* (Walker, 1863)	2013.01.01	2019.01.28	2113	172	1871	
28	**Limacodidae**						
29	*Doratifera pinguis (*Walker, 1855)	1994.01.01	2019.01.28	7342	719	4963	
30	**Pyralidae, Epipaschiinae**						
31	Epipaschiinae near Salma and Orthaga with 25-35 mm wingspan	2013.01.01	2019.01.28	2113	312	1871	
32	*Spectrotrota fimbrialis* (Warren, 1891)	2013.01.01	2019.01.28	2113	173	1871	
33	**Pyralidae, Endotrichinae**						
34	*Endotricha ignealis (*Guenée, 1854)	2012.01.11	2019.01.28	2469	185	1921	
35	**Pyralidae, Phycitinae**						
36	*Etiella behrii* (Zeller, 1848)	2012.11.14	2019.01.28	2161	672	2165	M
37	*Faveria tritalis (*Walker, 1863)	2012.02.04	2019.01.28	2445	3775	2030	
38	**Pyralidae, Pyralinae**						
39	*Ocrasa albidalis (*Walker, 1866)	2013.01.01	2019.01.28	2113	259	1871	
40	*Gauna aegusalis* (Walker, 1858)	2012.01.11	2019.01.28	2469	139	1921	
41	**Crambidae, Spilomelinae**						
42	*Nacoleia rhoealis* (Walker 1859)	2012.01.01	2019.01.28	2479	1492	2119	
43	*Sedenia rupalis* (Guenée, 1854)	2012.11.15	2019.01.28	2160	143	1911	
44	*Metasia capnochroa* (Meyrick, 1884)	2015.01.01	2019.01.28	1383	1207	1225	
45	**Crambidae, Pyraustinae**						
46	*Achyra affinitalis (*Lederer, 1863)	2011.09.28	2019.01.28	2574	2060	2283	M
47	*Uresiphita ornithopteralis* (Guenée, 1854)	1992.01.01	2019.01.28	8073	3235	5424	
48	**Crambidae, Glaphyriinae**						
49	*Hellula hydralis (*Guenée, 1854)	1993.01.01	2019.01.28	7707	2545	5184	M
50	**Crambidae, Scopariinae**						
51	*Scoparia crocospila* (Turner, 1922)	2013.01.01	2019.01.28	2113	119	1871	
52	**Crambidae, Crambinae**						

53	*Hednota sp. near crypsichroa(* Lower, 1893)	2012.01.01	2019.01.28	2479	7384	2119	
54	*Hednota pedionoma* (Meyrick, 1885)	2012.01.01	2019.01.28	2479	1997	2119	
55	*Hednota relatalis (*Walker, 1863)	2012.01.01	2019.01.28	2479	1821	2119	
56	*Hednota grammellus (*Zeller, 1863)	2013.01.01	2019.01.28	2113	6208	1871	
57	*Hednota invalidellus* (Meyrick, 1879)	2013.01.01	2019.01.28	2113	543	1871	
58	*Culladia cuneiferellus (*Walker, 1863)	2012.01.01	2019.01.28	2479	5537	2119	
59	*Ptochostola microphaeellus* (Walker, 1863)	2011.08.11	2019.01.28	2622	13152	2171	
60	**Crambidae, Acentropinae**						
61	*Hygraula nitens* (Butler, 1880)	2013.01.01	2019.01.28	2113	406	1871	
62	**Crambidae, Schoenobiinae**						
63	*Tipanaea patulella* Walker, 1863	2012.11.15	2019.01.28	2160	284	1911	
64	**Saturniidae, Saturniinae**						
65	*Opodiphthera helena* (White, 1843)	1992.01.01	2019.01.28	8073	158	5424	
66	**Geometridae, Sterrhinae**						
67	*Scopula rubraria (*Doubleday, 1843)	2014.01.01	2019.01.28	1748	2977	1538	
68	*Idaea costaria* (Walker, 1863)	2018.01.01	2019.01.28	392	114	683	
69	**Geometridae, Larentiinae**						
70	*Epyaxa subidaria* (Guenée, 1857)	1992.01.01	2019.01.28	8073	4368	5424	
71	*Eupitheciini* Tutt,1896 near *Phrissogonus* Butler and *Chloroclystis* Hübner	2012.01.01	2019.01.28	2479	3709	2119	
72	**Geometridae, Ennominae**						
73	*Rhynchopsota delogramma* (Lower, 1903)	2012.01.01	2019.01.28	2479	109	2119	
74	*Chlenias spp.*	2013.01.01	2019.01.28	2113	161	1871	
75	*Mnesampela privata* (Guenée, 1857)	1993.01.01	2019.01.28	7707	498	5184	
76	*Thalaina selena* (Doubleday, 1845)	1993.01.01	2019.01.28	7707	1401	5183	
77	*Gastrina cristaria (*Guenée, 1866)	2014.01.01	2019.01.28	1748	130	1538	
78	**Arctiidae, Arctiinae**						
79	*Utetheisa pulchelloides (*Hampson, 1907)	1992.01.01	2019.01.28	8073	4565	5424	M
80	*Nyctemera amicus* (White, 1841)	2013.01.01	2019.01.28	2113	20	1871	

81	*Spilosoma canescens* (Butler, 1875)	1992.01.01	2019.01.28	8073	99	5424	
82	*Spilosoma glatignyi* (Le Guillou, 1841)	1992.01.01	2019.01.28	8073	183	5424	
83	**Arctiidae Lithosiinae**						
84	*Asura cervicalis* (Walker, 1854)	2013.01.01	2019.01.28	2113	278	1871	
85	*Palaeosia* sp. not *bicosta* (Walker, 1854)	2012.12.26	2019.01.28	2119	389	1877	
86	**Erebidae, Calpinae**						
87	*Rhapsa suscitatalis* (Walker, 1859)	1992.01.01	2019.01.28	8073	441	5424	
88	*Praxis porphyretica* (Guenée, 1852)	1992.01.01	2019.01.28	8073	701	5424	
89	*Praxis edwardsii* (Guenée, 1852)	1992.01.01	2019.01.28	8073	301	5424	
90	**Erebidae, Lymantriinae**						
91	*Acyphas semiochrea* (Herrich-Schäffer, 1855)	2013.01.01	2019.01.28	2113	172	1871	
92	*Crioa hades* (Lower, 1903)	1992.01.01	2019.01.28	8073	131	5424	
93	**Erebidae, Catocalinae**						
94	*Alapadna pauropis* (Turner, 1902)	2002.01.01	2019.01.28	4847	151	3575	
95	*Pantydia sparsa* (Guenée, 1852) and *P. diemeni* (Guenée, 1852)	1992.01.01	2019.01.28	8073	647	5424	
96	**Noctuidae, Plusinae**						
97	*Chrysodeixis argentifera* (Guenée, 1852)	1992.01.01	2019.01.28	8073	741	5424	M
98	**Noctuidae, Amphipyrinae**						
99	*Neumichtis expulsa* (Guenée, 1852)	1992.01.01	2019.01.28	8073	135	5424	
100	*Hypoperigea tonsa* (Guenée, 1852)	1992.01.01	2019.01.28	8073	267	5424	
101	*Thoracolopha near flexirena* (Walker, 1865)	*1992.01.01*	*2019.01.28*	*8073*	*1875*	*5424*	
102	*Proteuxoa tortisigna* (Walker, 1857)	1992.01.01	2019.01.28	8073	2947	5424	
103	*Proteuxoa bistrigula* (Walker, 1857)	1992.01.01	2019.01.28	8073	736	5424	
104	*Proteuxoa hydraecioides* (Guenée, 1852)	1992.01.01	2019.01.28	8073	317	5424	
105	*Proteuxoa sanguinipuncta* (Guenée, 1852)	1992.01.01	2019.01.28	8073	3722	5424	
106	*Proteuxoa rubripuncta* (Turner, 1933)	1996.01.01	2019.01.28	6612	131	5424	
107	*Proteuxoa porphyrescens* (Lower, 1902)	1992.01.01	2019.01.28	8073	185	5424	
108	*Proteuxoa amaurodes* (Lower, 1902)	1992.01.01	2019.01.28	8073	3658	5424	

109	*Proteuxoa hypochalchis* (Turner, 1902)	1992.01.01	2019.01.28	8073	3724	5424	
110	Proteuxoa near instipata (Walker, 1857)	1992.01.01	2019.01.28	8073	288	5424	
111	*Athetis tenuis* (Butler, 1886)	1992.01.01	2019.01.28	8073	1669	5424	
112	**Noctuidae, Hadeninae**						
133	*Leucania obumbrata* (T.P. Lucas, 1894)	1992.01.01	2019.01.28	8073	236	5424	
114	*Xylina ligniplena* (Walker, 1857)	1992.01.01	2019.01.28	8073	187	5424	
115	*Persectania ewingii* (Westwood, 1839)	1992.01.01	2019.01.28	8073	8818	5424	M
116	*Dasygaster padockina* (Le Guillou, 1841)	1992.01.01	2019.01.28	8073	2482	5424	
117	*Leucania obusta* (Guenée, 1852)	1992.01.01	2019.01.28	8073	520	5424	
118	*Mamestra dictyota* (Lower, 1902)	1992.01.01	2019.01.28	8073	170	5424	
119	*Mythimna convecta* (Walker, 1857)	1992.01.01	2019.01.28	8073	116	5424	M
120	*Leucania uda* (Guenée, 1852)	1992.01.01	2019.01.28	8073	365	5424	
121	**Noctuidae, Noctuinae**						
122	*Agrotis infusa* (Boisduval, 1832)	1992.01.01	2019.01.28	8073	1206	5424	M
123	*Agrotis munda* (Walker, 1857)	1992.01.01	2019.01.28	8073	4746	5424	M
124	*Agrotis porphyricollis* Guenée, 1852	1992.01.01	2019.01.28	8073	7201	5424	
125	*Diarsia intermixta* (Guenée, 1852)	1992.01.01	2019.01.28	8073	1902	5424	
126	**Noctuidae, Heliothinae**						
127	*Helicoverpa punctigera* (Wallengren, 1860)	1992.01.01	2019.01.28	8073	4225	5424	M
128	**Nolidae, Nolinae**						
129	*Uraba lugens* (Walker, 1863)	1999.01.01	2019.01.28	5943	4511	5338	
130	**Choreutidae, Choreutinae**						
131	*Tebenna micalis* (Mann, 1857)	2017.01.01	2019.01.28	757	109	695	
132	**Anthelidae, Anthelinae**						
133	*Pterolocera near leucocera* (Turner 1921)	1993.01.01	2019.01.28	7707	116	5184	

Note: M = Migrating species

Notes for Table 6. 2. 1

Notes by L Hill based on the Checklist of the Lepidoptera of Australia by Nielsen, Edwards and Rangsi, 1996, Monographs on Australian Lepidoptera Vol. 4., CSIRO Publishing, Collingwood, 529 pages.

1 1996 Checklist pages 24-26, no subfamilies

2	The 1996 Checklist page 24 assigns Fraus to informal 'primitive Hepialidae' classification because monophyly with Hepialidae is uncertain
3	1996 Checklist page 33-35, no subfamilies
4	1996 Checklist page 33, no subfamily classification, originally described by Walker in Tinea
5	1996 Checklist page 53, all nine genera in one subfamily (Plutellinae)
6	1996 Checklist page 53, Subfamily Plutellinae; Originally described by Linnaeus in Phalaena Tinea
7	1996 Checklist pages 60-84
8	Subfamily Oecophorinae; Originally described by Walker in Palparia
9	Subfamily Oecophorinae; Originally described by Meyrick in Philobota. Note P. mathematica (Meyrick 1883) is an allied species but the 1996 Checklist does not formally list a 'mathematica' group of species within Philobota
10	Subfamily Oecophorinae; Originally described by Walker in Oecophora
11	Subfamily Oecophorinae; Originally described by Newman in Depressaria
12	1996 Checklist pages 84-85
13	1996 Checklist Subfamily Stathmopodinae; Originally described by Meyrick in Stathmopoda in October 1897
14	1996 Checklist pages 85-89
15	1996 Checklist Subfamily Xyloryctinae; Originally described by Lewin in Cryptophasa
16	1996 Checklist pages 111-114
17	1996 Checklist page 112, Subfamily Gelechiinae; Originally described by Zeller in Gelechia
18	1996 Checklist pages 116-117, no subfamilies
19	1996 Checklist page 116, originally described by Meyrick in Macrotona
20	1996 Checklist page 93, no subfamilies, also known as Eupistidae
21	1996 Checklist page 93, originally described by Kollar in Ornix
22	1996 Checklist pages 157-158
23	1996 Checklist page 184, originally described by Duponchel in Pterophorus
24	1996 Checklist pages 126-128
25	1996 Checklist, see page 126, For example Tortrix constrictana Walker 1866 and some species previously assigned to Capua and Dichelia
26	1996 Checklist page 137 treats Heliocosma, Choristis, Hyperxena and Acmosara separately from Tortricidae
27	1996 Checklist, page 137 and 125: Heliocosma group was once classified as Tortricidae: Tortricinae: Cochylini but now cannot be assigned to family; H. incongruana was originally described by walker in Conchylis
28	1996 Checklist pages 145-146
29	1996 Checklist page 146, originally described by Walker in Pelora
30	1996 Checklist pages 171-173
31	1996 Checklist page 172, genera such as Salma Walker 1863 and Orthaga Walker 1859, in Epipaschiinae (Pococerinae) not Endotrichinae
32	1996 Checklist page 171, originally described in Spectrotrota
33	1996 Checklist page 173
34	1996 Checklist page 173, originally described in Endotricha
35	1996 Checklist pages 175-182
36	1996 Checklist page 177, Phycitini; Originally described by Zeller in Pempelia
37	1996 Checklist page 176, Phycitini; Originally described by Walker in Hypochalcia
38	1996 Checklist pages 173-175
39	In 1996 Checklist page 174 as Pyralidae, Pyralinae, Pyralini; originally described by Walker in Ocrasa
40	In 1996 Checklist page 174 as Pyralidae, Pyralinae, Pyralini; originally described by Walker in Pyralis
41	1996 Checklist does not recognize Crambidae as family but allocates the Crambinae genera to Pyralidae
42	In 1996 Checklist page192 as Pyralidae, Pyraustinae, Spilomelini; Originally described by Walker in Desmia
43	In 1996 Checklist page 192 as Pyralidae, Pyraustinae, Spilomelini
44	In 1996 Checklist page 193 as Pyralidae, Pyraustinae, Spilomelini; Originally described by Meyrick in Eurycreon
45	1996 Checklist page 189 separates Pyraustinae from Crambinae within Pyralidae

46 In 1996 Checklist page 190 as Pyralidae, Pyraustinae, Pyraustini; originally described by Lederer in Botys
47 In 1996 Checklist page 190 as Pyralidae, Pyraustinae, Pyraustini; originally described by Guenee in Mecyna
48 1996 Checklist page 188 separates Glaphyriinae from Crambinae within Pyralidae
49 In 1996 Checklist page 188 as Pyralidae, Glaphyriinae
50 1996 Checklist page 186 separates Scopariinae from Crambinae within Pyralidae
51 In 1996 Checklist page 186 as Pyralidae, Scopariinae, Scopariini; originally described by Turner in Scoparia
52 1996 Checklist treats Crambinae as subfamily within Pyralidae including Hednota, Culladia and Ptochostola but excluding genera of Spilomelinae, Pyraustinae, Glaphyriinae and Scopariinae
53 In 1996 Checklist page 183 as Pyralidae, Crambinae; originally described by Lower in Hednota
54 In 1996 Checklist page 183 as Pyralidae, Crambinae; originally described by Meyrick in Thinasotia (sic)
55 In 1996 Checklist page 183 as Pyralidae, Crambinae; originally described by Walker in Crambus
56 In 1996 Checklist page 183 as Pyralidae, Crambinae; originally described by Zeller in Crambus
57 In 1996 Checklist page 183 as Pyralidae, Crambinae; originally described by Meyrick in Crambus
58 In 1996 Checklist page 183 as Pyralidae, Crambinae; originally described by Walker in Crambus
59 In 1996 Checklist page 184 as Pyralidae, Crambinae; originally described by Walker in Crambus
60 1996 Checklist page 184 treats Acentropinae as junior synonym of Nymphulinae
61 In 1996 Checklist page 184 as Pyralidae, Nymphulinae; originally described by Butler in Paraponyx (sic)
62 1996 Checklist page 187 treats Schoenobiinae as subfamily of Pyralidae separate from Crambinae
63 In 1996 Checklist page 184 as Pyralidae, Schoenobiinae; originally described by Walker in Tipanaea
64 1996 Checklist pages 264-265, all six genera in one subfamily
65 1996 Checklist page 264, originally described by White in Saturnia
67 1996 Checklist page 222, originally described by Doubleday in Ptychopoda
68 1996 Checklist page 223, originally described by Walker in Acidalia
70 1996 Checklist page 225, originally described by Guenee in Coremia
71 Geometridae, Larentiinae, Eupitheciini, near genera Phrissogonus Butler 1882 and Chloroclystis Hübner 1825
73 1996 Checklist page 202, Ennominae, Nacophorini; originally described by Lower in Rhyncopsota
74 1996 Checklist page 203, Ennominae, Nacophorini; Chlenias Guenėe 1857; two or more species
75 1996 Checklist page 204, Ennominae, Nacophorini; originally described by Guenėe in Idiodes
76 1996 Checklist page 204, Ennominae, Nacophorini; originally described by Doubleday in Callimorpha
77 1996 Checklist page 203, Ennominae, Nacophorini; originally described by Guenėe in Gastrina
79 1996 Checklist page 283, originally described by Hampson in Utetheisa
80 1996 Checklist page 283, originally described by White in Agagles
81 1996 Checklist page 284, originally described by Butler in Ardices
82 1996 Checklist page 284, originally described by LeGuillou in Chelonia
84 1996 Checklist page 280, originally described by Walker in Asura
85 Undescribed species code-named Palaeosia sp. (1) by Marriott in second edition, 2015, Moths of Victoria, part 2, page 27, Published by Entomological Society of Victoria ISBN 978-0-9805802-2-8
87 1996 Checklist page 301, Noctuidae, Catocalinae; originally described by Walker in Hypena
88 1996 Checklist page 305, Noctuidae, Catocalinae; originally described by Guenėe in Praxis
89 1996 Checklist page 305, Noctuidae, Catocalinae; originally described by Guenėe in Praxis
91 1996 Checklist page 277, Lymantriidae; originally described by Herrich-Schäffer in Porthesia
92 1996 Checklist page 303, Noctuidae, Catocalinae; originally described by Lower in Gadirthra (sic)
94 1996 Checklist page 301, Noctuidae, Catocalinae; originally described by Turner in Alapadna
95 1996 Checklist page 302, Noctuidae, Catocalinae; both originally described in Pantydia
97 1996 Checklist page 308, Noctuidae, Plusiinae; originally described in Plusia
99 1996 Checklist page 322, Noctuidae, Acronictinae/Amphipyrinae; originally described in Hadena
100 1996 Checklist page 324, Noctuidae, Acronictinae/Amphipyrinae; originally described in Perigea
101 1996 Checklist page 327, Noctuidae, Acronictinae/Amphipyrinae, Proteuxoa; originally described in Apamea

102	1996 Checklist page 327, Noctuidae, Acronictinae/Amphipyrinae; originally described in Ochropleura
103	1996 Checklist page 328, Noctuidae, Acronictinae/Amphipyrinae; originally described in Hadena
104	1996 Checklist page 328, Noctuidae, Acronictinae/Amphipyrinae; originally described in Agrotis
105	1996 Checklist page 328, Noctuidae, Acronictinae/Amphipyrinae; originally described in Amphipyra (likely to be resurrected in Peripyra in future by Hitchcock)
106	1996 Checklist page 328, Noctuidae, Acronictinae/Amphipyrinae; originally described in Amphopyra (sic) (likely to be resurrected in Peripyra in future by Hitchcock)
107	1996 Checklist page 328, Noctuidae, Acronictinae/Amphipyrinae; originally described in Caradrina
108	1996 Checklist page 328, Noctuidae, Acronictinae/Amphipyrinae; originally described in Agrotis
109	1996 Checklist page 328, Noctuidae, Acronictinae/Amphipyrinae; originally described in Agrotis; possibly not true Proteuxoa
110	1996 Checklist page 328, Noctuidae, Acronictinae/Amphipyrinae; perhaps P. instipata (Walker 1857); Code-name of Hill is Proteuxoa DPILH9
111	1996 Checklist page 326, Noctuidae, Acronictinae/Amphipyrinae; originally described in Radinogoes
133	1996 Checklist page 329, no available genus, use original genus which was Leucania
114	1996 Checklist page 329, no available genus, use original genus which was Xylina
115	1996 Checklist page 329, original genus was Noctua
116	1996 Checklist page 328, original genus was Noctua
117	1996 Checklist page 329, no available genus, use original genus which was Leucania
118	1996 Checklist page 329, no available genus, use original genus which was Mamestra
119	1996 Checklist page 329, original genus was Leucania
120	1996 Checklist page 330, original genus was Leucania
122	1996 Checklist, page 331, Noctuidae, Noctuinae, original genus was Noctua
123	1996 Checklist, page 331, Noctuidae, Noctuinae, original genus was Agrotis
124	1996 Checklist, page 331, Noctuidae, Noctuinae, original genus was Agrotis
125	1996 Checklist, page 331, Noctuidae, Noctuinae, original genus was Noctua
127	1996 Checklist, page 333, Noctuidae, Heliothinae, original genus was Heliothis
129	1996 Checklist, page 314, Noctuidae, Nolinae, original genus was Uraba
130	As in Heppner and Duckworth 1971
131	1996 Checklist page 142, Choreutidae, Choreutinae (synonymous Simaethidae, Hemerophilidae); original genus was Choreutis
133	1996 Checklist page 260, original genus of P. leucocera was Anthela

6. 3 Methods

The methods are described in detail in Chapter 1. 1. 3.
We separately examined all the catch data in the groups of Microlepidoptera, Macrolepidoptera and migratory species.
The migratory species were further divided into two groups. A separate group was formed of data when the value of relative catch (RC) was greater than 1 (high catch). The other group was for data when the value of relative catch (RC) was less than 1 (low catch). According to the studies of Drake et al. (1981) and Hill (1993, 2014, 2017), it was assumed that the higher catches were from specimens of species that migrated from the Australian continent to Tasmania during their migration. And low catch values come from few individuals of the few species that have developed locally in Tasmania. This assumption seems to be confirmed by the fact that the high catch group has 35,463 moths and 8,266 observations, while the low catch group has 2,763 moths and 3,002 observations.

6. 4 Results and Discussion

In our current work, we investigated the effect of Sun's and Moon's features on light-trapping of moths that have not yet been studied by any Australian species. Factor analysis was used to select from the 22 traits that have the greatest influence on light-trapping.
We used data from a total of 92 moth species divided into three groups: Microlepidoptera, Macrolepidoptera and Migrants. The species of each group were processed together.
According to our results, light trapping of both Microlepidoptera and Macrolepidoptera species is significantly related to 12 characteristics of Sun and Moon. Their influence can thus be considered as generalized for Tasmanian moth species, similar to Central European and North American species.
The results can be seen in Figures 6. 4. 1 – 6. 4. 33.

Figure 6. 4. 1 Light-trap catch of Microlepidoptera sp. complex in connection with the night sky polarization originated by the Sun

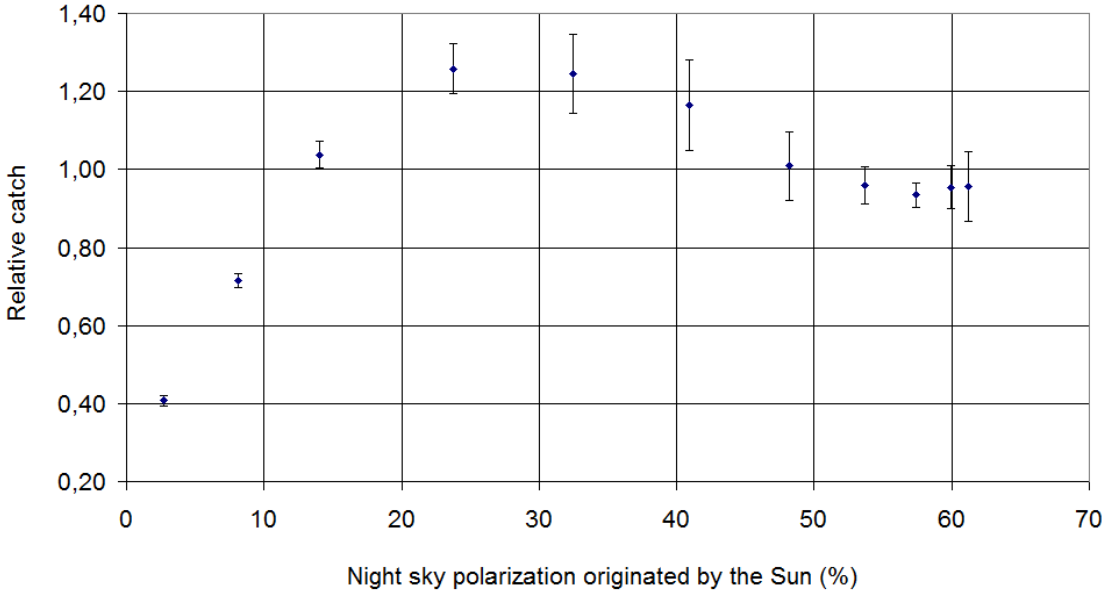


Figure 6. 4. 2 Light-trap catch of Microlepidoptera sp. complex in connection with the night sky polarization originated by the Moon

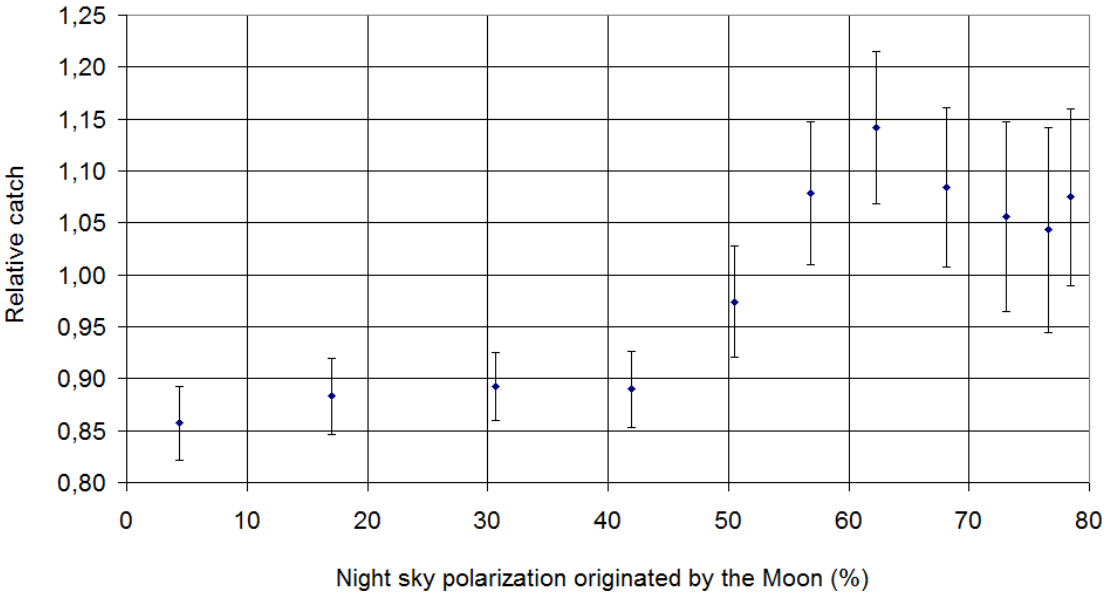


Figure 6. 4. 3 Light-trap catch of Microlepidoptera sp. complex in connection with the gravitational potential of the Sun

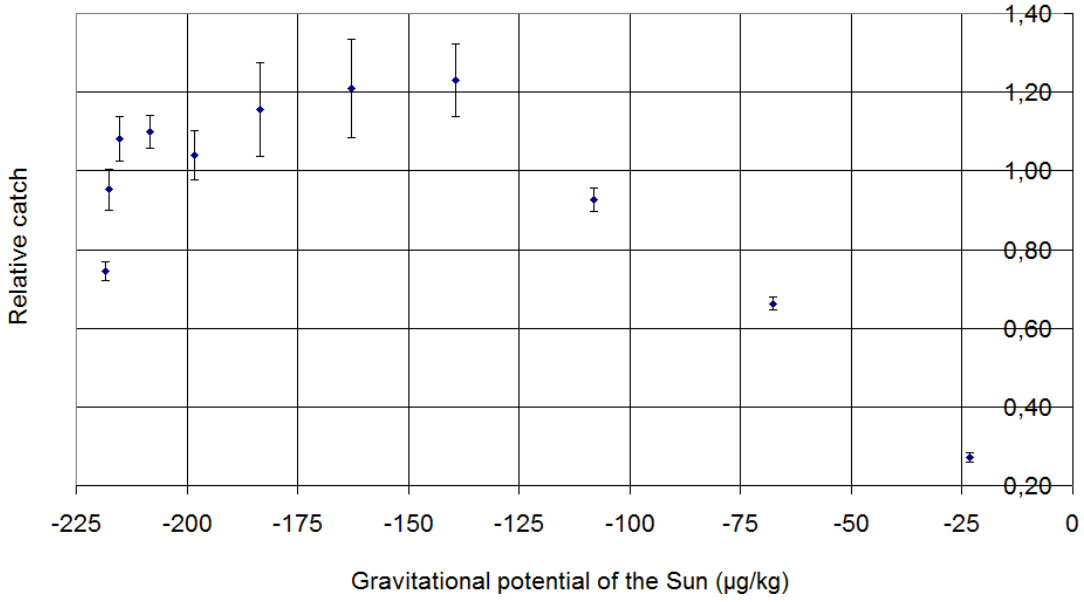


Figure 6. 4. 4 Light-trap catch of Microlepidoptera sp. complex in connection with the gravitational potential of the Moon

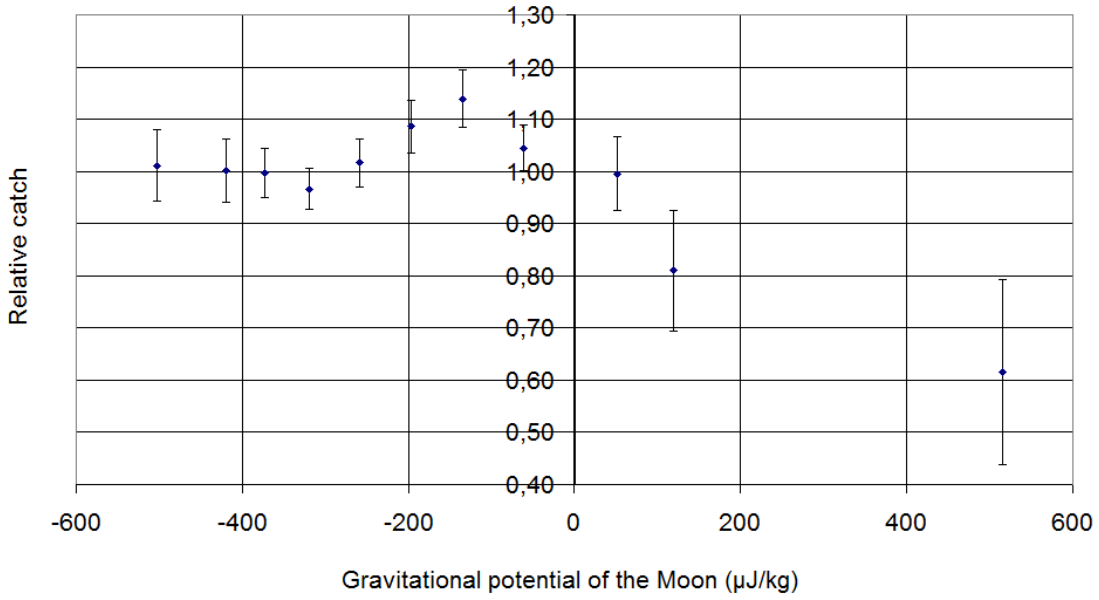


Figure 6. 4. 5 Light-trap catch of Microlepidoptera sp. complex in connection with the gravitational potential of the Sun+Moon

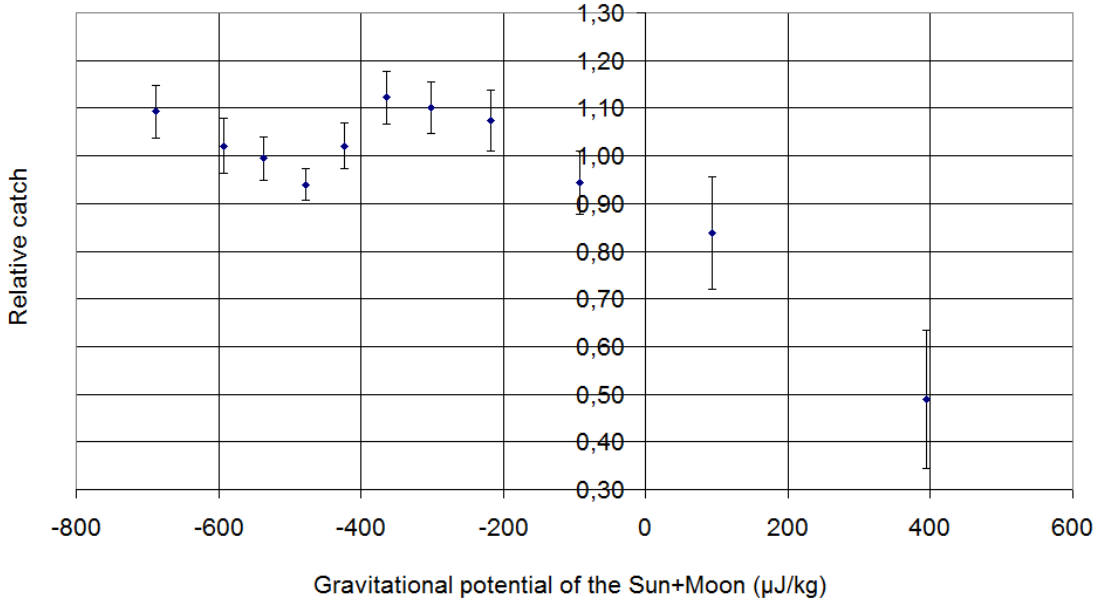


Figure 6. 4. 6 Light-trap catch of Microlepidoptera sp. complex in connection with the altitude of Sun's Arago point

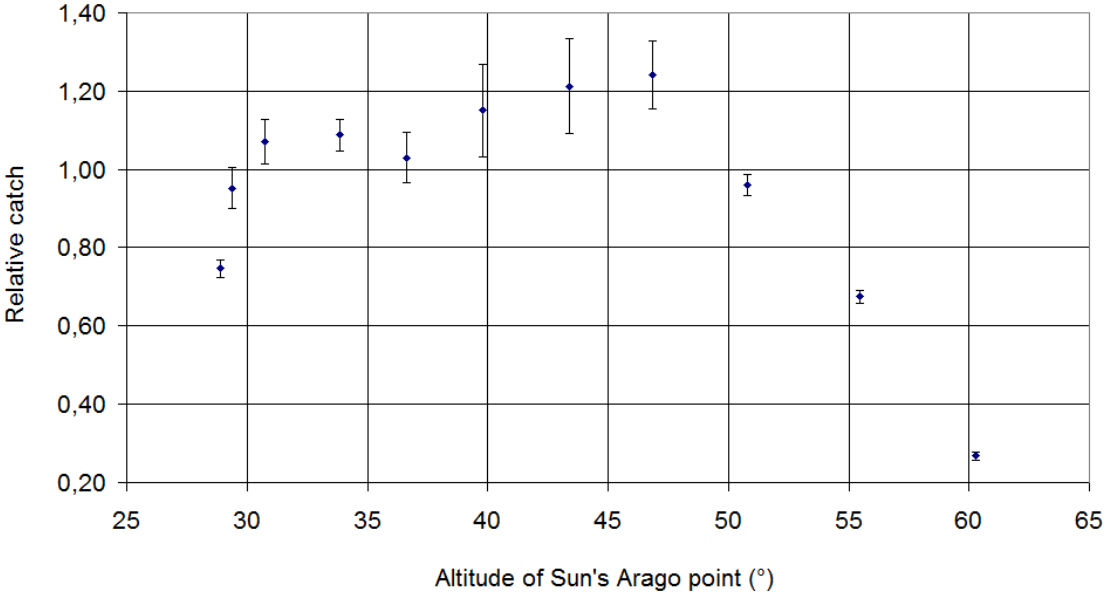


Figure 6. 4. 7 Light-trap catch of Microlepidoptera sp. complex in connection with the altitude of the Moon's Babinet point

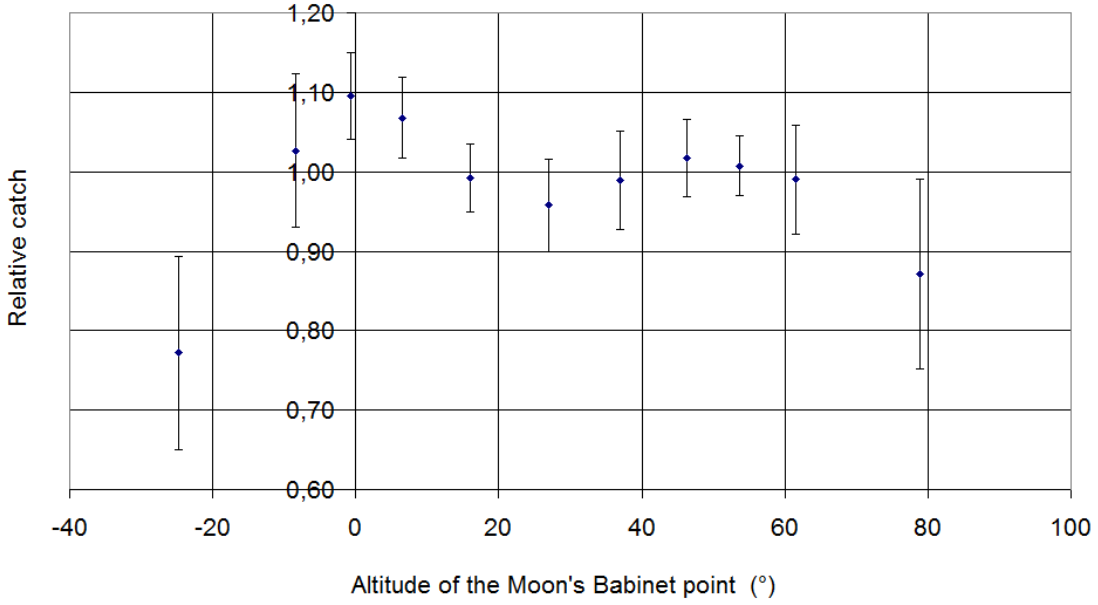


Figure 6. 4 8 Light-trap catch of Microlepidoptera sp. complex in connection with the phase angle groups of the Moon (0°=New Moon, 90°=First Quarter, 180°= Full Moon, 270°=Last Quarter)

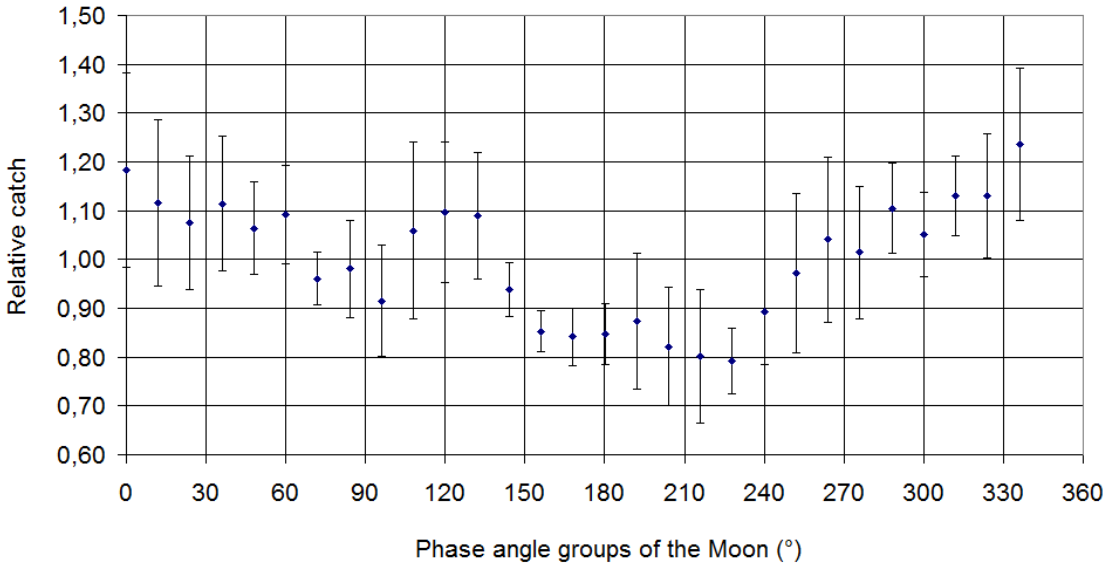


Figure 6. 4. 9 Light-trap catch of Microlepidoptera sp.complex in connection with the polarized moonlight (First Quarter)

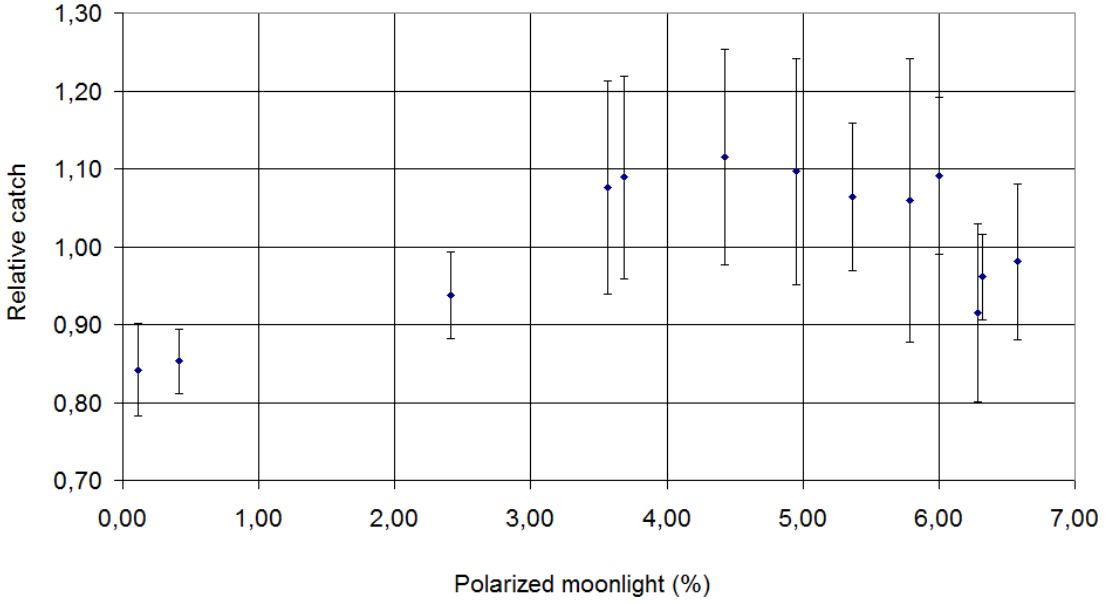


Figure 6. 4. 10 Light-trap catch of Microlepidoptera sp. complex in connection with the apparent magnitude of the Moon

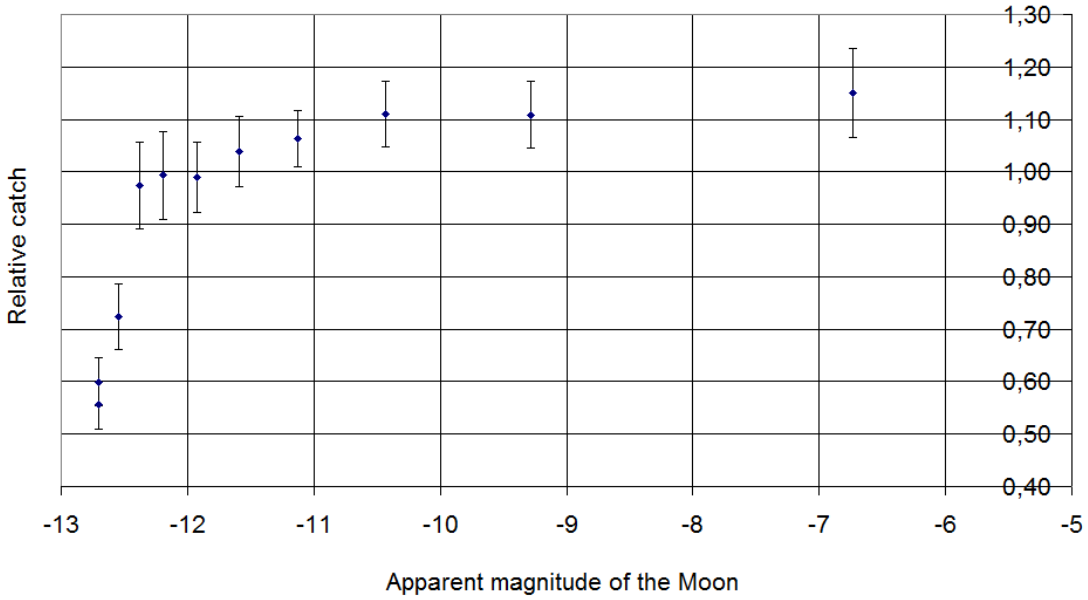


Figure 6. 4. 11 Light-trap catch of Microlepidoptera sp. complex in connection with the illuminated fraction of the Moon

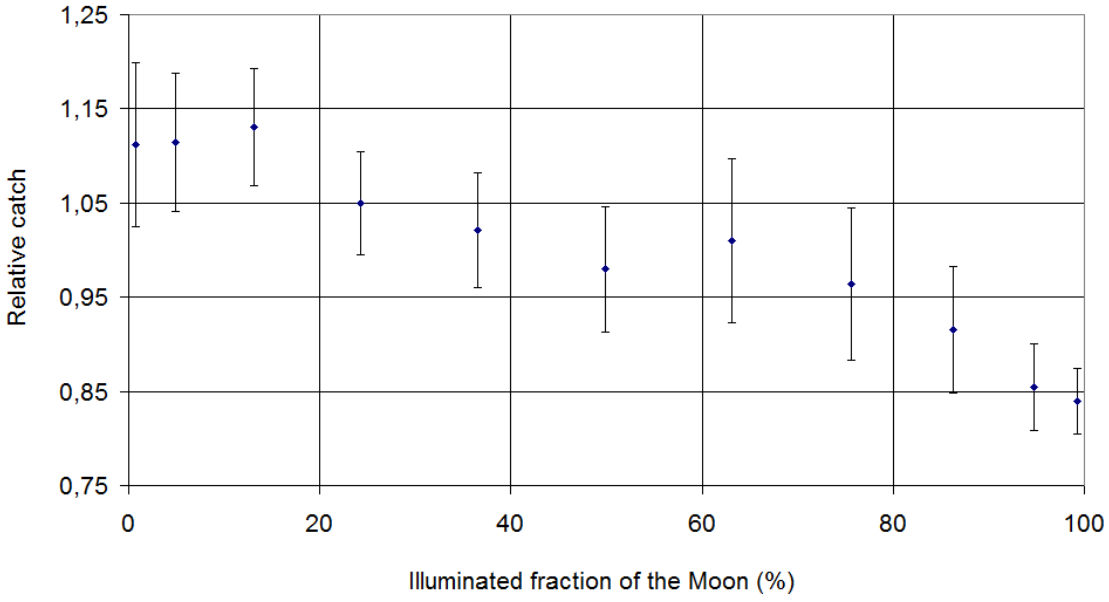


Figure 6. 4. 12 Light-trap catch of Microlepidoptera sp. complex in connection with the moonlight

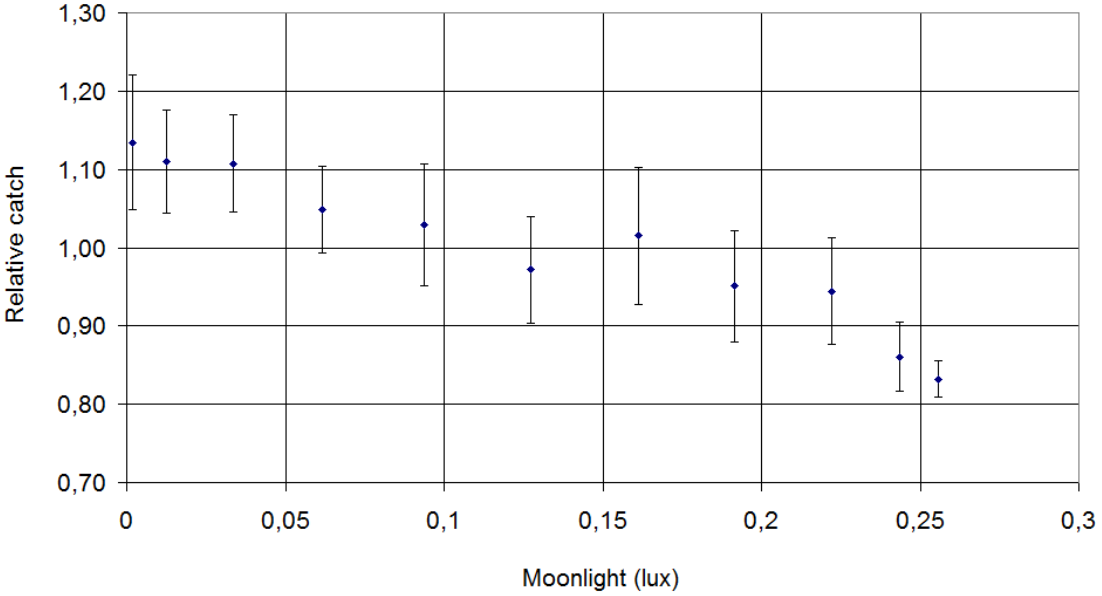


Figure 6. 4. 13 Light-trap catch of Macrolepidoptera sp. complex in connection with night sky polarization originated by the Sun

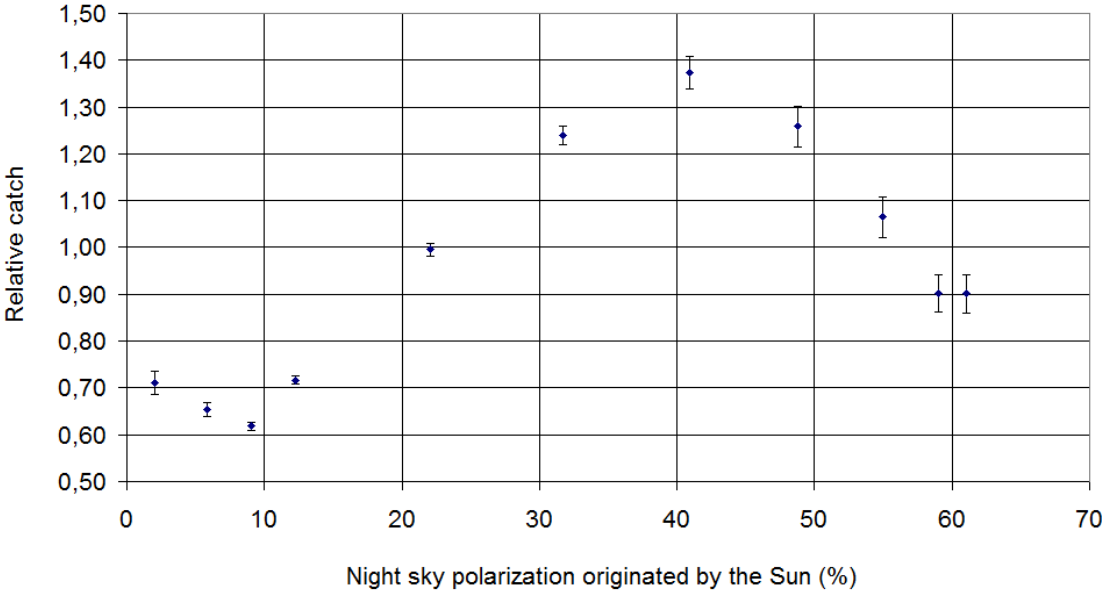


Figure 6. 4. 14 Light-trap catch of Macrolepidoptera sp. complex in connection with night sky polarization originated by the Moon

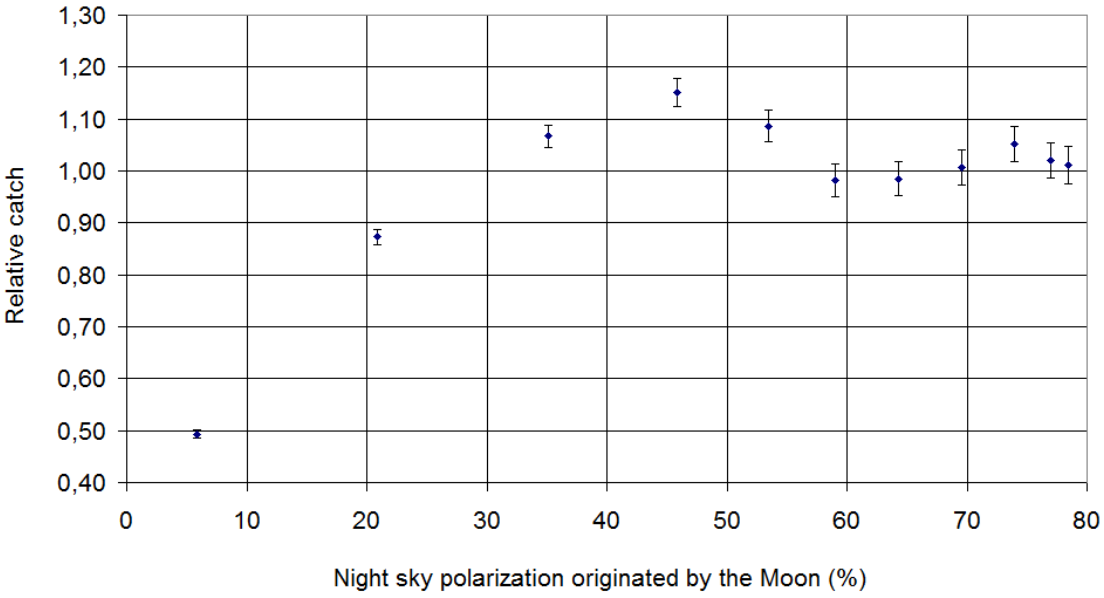


Figure 6. 4. 15 Light-trap catch of Macrolepidoptera sp. complex in connection with the gravitational potential of the Sun

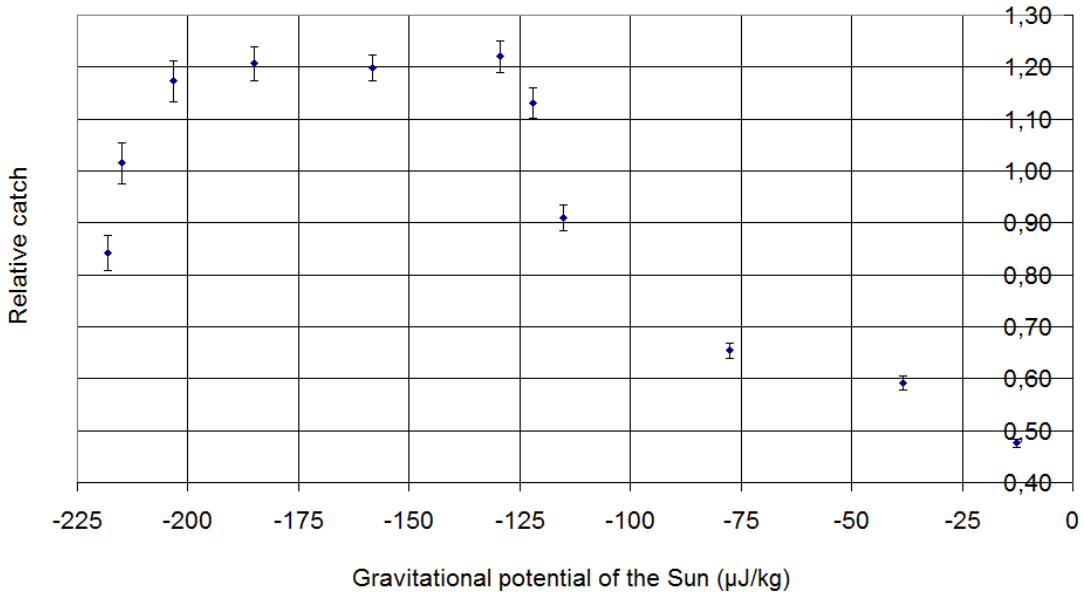


Figure 6. 4. 16 Light-trap catch of Macrolepidoptera sp. complex in connection with the gravitational potential of the Moon

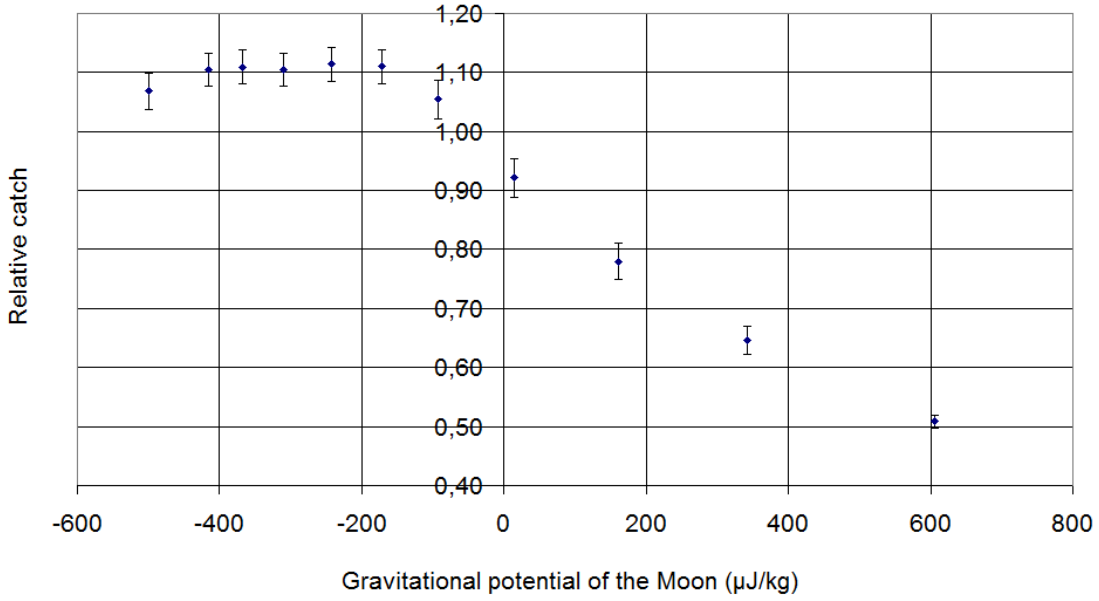


Figure 6. 4. 17 Light-trap catch of Macrolepidoptera sp. complex in connection with the gravitational potential of the Sun+Moon

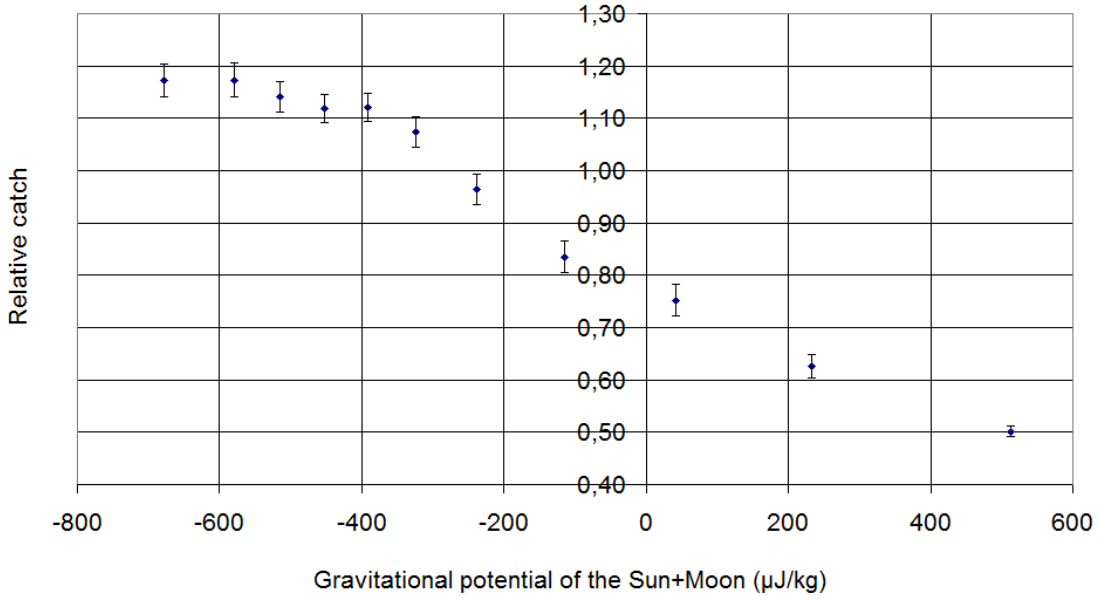


Figure 6. 4. 18 Light-trap catch of Macrolepidoptera sp. complex in connection with the altitude of Sun's Arago point

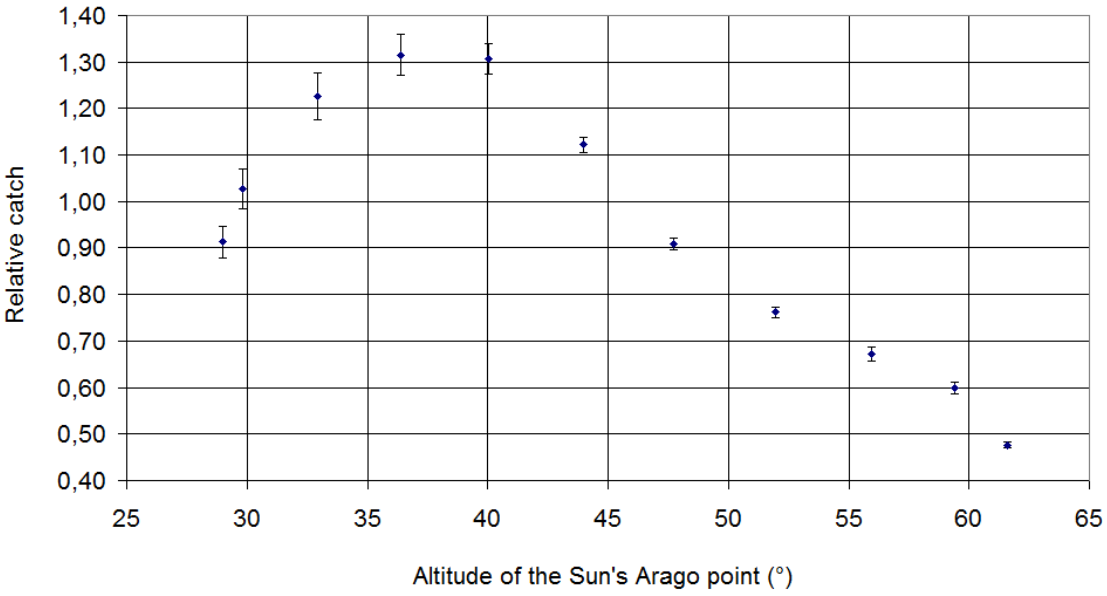


Figure 6. 4. 19 Light-trap catch of Macrolepidoptera sp. complex in connection with the altitude of the Moon's Babinet point

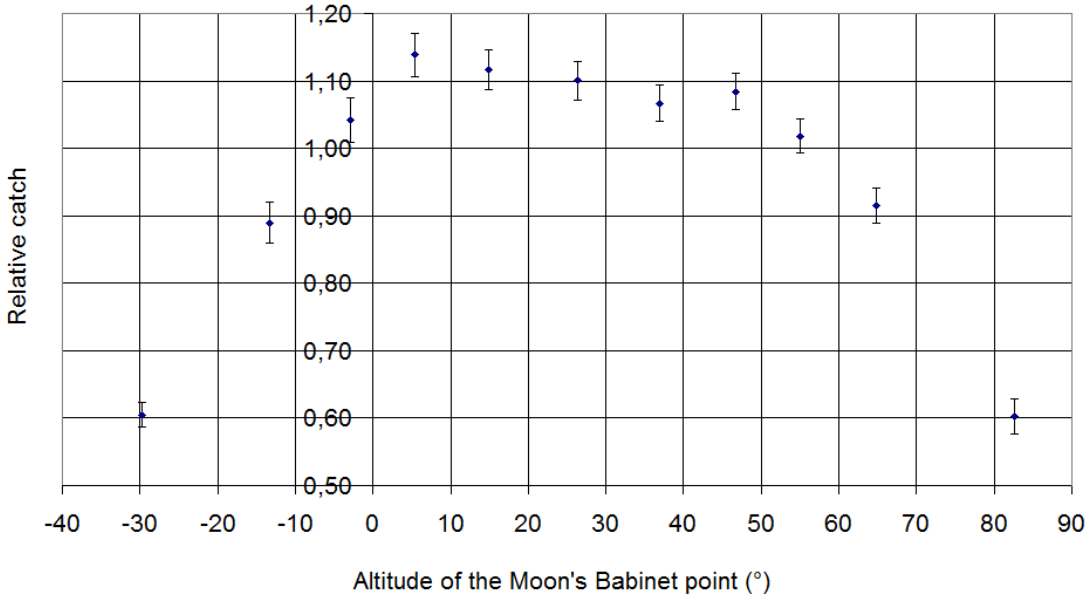


Figure 6. 4. 20 Light-trap catch of Macrolepidoptera sp. complex in connection with the phase angle groups of the Moon (0°=New Moon, 90°=First Quarter, 180°= Full Moon, 270°=Last Quarter)

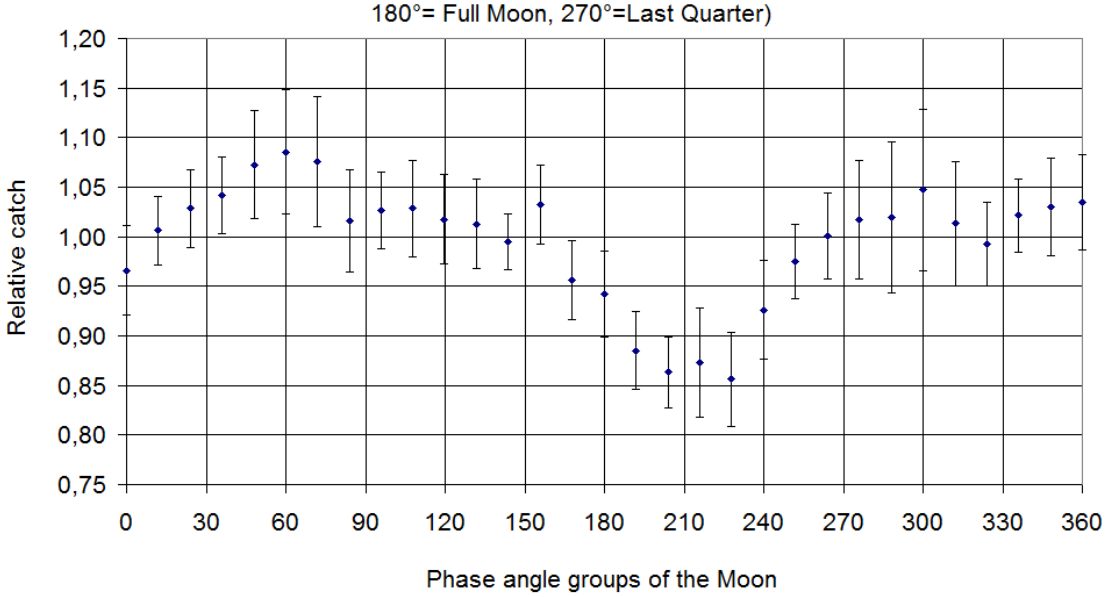


Figure 6. 4. 21 Light-trap catch of Macrolepidoptera sp. complex in connection with the polarized moonlight (Last Quarter)

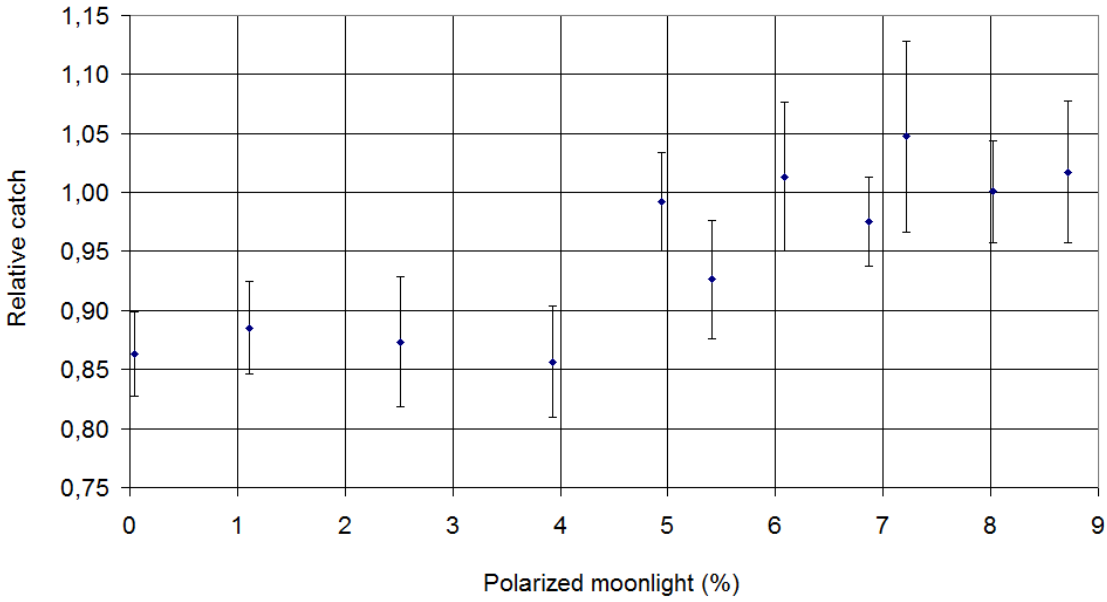


Figure 6. 4. 22 Light-trap catch of Macrolepidoptera sp. complex in connection with the apparent magnitude of the Moon

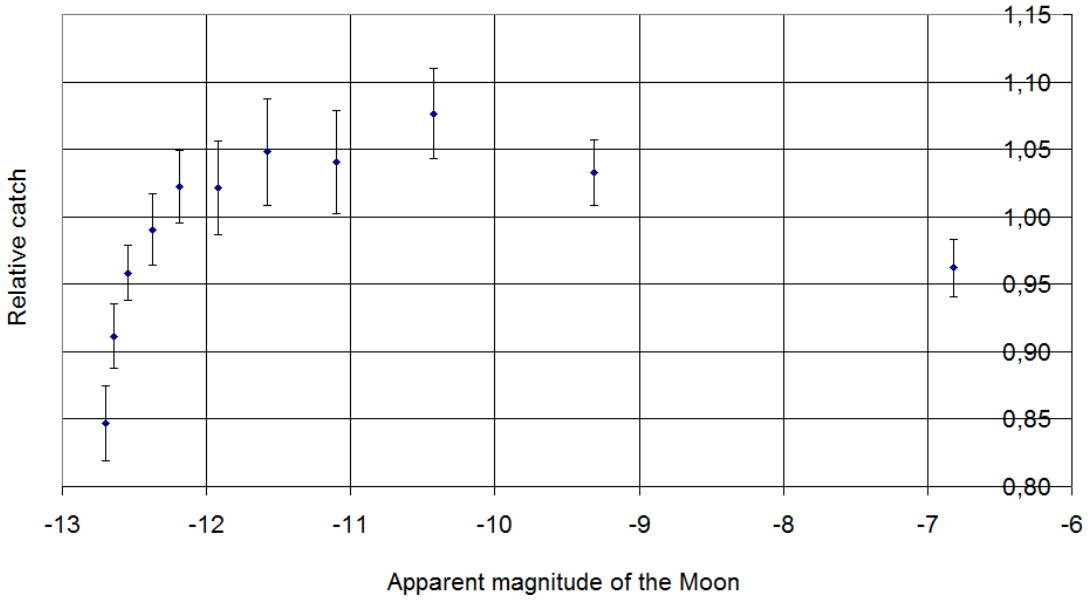


Figure 6. 4. 23 Light-trap catch of Macrolepidoptera sp. complex in connection with the illuminated fraction of the Moon

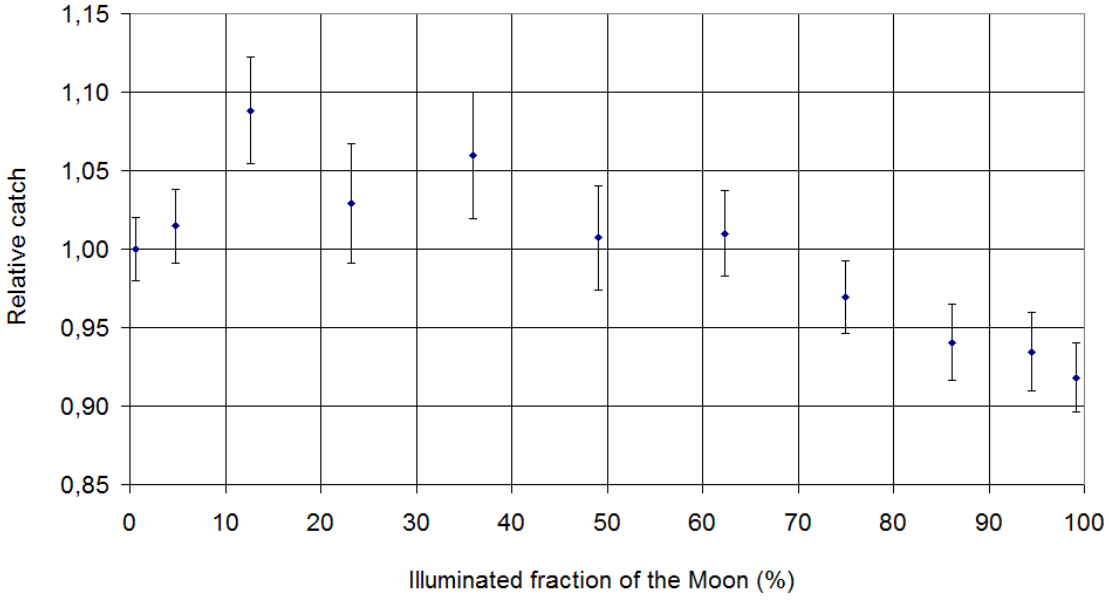


Figure 6. 4. 24 Light-trap catch of Macrolepidoptera sp. complex in connection with the moonlight (lux)

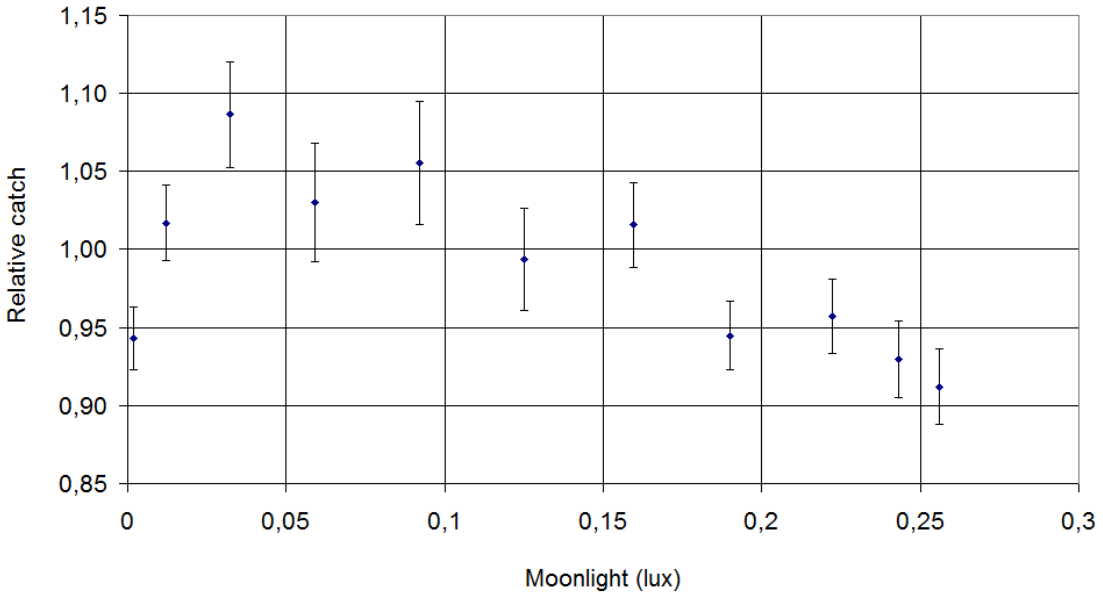


Figure 6. 4. 25 Light-trap catch of migratory sp. complex in connection with the night sky polarization of the Sun (Relative catch is less than 1)

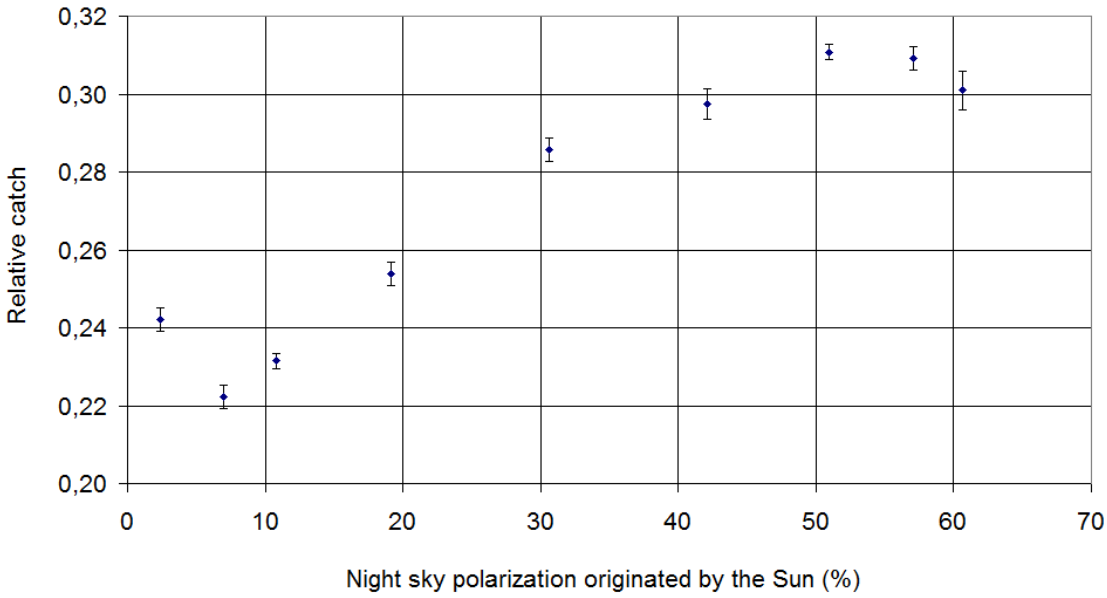


Figure 6. 4. 26 Light-trap catch of migratory sp. complex in connection with the night sky polarization of the Moon (Relative catch is less than 1)

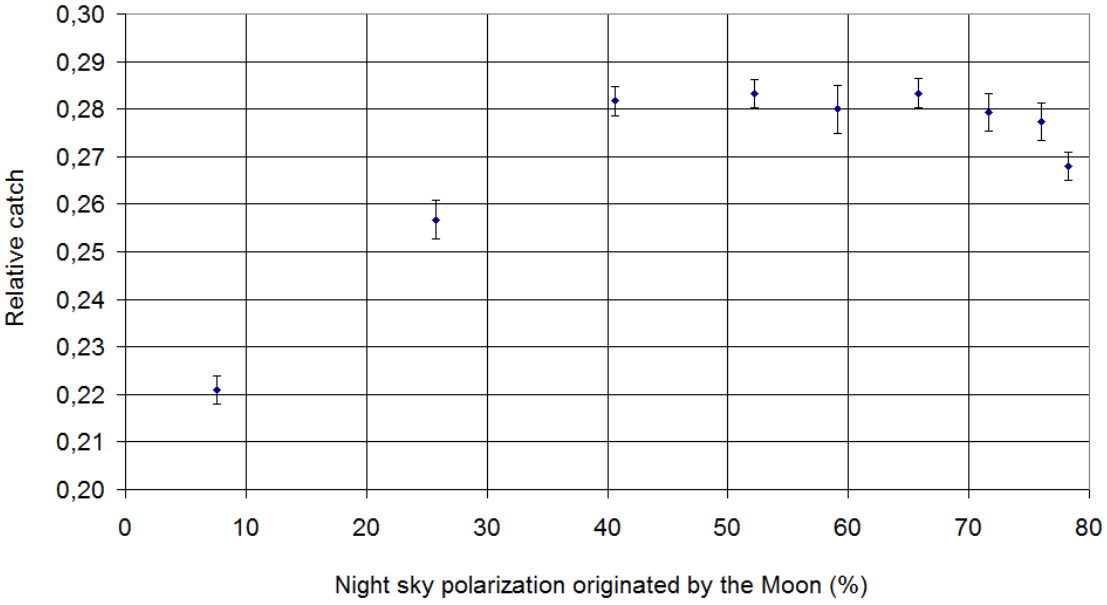


Figure 6. 4. 27 Light-trap catch of migratory sp. complex in connection with the gravitational potential of the Sun (Relative catch is less than 1)

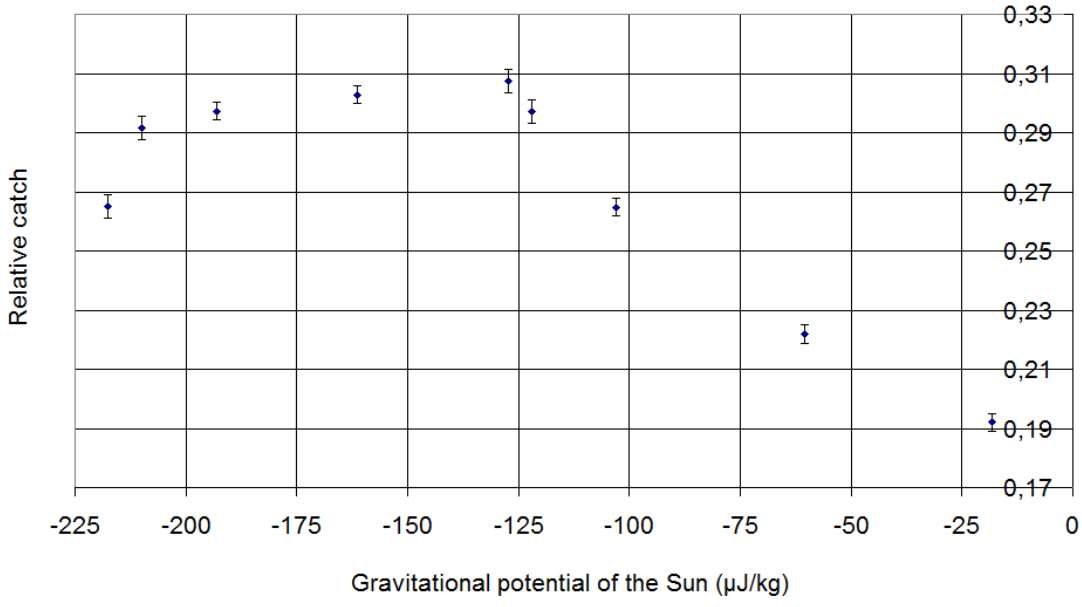


Figure 6. 4. 28 Light-trap catch of migratory sp. complex in connection with the gravitational potential of the Moon (Relative catch is less than 1)

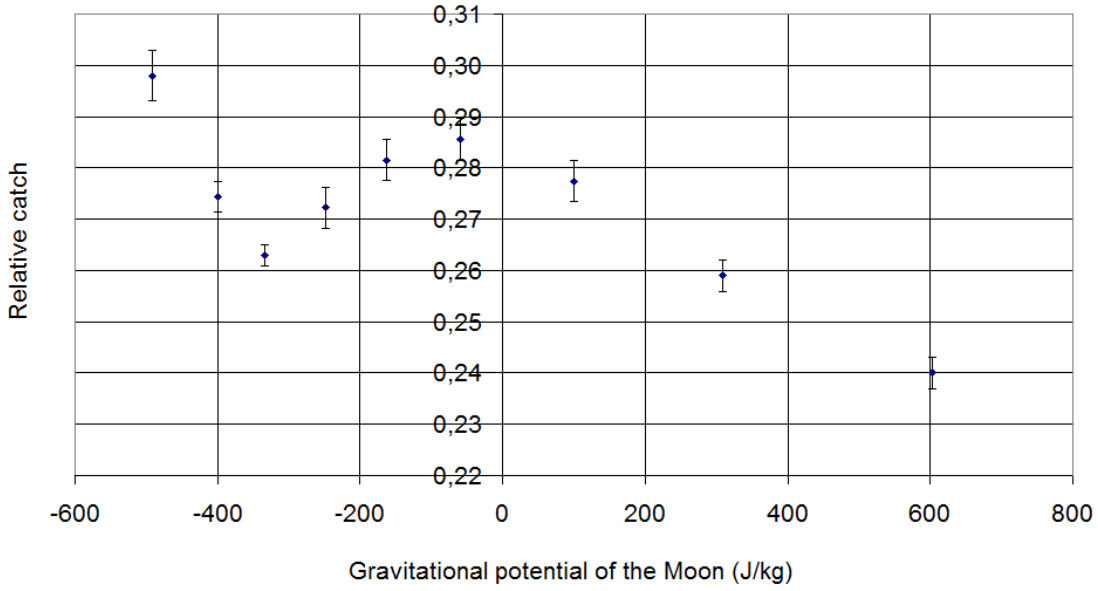


Figure 6. 4. 29 Light-trap catch of migratory sp. complex in connection with the gravitational potential of the Sun+Moon (Relative catch is less than 1)

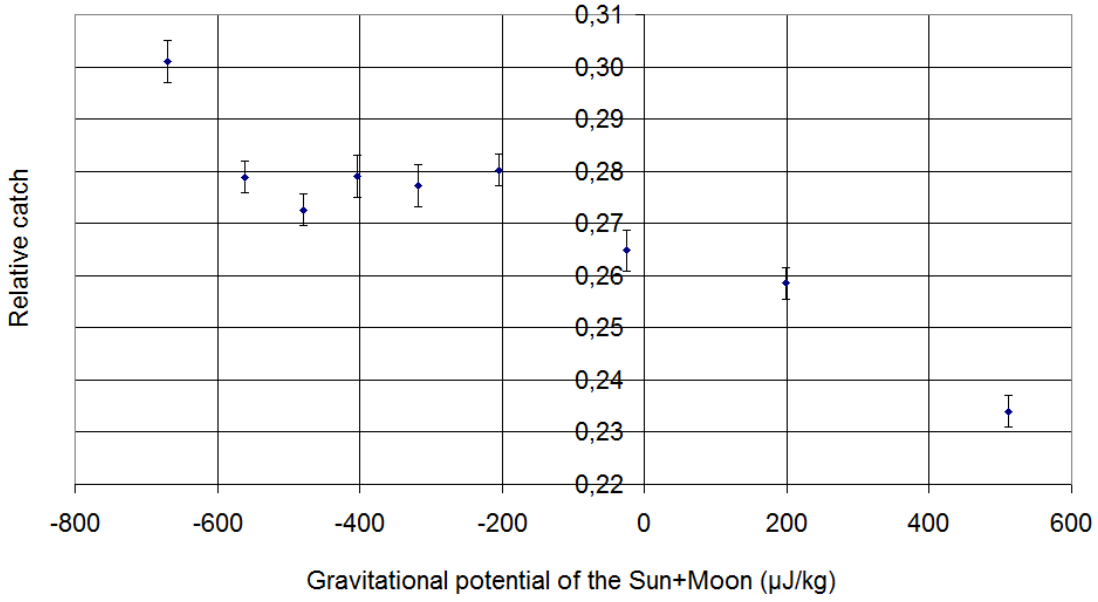


Figure 6. 4. 30 Light-trap catch of migratory sp. complex in connection with the altitude of the Sun's Arago point (Relative catch is less than 1)

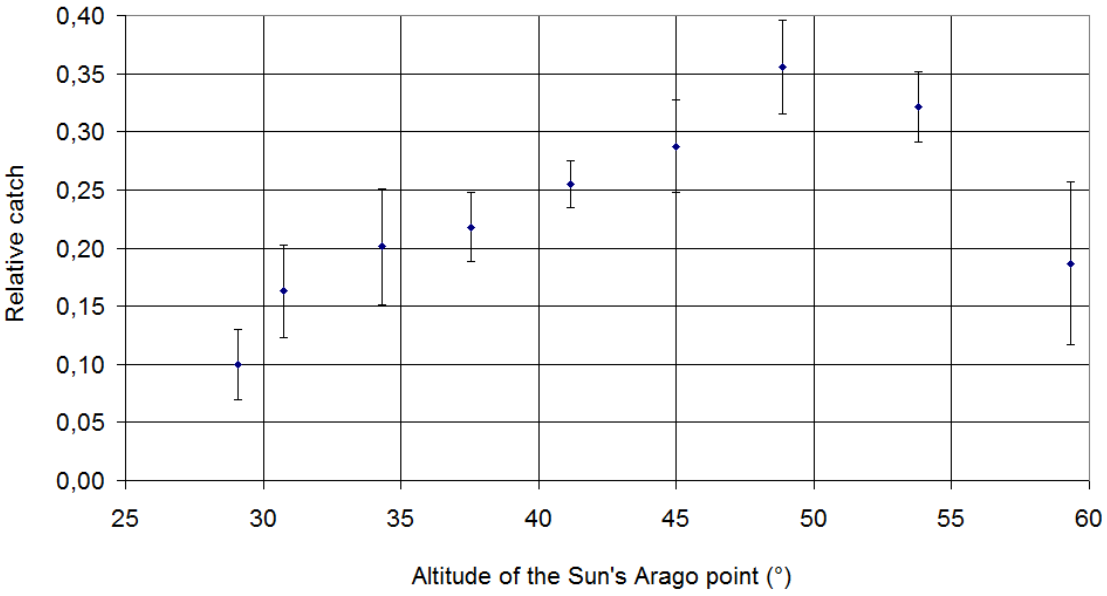


Figure 6. 4. 31 Light-trap catch of migratory sp. complex in connection with the altitude of the Moon's Babinet point (Relative catch is less than 1)

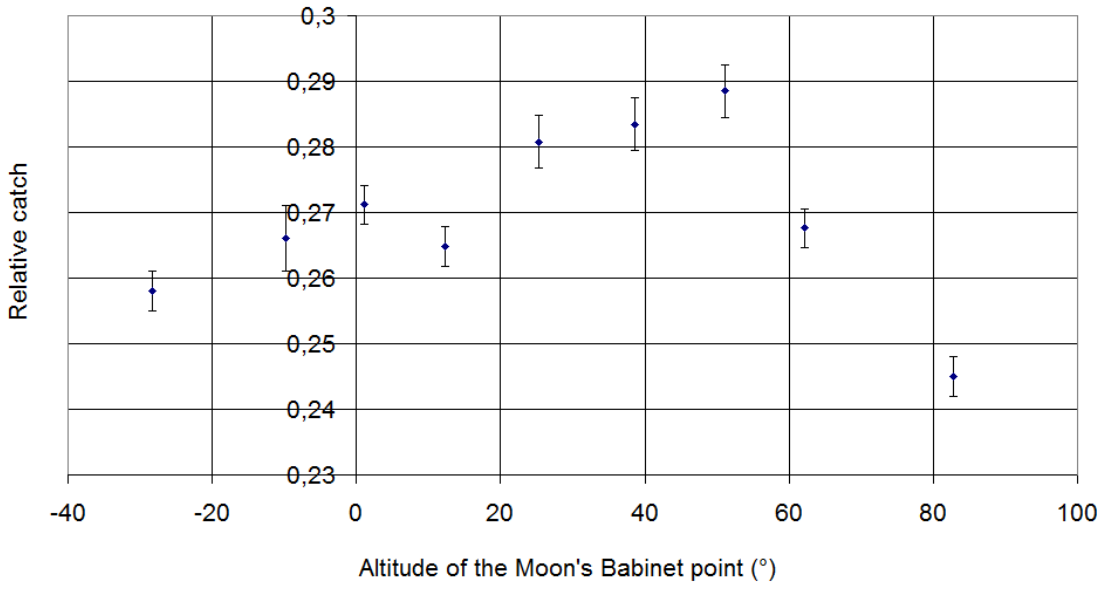


Figure 6. 4. 32 Light-trap catch of migratory sp. complex in connection with the phase angle groups of the Moon (Relative catch is less than 1), (0 = New Moon, 180 =Full Moon)

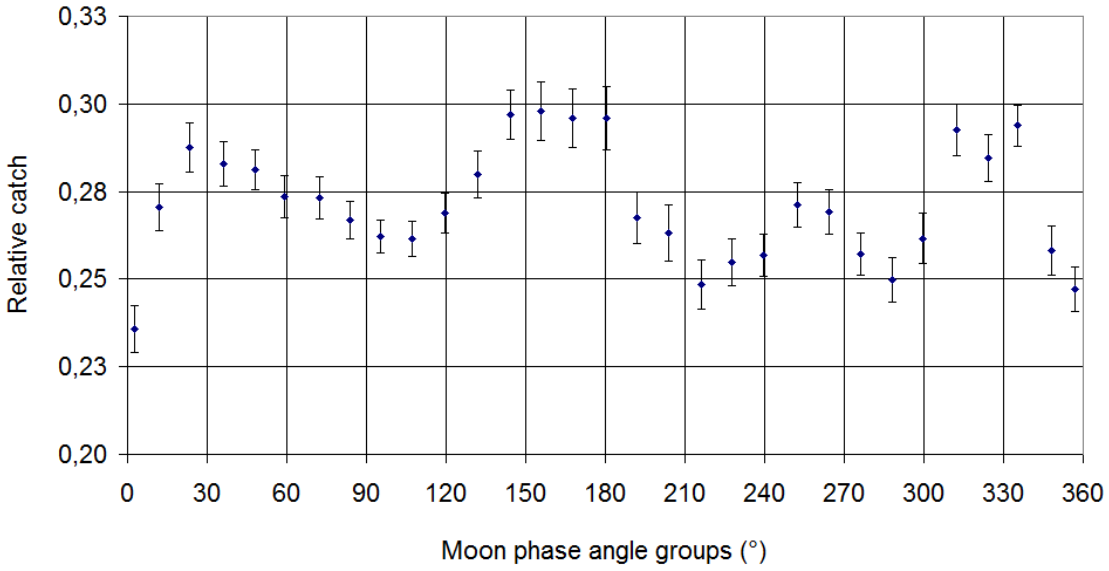
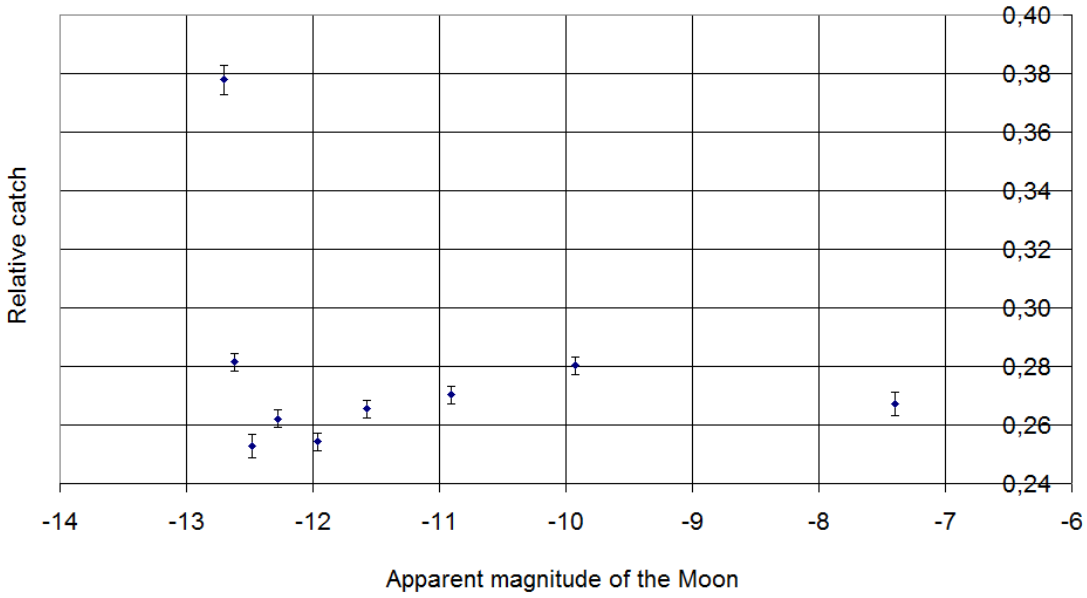


Figure 6. 4. 33 Light-trap catch of migratory spec. complex in connection with the apparent magnitude of teh Moon (Relative catch is less than 1)



The factor analysis yielded unexpected results in the investigation of migratory species. There was not any correlation with any characteristics of Sun and Moon in the low catch group.

Therefore, this group was not further investigated. However, in the future we will examine, by species, which meteorological factor and, possibly, the Sun or the Moon, which influence the trapping of migratory species. However, in the future we will study,

by species, which meteorological factor or feature of the Sun and Moon may influence the trapping of migratory species.
In the presumably locally evolving (low catch) group, similar results were obtained for non-migrating Microlepidoptera and Macrolepidoptera species, both on the basis of factor analysis and in relation to each characteristics. However, in contrast to the above, no significant results were obtained with either the illuminated moon surface, moonlight, or polarized moonlight. The locally evolving individuals appear to be as sensitive to the features of the Sun and Moon as non-migratory species.

6. 5 References

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6. 6 SUPPLEMENT

Insect species enumerated at Stony Rise
All Noctuidae were enumerated (c. 116 species) and an increasing list up to about 50 other species including, among others:

Lepidoptera
Anthelidae: *Pterolocera* sp. (reddish brown, not grass anthelid).
Arctiidae: *Spilosoma glatygnyi* (Le Guillou), woolly bear caterpillar and *S. canescens* (Butler), dark spotted tiger moth; *Utetheisa pulchelloides* Hampson, heliotrope moth.
Gelechiidae: *Phthorimaea operculella*, potato tuber moth.
Geometridae: *Epyaxa subidaria* (Guenée); *Mnesampela privata* (Guenée), autumn gum moth; *Thalaina selenaea* (Doubleday) and *T. inscripta* Walker, satin moths.
Hepialidae: *Fraus simulans*, lesser ghost moth; *Oncopera* spp., corbies; *Oxycanus antipoda*, oxycanus grass grub.
Limacodidae: *Doratifera pinguis* (Walker), cup moth.
Notodontidae: *Trichiocercus sparshalli* (Curtis).
Plutellidae: *Plutella xylostella*, diamondback moth.
Pyralidae: *Achyra affinitalis* (Lederer), cotton web spinner; *Culladia cuneiferellus* (Walker); *Etiella behrii* (Zeller), lucerne seed web moth; *Hednota crypsichroa* Lower, *H. relatalis* (Walker) and *H. pedionoma* (Meyrick) , pasture webworms; *Hellula hydralis* Guenée, cabbage-centre grub; *Nacoleia rhoealis* (Walker); *Ptochostola microphaeellus* (Walker); *Sceliodes cordalis* (Doubleday), eggfruit caterpillar; *Uresiphita ornithopteralis* (Guenée), tree lucerne moth.
Saturniidae: *Opodiphthera helena* (White), Helena gum moth.
Sphingidae: *Hippotion scrofa* (Boisduval), scrofa hawk moth; *H. celerio* (Linnaeus), vine hawk moth.
Coleoptera
Scarabaeidae: *Acrossidius tasmaniae,* blackheaded pasture cockchafer; *Adoryphorus couloni*, redheaded pasture cockchafer.
Diptera
Syrphidae: *Melangyna* sp., hover fly.

Hemiptera
Lygaeidae: *Nysius vinitor* Bergroth, Rutherglen bug; *Remaudiereana inornata* (Walker); *Neolethaeus australiensis* Woodward.
Miridae: *Creontiades dilutus* (Stål), green mirid; *Stenotus binotatus* (Fabricius); *Chaetedus longiceps* Eyles.
Nabidae: *Nabis kinbergii* Reuter, Pacific damsel bug.
Tettigarctidae: *Tettigarcta tomentosa* White, hairy cicada.
Hymenoptera
Ichneumonidae: *Netelia* species and *Dicamptus* species.
Neuroptera
Chrysopidae: *Apertochrysa edwardsi* (Banks); *Mallada signata* (Schneider), green lacewing; *M. tripunctata* (McLachlan); *Nothancyla verreauxi* Navas.
Conipterygidae: *Coniopteryx* sp.; *Neosemidalis* sp.
Hemerobiidae: *Micromus tasmaniae* (Walker), brown lacewing; *Drepanacra binocula* (Newman); *Psychobiella sordida* (Banks); *Psectra nakaharai* New; *Megalomima berothoides* (McLachlan); *Notherobius nothofagi* New.
Osmylidae: unidentified species.
Sisyridae: *Sisyra* sp.

CHAPTER 7
USA (Nebraska and North Carolina)

Light-trap Catch of the Lepidoptera Species in Connection with the Sun's and Moon's Characteristics (BL Traps)

Nowinszky L., Puskás J., Kiss M., Barta A.

7. 1 Introduction

There are used light-traps for forecast of harmful insects in several states in the USA. The light-trap catch data can be found on the web. The black light traps (BLT) of North Carolina and Nebraska supplied a huge scientific material over the past two decades for entomological basic research, and plant protection prognostics work for the farmers.
These light traps are primarily used to inform farmers. We did not find any studies from their data related to the topic of our current work. However, we refer to an important new result.
Nielsen et al. (2013) found the New Jersey light trap network suitable for the early detection of the invasive species *Halyomorpha halys* Stål (Hemiptera: Pentatomidae). This statement may be true for other species.
In our own studies, we have already processed light trap data collected in the USA in Nebraska and North Carolina states.
Puskás et al. (2007) ascertain that from the difference significant on the night of the hurricane and the one preceding it the insects have a presentiment of the hurricane already the night before. Obviously, there is no catch during the passage of the hurricane, while the catch is high on the following night. So instead of perishing, the insects survive the hurricane.
It has been known ever since the beginning of the 19th century that the light of the sky is partly polarized. This is because the light from the Sun gets scattered by the molecules and aerosol particles of the atmosphere (Raleigh scattering, Mie effect). The degree of polarization is char-acterized by the quotient of the quantity of polarized and non-polarized light. The existing state of polarization is always determined by a combination of the geographical location, the season of the year, the angle of incidence of the Sun's radiation, the aerosol saturation of the atmosphere and several microclimatic factors. A clear sky always generates less polarized light than a clouded or especially a completely overcast sky. According to Lipsky and Bondarenko (1970) maximum polarization appears in an area some 85° from the direction of the Sun.
The results of Nowinszky & Puskás (2012) indicate that when a high proportion of moonlight is polarized, flight activity of *Caenurgina erechtea* Cramer, *Heliothis zea* Boddie, and *Striacosta albicosta* Smith increases but when there is a low level of polarization, as at a full moon, flight activity decreases in North Carolina and Nebraska States (USA).
Our recent paper (Nowinszky et al. 2019a) deals with the night sky polarization originated by the Sun in relationship with the success of light trap catch of insects in Nebraska and North Carolina states between 1994 and 2017. The Sun's sky polarization can be seen for the insects all the nights. The sky polarization is dissimilar from each of the midnight hours of catching periods. We conclude from this indisputable reality that the apex of the swarming of each species is closely related to a given value of the polarization in the nightly sky, which relates to the calendar date. Our latest paper (Nowinszky et al. 2019b) treats with certain features of night sky and the Moon in connection with the success of light trap catch of European Corn-

borer (*Ostrinia nubilalis* Hübner, 1790) in Hungary and Nebraska and North Carolina states of USA between 1959-2006 and 1994-2017. The features were examined as follows: Altitude of the Sun's Arago point above horizon, altitude of the Moon's Babinet point above horizon, altitude of the Moon above horizon, apparent magnitude of the Moon, illuminated fraction of the Moon and the moonlight lux value. We found that the neutral points of the sky and some features of the Moon that have not yet been investigated by others influence catch. A similar effect can be seen in the results of the light-trap catch of the *Ostrinia nubilalis* Hbn. both in Hungary and in America.

7. 2 Material

UNL Extension Entomology is monitoring crop insect pests (primarily moths) using black light traps at the Haskell Ag Laboratory near Concord, the South Central Ag Laboratory near Clay Center, and the West Central Research and Extension Center near North Platte.
In this investigation the BL traps data of USA States of North Carolina and Nebraska were used. These were downloaded from North Carolina Pest News on the Internet and the North Carolina Cooperative Extension Service websites. The light-trap collecting data of Nebraska State were from the years among 2000 and 2017 and the North Carolina State traps' material was found in years between 1994 and 2010. In these states, 15 W BL traps were in operation. The data collection was published several times each year for farmers, in order to utilize these data in their plant protection works. We could investigate only the data of eight species, because enough catch data were found (Table 1).

Table 1 Catching data of examined species

Species	Years	Insects	Data	Nights
Erebidae				
Yellow Wolly Bear *Spilosoma virginica* (Fabricius, 1798		45,843	1,743	1,288
Woolly Bear *Pyrrharctia isabella* J.E-Snith, 1797	6	10,300	290	277
Banded Tiger Moth *Apanthesis vittata* Fabricius, 1787	3	1,174	272	254
Forage Looper *Caenurgina erechtea* Cramer, 1780	16	36,531	2,106	1,353
Corn Earworm *Heliothis zea* Boddie, 1850	22	75,023	23,061	1,307
Western Bean Cutworm *Striacosta albicosta* Smith, 1888	18	86,519	1,358	693
Dingy Cutworm *Feltia jaculifera* (Guenée, 1852)	4	10,855	170	63
Celery Looper *Anagrapha falcifera* Kirby, 1837	18	4,957	491	211

7. 3 Methods

We calculated the Sun's and Moon's features (see also Chapter 1. 2) for the geographical coordinates of Lenoir (North Carolina) and Clay City (Nebraska). For this we first determined the celestial position of the Sun and the Moon for every point in time of the above interval for a geographic position of 35° 54' 50" N and 81° 32' 20" W at Lenoir and 40° 31' 20" N and 98° 3' 18" W at Clay City.

We had only one collection data from a whole night, so we worked with the polarization data calculated for 11 p.m. (GT).
We have examined the effectiveness of Sun's and Moon's features for the catching individuals. We did not receive significant values for the night sky polarization of Moon, so these results are not published. We depicted on figures the results of all the Sun's and Moon's features and the connection with catching data of Macrolepidoptera sp. complex. Figures also show the confidence intervals.
We depicted the results coming from the different features and the connection with light-trap catch. Figures also show the confidence intervals.

7. 4 Results and Discussion

Our results are shown in Figures 1-9.

Figure 7. 4. 1 Light-trap catch of Macrolepidoptera sp. complex in connection with the night sky polarization originated by the Sun (Nebraska and North Carolina)

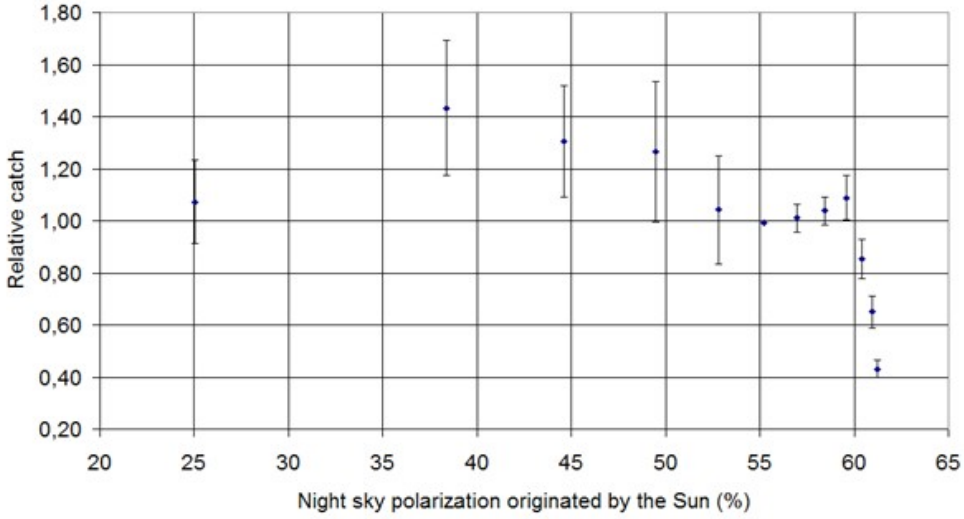


Figure 7. 4. 2 Light-trap catch of Macrolepidoptera sp. complex in connection with the gravitational potential of the Sun (Nebraska and North Carolina)

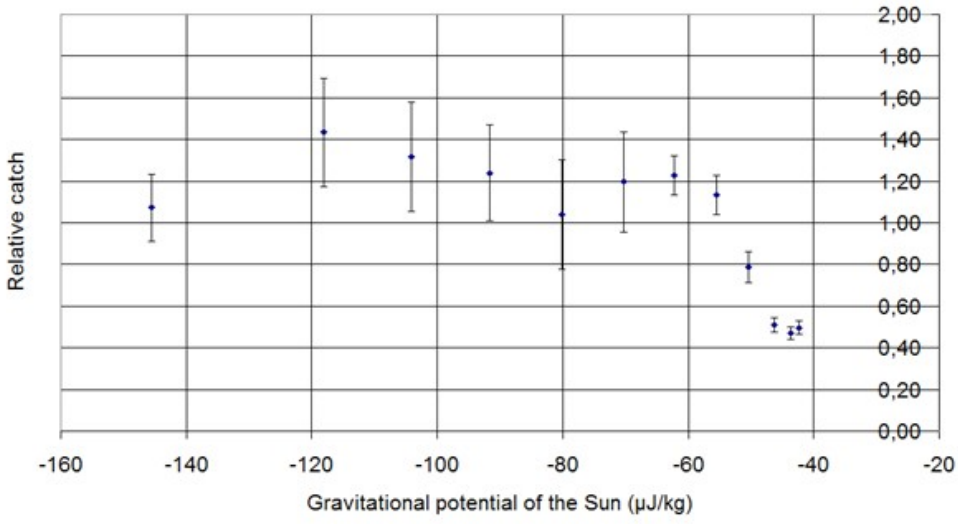


Figure 7. 4. 3 Light-trap catch of Macrolepidoptera sp. complex in connection with the gravitational potential of the Sun+Moon (Nebraska and North Carolina)

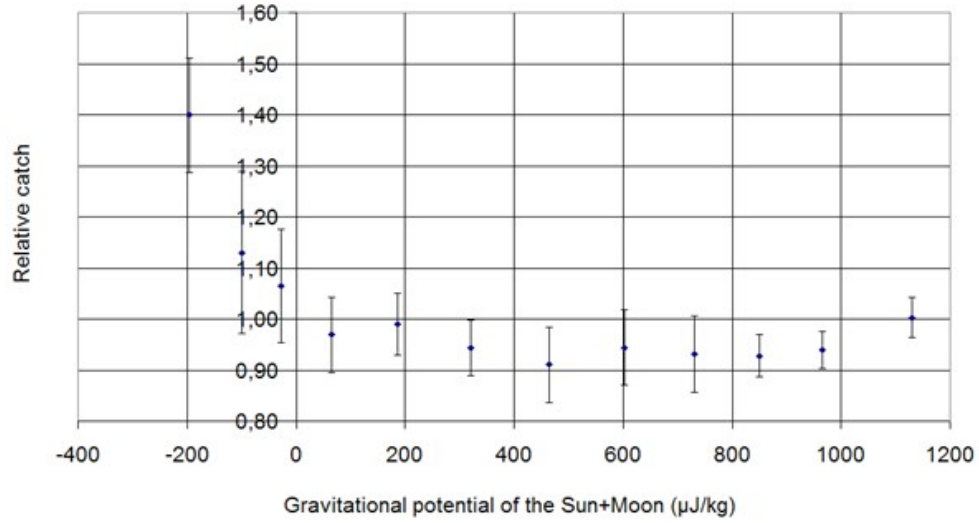


Figure 7. 4. 4 Light-trap catch of Macrolepidoptera sp. complex in connection with the altitude of the Sun's Arago point (Nebraska and North Carolina)

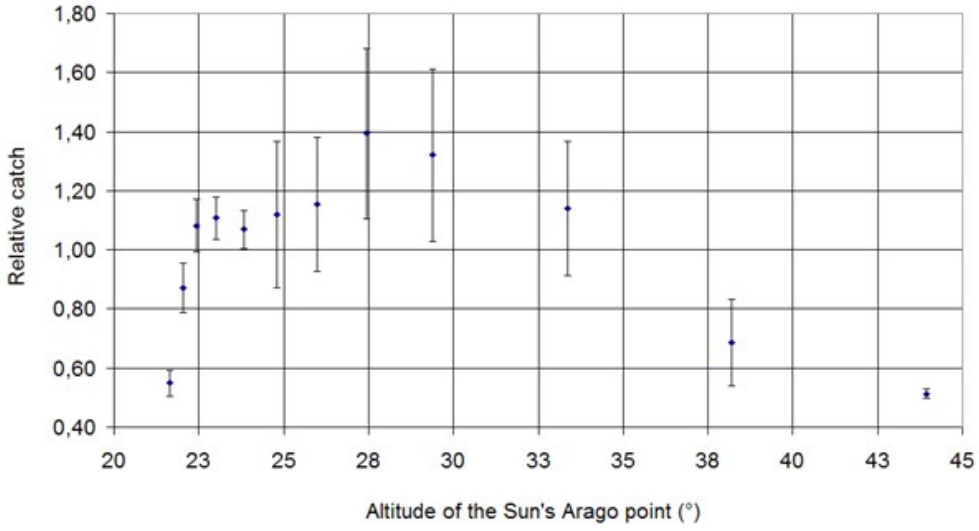


Figure 7. 4. 5 Light-trap catch of Macrolepidoptera sp. complex in connection with the altitude of the Moon's Babinet point (Nebraska and North Carolina)

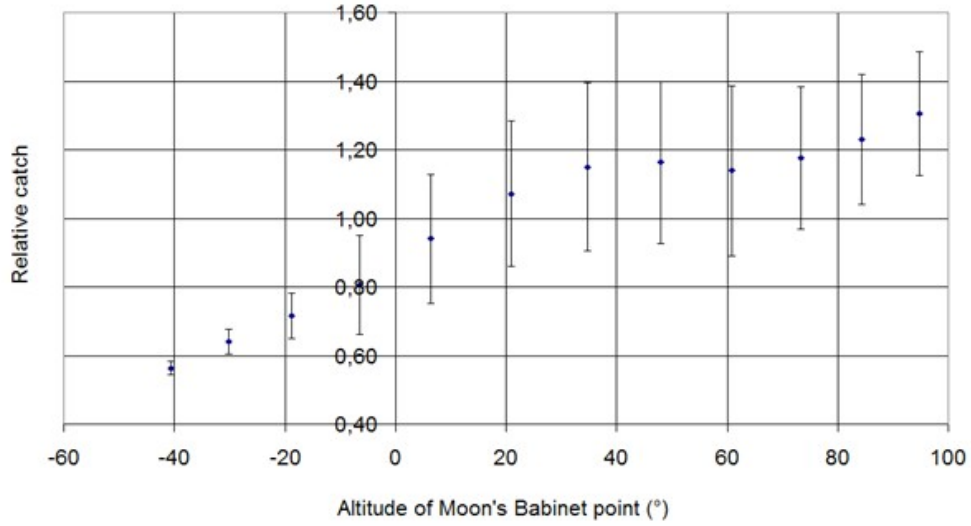


Figure 7. 4. 6 Light-trap catch of Macrolepidoptera sp. complex in connection with the phase angle groups of the Moon (Nebraska and North Carolina)
(0° and 360° = New Moon, 180° = Full Moon)

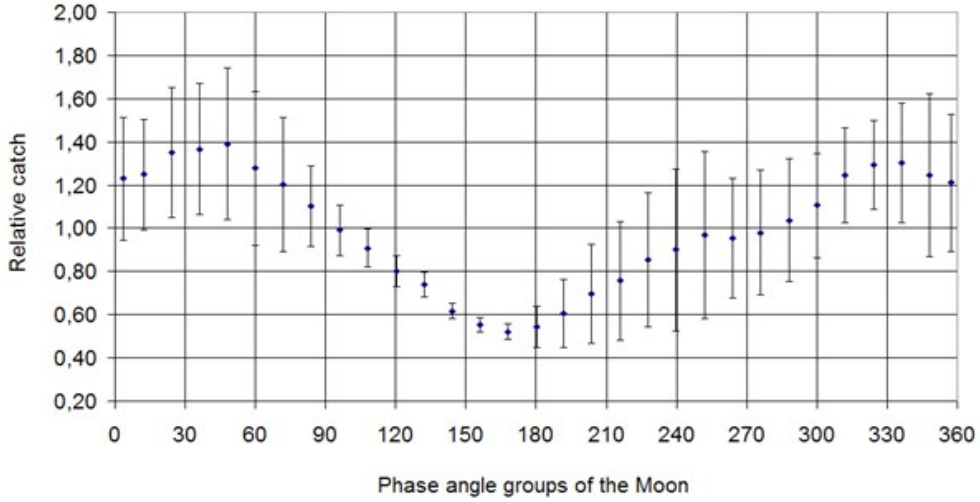


Figure 7. 4. 7 Light-trap catch of Macrolepidoptera sp. complex in connection with the apparent magnitude of the Moon (Nebraska and North Carolina)

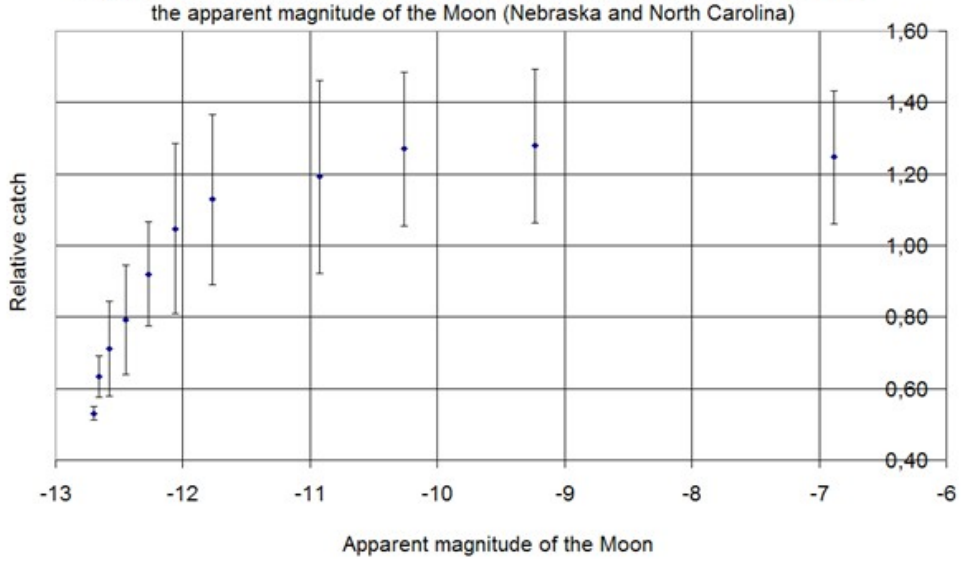


Figure 7. 4. 8 Light-trap catch of Macrolepidoptera sp. complex in connection with the illuminated fraction of the Moon (Nebraska and North Carolina)

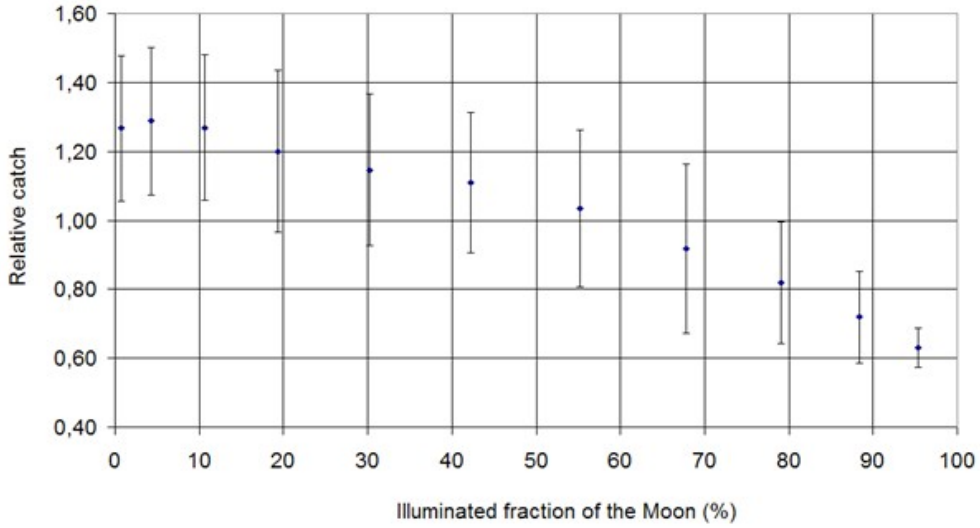
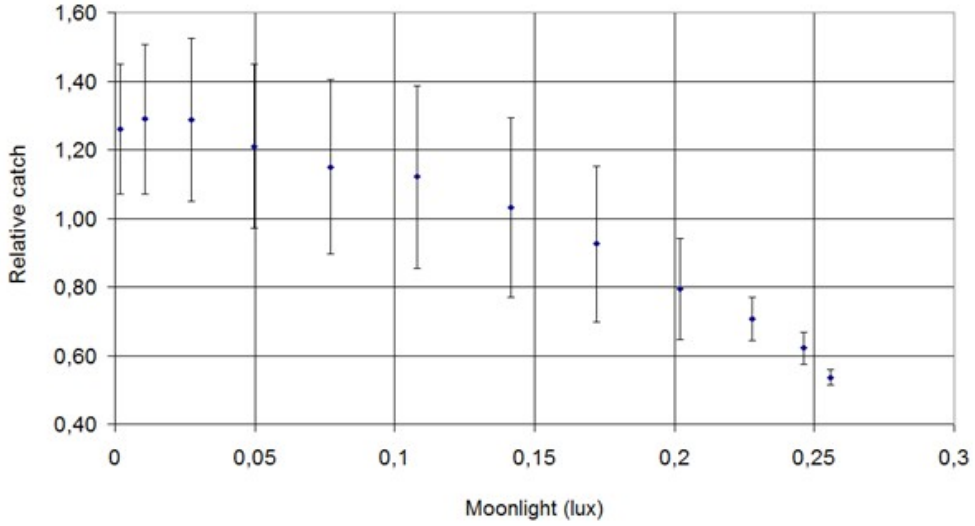


Figure 7. 4. 9 Light-trap catch of Macrolepidoptera sp. complex in connection with the moonlight (Nebraska and North Carolina)



Light trap data from the states of Nebraska and North Carolina also gave similar results between the Sun's gravitational potential and the sky polarization and the light-trap catch as in Central Europe and Australia.

The polarization of the night sky originated by the Sun is different from each of the midnight hours of collecting periods. We believe that the most successful catch of each species has different polarization values. From this fact we conclude that the peak of the swarming of each species is closely related to a given value of the polarization in the sky, which is related to the calendar date.

It is striking, however, that we did not find any connection between the gravity of the Moon and the celestial polarization it produces. However, both the Sun's Arago Point and the Moon's Babinet Point influenced light-trap catch.

We found a high catch in the environment of New Moon. This is confirmed by the other features of the Moon, the apparent magnitude of the Moon, the percentage of its illuminated surface, and the moonlight.

7. 5 References

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CHAPTER 8
(Central Europe, Hungary)

Pheromone Trap Catch of the Microlepidoptera Species in Connection with the Sun's and Moon's Characteristics

Puskás J., Nowinszky L., Kiss M., Barta A., † Barczikay G.

8. 1 Introduction

Pheromone traps, besides light-traps, play an important role in the forecasting system of insect pests. However, the efficiency of the traps can be modified by several biotic and abiotic factors in both the collection method. Understanding these would be exceptionally important.
If the number of the specimens increases after each renewal of the pheromone capsule replacement we receive regularly a false result about the real course of swarming (Voigt et al., 2010). Tóth et al. (2010) suggest there is a disadvantage with pheromone traps, that they only catch male individuals. Therefore, researchers worldwide engaged for developing new attractants suitable for females.
Research work is complicated by the fact that the catch result is not daily counted in most cases, but according to the proposal of Tóth (2003) 2-3 days together, aggregated. Ghobari et al. (2009) also checked in every second day the number of captured (*Tortrix viridana* L.) individuals in Iran. Abbes & Chermiti (2011) renewed the sex pheromone capsules every four weeks and the number of captured males of Tomato Leafminer (*Tuta absoluta* Meyrick) was recorded every week before the change of the sticky cardboards. Sípos (2012) caught by pheromone traps the Raspberry Cane Midge (*Resseliella theobaldi* Barnes) males. She changed the sticky sheets once a week and pheromone capsules once per several months. Hári (2014) counted fruit moths twice weekly and replaced the lures every 4-6 weeks. The sticky sheets were exchanged on the basis of saturation and degree of contamination.
Pénzes et al. (2010) claimed that sex pheromone traps can be used effectively for forecasting if the collected insects are counted daily. Giri et al. (2014) counted the number of Potato Tuber Moth (*Phthorimaea operculella* Zeller), caught by pheromone trap, every morning between 6 and 8 a.m. in Nepal. Nasseh & Moharam (1991) captured and counted African Armyworm (*Spodoptera exempta* Walker) moths daily and changed the pheromone capsules every three weeks.
The attracting force of pheromone capsules is not weakened by moonlight. Consequently, any lunar influence detected shall not be explained by the change of collecting distance or the suspected effect of moonlight in decreasing flight activity. Kehat et al. (1975) used traps containing live intact females and synthetic pheromone to collect the Cotton Leaf-worm (*Spodoptera littoralis* Boisduval) on cotton fields in Israel. No correlation between the catch and the lunar phases could be found.
Collecting with synthetic pheromone traps in Malawi, Marks (1976) found that moonlight had no hindering influence on captures of the Pink Bollworm (*Pectinophora gossypiella* Saud). During 1981 and 1982 in maize and sorghum fields in western Kenya, Ho and Reddy (1983) caught the following moth species using light traps and pheromone traps baited with intact females: The African White Stem Borer (*Maliarpha separatella* Ragonot), the Spotted Stalk Borer (*Chilo partellus* Swinhoe), the African Sugarcane Borer (*Eldana saccharina* Walker),

the African Pink Stem Borer (*Sesamia calamistis* Hampson) and the Maize Stalk Borer (*Busseola fusca* Fuller). They found moonlight to have a stronger influence on the catch by light traps than on the catch by pheromone traps. Hoffmann et al. (1991) operated a pheromone trap in California to catch Corn Earworm (*Heliothis zea* Boddie) and Darker-spotted Straw Moth (*Heliothis phloxiphaga* Grote & Robinson). Lunation did not have an influence on the timing of catch peaks. Suckling and Brown (1992) operated pheromone traps in an orchard in New Zealand between 1989 and 1991, to monitor populations of the Black-lyre Leafroller (*Ctenopseustis herana* Walker), the Green Headed Leafroller (*Planotortrix octo* Dugdale), the Codling Moth (*Cydia pomonella* Linnaeus) and the Light Brown Apple Moth (*Epiphyas postvittana* Walker). Lunation did not have a significant influence. In their pheromone trap experiments focusing on the Scarce Bordered Straw (*Helicoverpa armigera* Hübner), Sekhar et al. (1995) did not observe any difference between the catch at a Full Moon and at a New Moon.

The following studies confirm the theory of decreased trapping efficiency of moths in the vicinity of a Full Moon. To record the weekly number of male specimens of the Potato Tuberworm (*Phthorimaea operculella* Zeller) Roux and Baumgartner (1995) operated pheromone traps on potato fields in Tunisia between 1986 and 1991. They detected a four-week cycle presumably influenced by the Moon. Operating sex pheromone traps, Parajulee et al. (1998) were monitoring the flight activity of the Corn Earworm (*Helicoverpa zea* Boddie) and the Tobacco Budworm (*Heliothis virescens* Fabricius) in Texas for 15 years, between 1982 and 1996. The daily catch of the trap was influenced by lunar phases. They revealed a significant positive correlation between the catch and the percentile value of lunar illumination. The maximal daily catch of the trap occurred at a Full Moon (71 %), followed by the values of the First Quarter (11 %), the Last Quarter (9 %) and that of the New Moon (9 %). Using pheromone traps, Rajaram et al. (1999) collected cotton pests in 1994 in India. They observed a characteristic difference between the nocturnal activity of the week of the Full Moon and the New Moon. The ratio of the week of Full Moon and New Moon was 1:1.40 for the Pink Bollworm *(Pectinophora gossypiella* Saunders) and 1:1.17 for the Oriental Leafworm Moth *(Spodoptera litura* Fabricius). Das and Katyar (2001) studied the pheromone trap catch of the Oriental Leafworm Moth *(Spodoptera litura* Fabricius) in India. The lowest catch results were recorded in the vicinity of Full Moon. According to their investigations, collecting is more efficient in the period between Full and New Moon than in the period between New and Full Moon. Between 1973 and 1990 Sheng et al. (2003) operated "Gossyplure" pheromone traps for the Pink Bollworm Moth *(Pectinophora gossypiella* Saunders) at 10 entomological forecast stations of China. The highest activity was recorded in the First Quarter, resulting in a significant catch peak. Kamarudin and Wahid (2004) used a pheromone trap to collect the Coconut Rhinoceros Beetle *(Oryctes rhinoceros* Linnaeus). Male beetles were more active during Full Moon. However, Gebresilassie et al. (2015) found that the number of *Phlebotomus orientalis* Parrot and the other *Phlebotomus* spp. from A4 sized sticky traps of polypropylene sheets coated with sesame oil did not differ in their density among the four lunar phases.

We have already studied the pheromone trap catch results in relation to the phases of the Moon (Nowinszky et al., 2010, 2016). We published the results of the pheromone trap catch of many species distributions for each moon phase. We also investigated, using new data, the cause of observed differences at different moon phases in our present study.

Examining the light-trap catches of the selected insect species, we found consequent alterations of the catching curves, which seemed to show high correlation to the polarization rate of the moonlight.

The effects of celestial polarization and gravity caused by the Sun and Moon have also been demonstrated on trapping of pheromone traps on eight Microlepidoptera species (Nowinszky et al. 2017).

8. 2 Material

For the present report, we worked with Csalomon type pheromone sticky traps in Bodrogkisfalud (48°10'N, 21°21'E; Borsod-Abaúj-Zemplén County, Hungary, Europe) between 1982 and 2013. Two traps were operated every year and every day between 1st April and 30th September. These traps caught eight Microlepidoptera species en masse.
The pheromone traps were placed on leafy trees of the same branches and vines at a distance of 50 meters between the traps. The height of each species was different, from 1.5 to 2 meters. The traps operated from 1st April to 30th September. Following the method of Tóth (2003), pheromone dispenser capsules were renewed at 6-8-week intervals. The number of caught moths was recorded daily, which is different from the general practice of counting the catch at two or three day intervals.
The pheromone traps operated in the same orchards and vineyards in every year. There were no affected by chemical pest control treatments.

The catching data of the harmful moth species are presented in Table 8. 2. 1.

Table 8. 2. 1 The caught species, catching years and number of moths, data and days

Families and Species	Years	Number of		
		Moths	Data	Days
Gracillariidae, Lithocolletinae Spotted Tentiform Leafminer *Phyllonorycter blancardella* Fabricius, 1781	1988, 1994-2013	91,906	4,027	3,849
Hawthorn Midget *Phyllonorycter corylifoliella* Hübner, 1796	2008-2013	10,202	1,712	967
Gelechiidae, Anacampsinae Peach Twig Borer *Anarsia lineatella* Zeller, 1839	1988, 1993-2013	14,714	3,572	3,502
Tortricidae,Tortricinae Vine Moth *Eupoecilia ambiguella* Hübner, 1796	1982-1983, 1985, 1987-1988	2,008	353	353
Tortricidae, Olethreutinae European Vine Moth *Lobesia botrana* Denis et Schiffermüller, 1775	1982-1985, 1993-2013	33,558	4,104	3,780
Codling Moth *Cydia pomonella* Linnaeus, 1758	1993-2013	16,079	3,841	3,606
Oriental Fruit Moth *Grapholita molesta* Busck, 1916	1993-2013	26,868	4,375	3587
Plum Fruit Moth *Grapholita funebrana* Treitschke, 1835	1982, 1993-2013	53,512	5,314	3,498

8. 3 Methods

The methods are described in detail in Chapter 1. 1. 3.

8. 4 Results

Our results are shown in Figures 8. 4. 1.- 8. 5. 10.

Figure 8. 4. 1 Pheromone trap catch of Microlepidoptera sp. complex in connection with the night sky polarization originated by the Sun

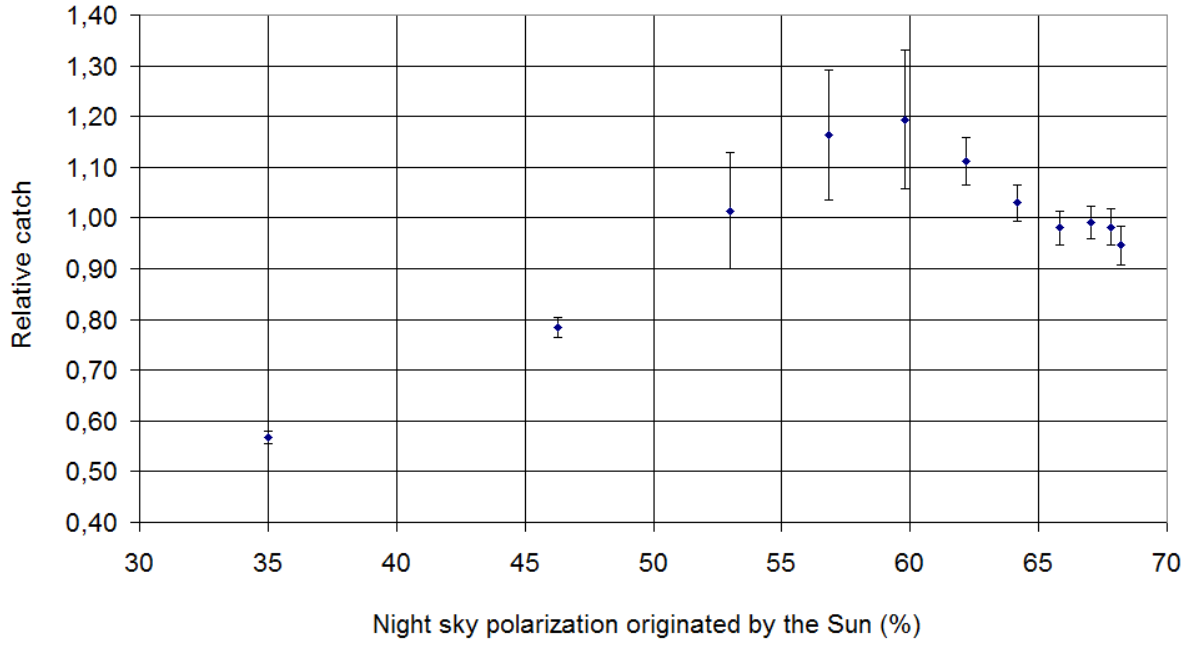


Figure 8. 4. 2 Pheromone trap catch of Microlepidoptera sp. complex in connection with the night sky polarization originated by the Moon

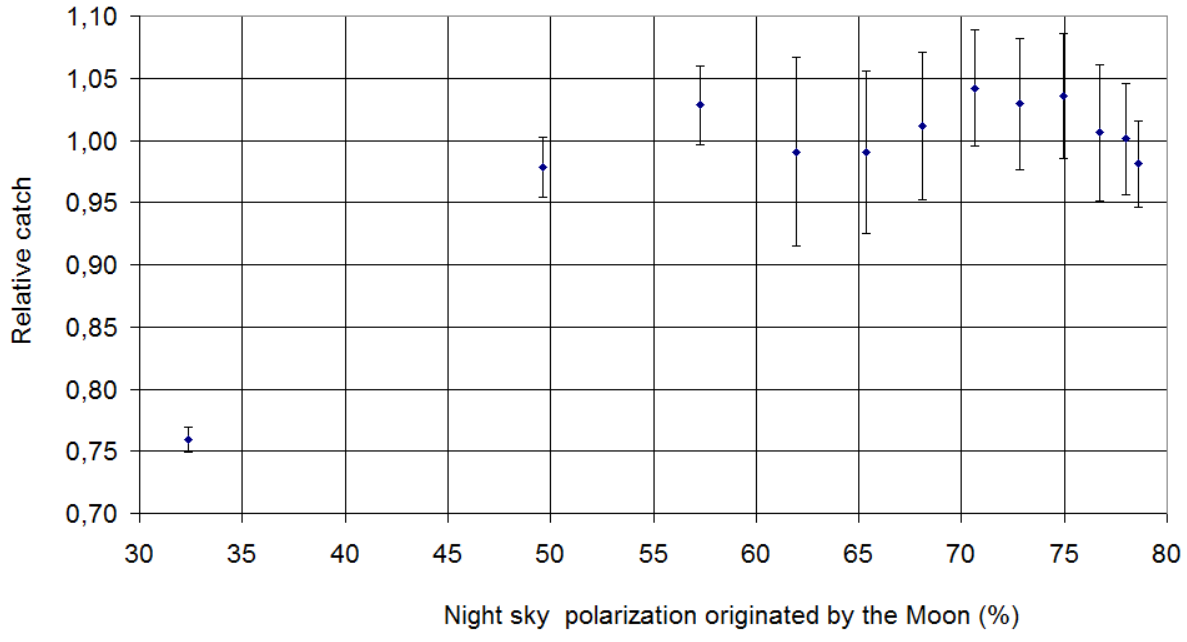


Figure 8. 4. 3 Pheromone trap catch of Microlepidoptera sp. complex in connection with the gravitational potential of the Sun

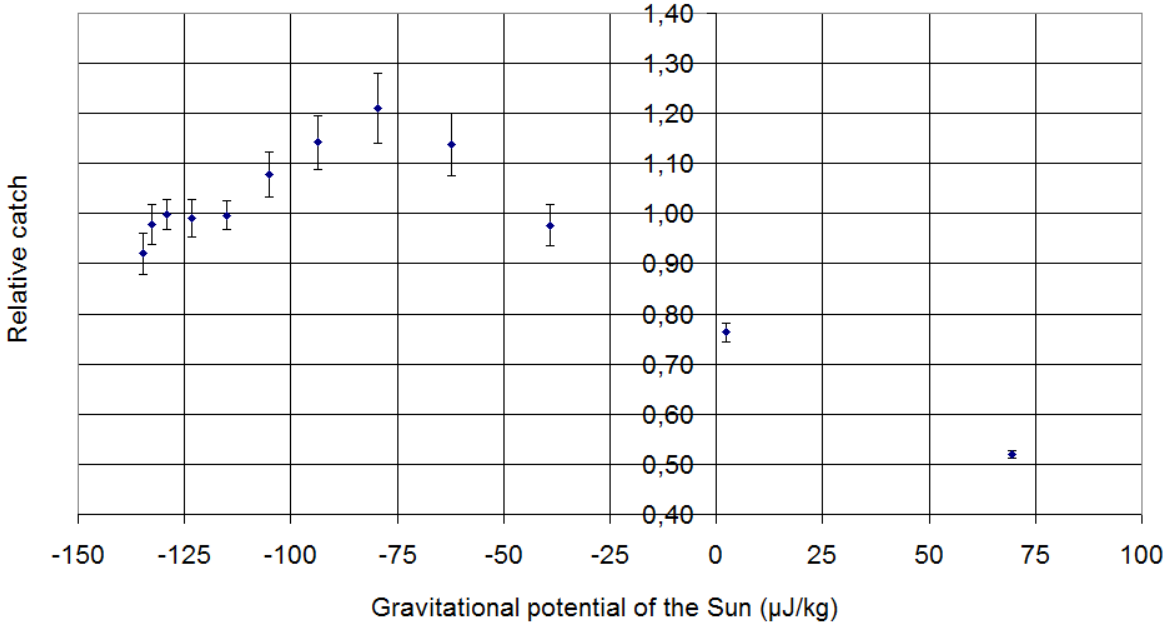


Figure 8. 4. 4 Pheromone trap catch of Microlepidoptera sp. complex in connection with the gravitational potential of the Moon

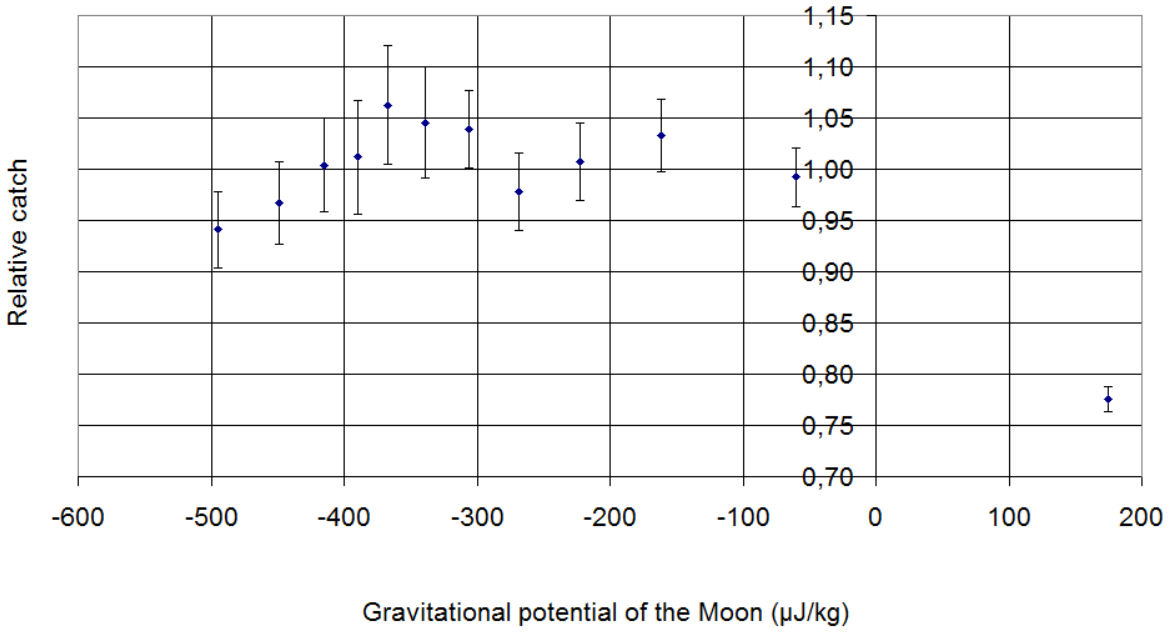


Figure 8. 4. 5 Pheromone trap catch of Microlepidoptera sp. complex in connection with the gravitational potential of the Sun+Moon

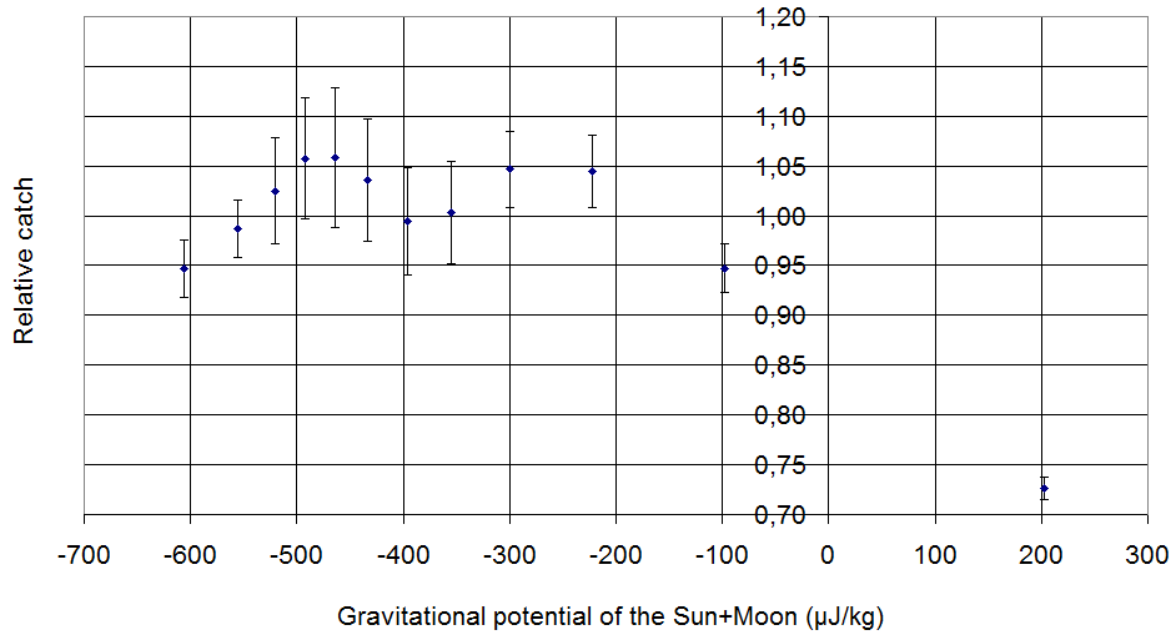


Figure 8. 4. 6 Pheromone trap catch of Microlepidoptera sp. complex in connection with the altitude of Sun's Arago point

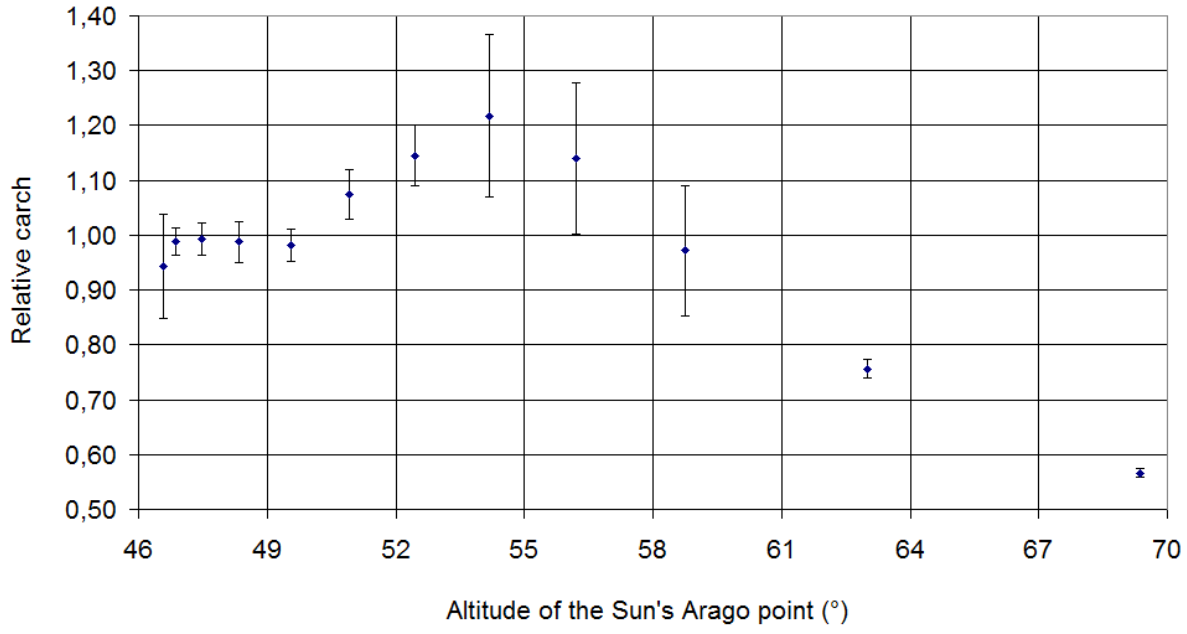


Figure 8. 4. 7 Pheromone trap catch of Microlepidoptera sp. complex in connection with the altitude of Moon's Babinet point

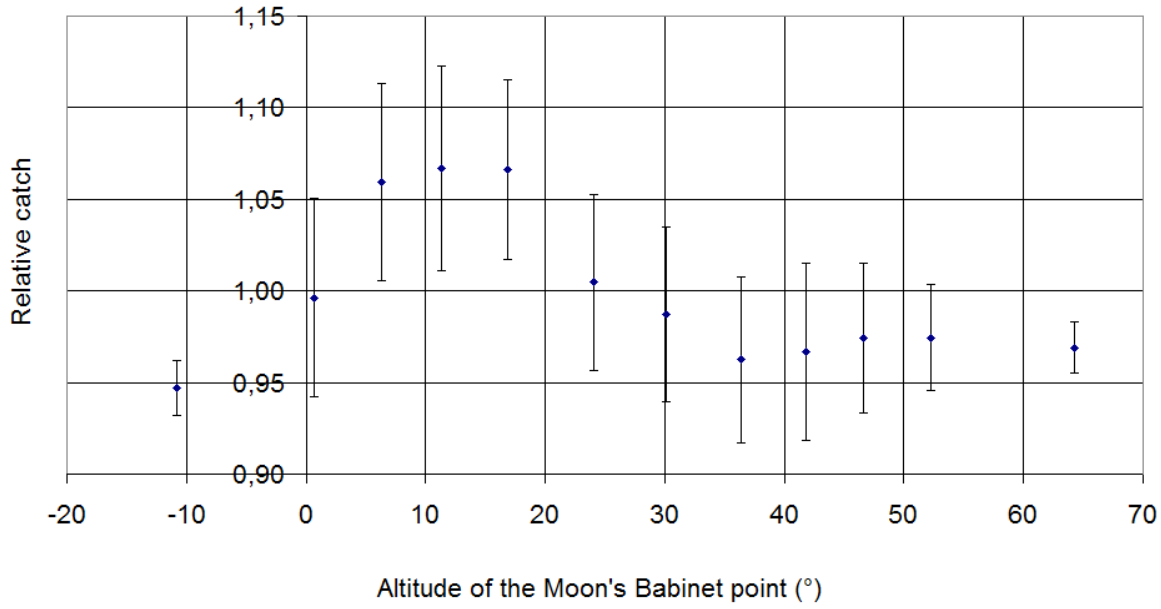


Figure 8. 4. 8 Pheromone trap catch of Microlepidoptera sp. complex in connection with the phase angle groups

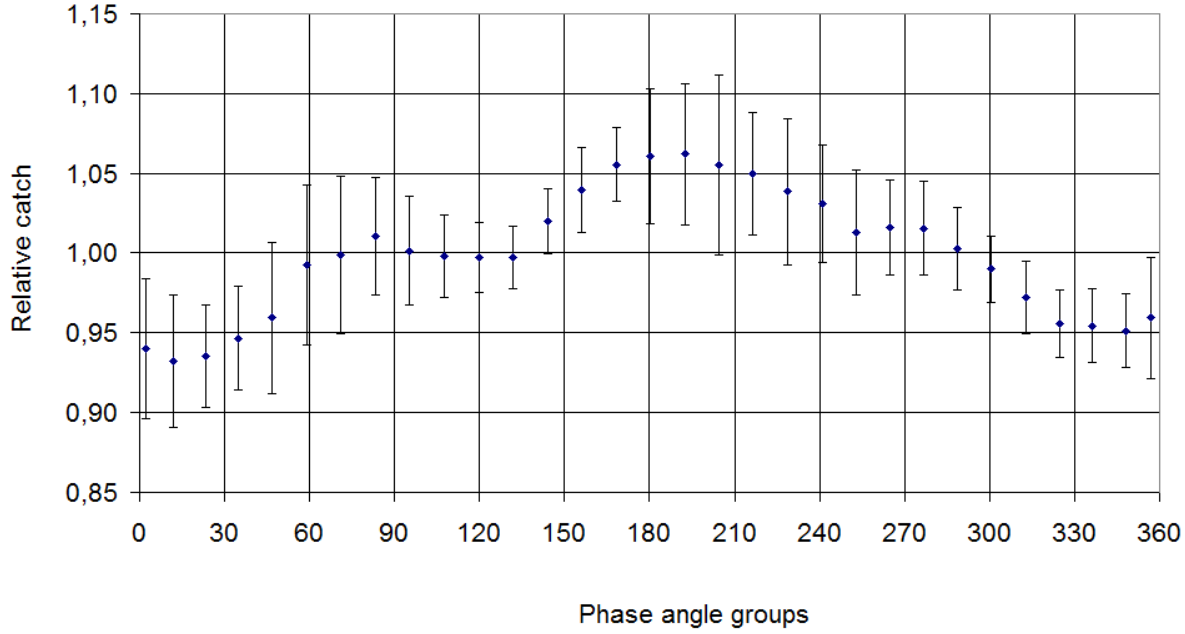


Figure 8. 4. 9 Pheromone trap catch of Microlepidoptera sp. complex in connection with the apparent magnitude of the Moon

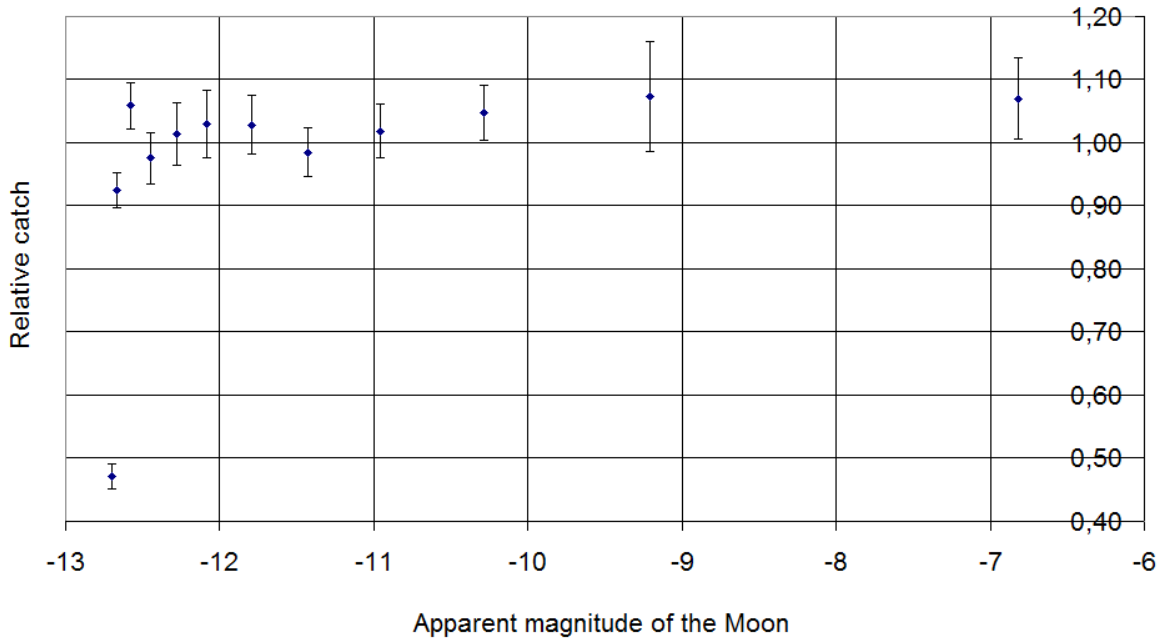
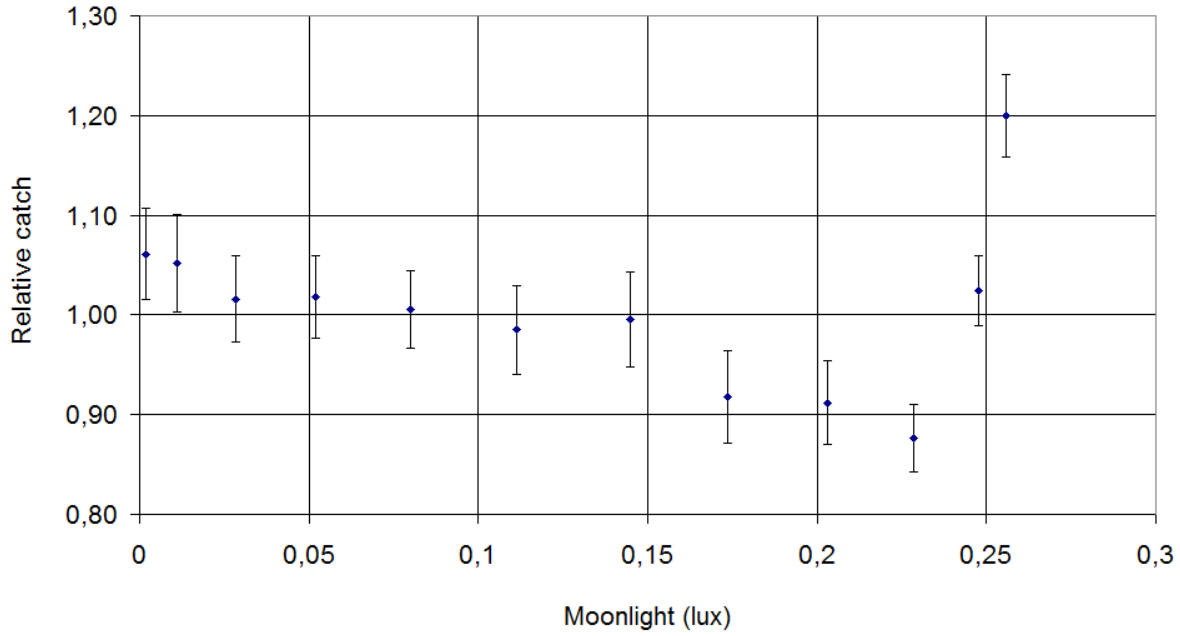


Figure 8. 4. 10 Pheromone trap catch of Microlepidoptera sp. complex in connection with the moonlight



Despite the fact that pheromone traps do not attract insects by light stimuli, our results demonstrate that certain features of both the Sun and the Moon influence the catching results of this trapping method.

For a discussion of celestial polarization and gravitation, see Chapter 1. 4.

At the environment of Full Moon, catches are high between the First Quarter and the Last Quarter, but the lowest at the New Moon. Accordingly, at 0.25 lux, which is the lux value at the Full Moon, the highest catch can be found. The relationship with the apparent luminance of the Moon is less clear, because only the low catch can be seen when the value is less than -12.6 magnitude.

8. 5 References

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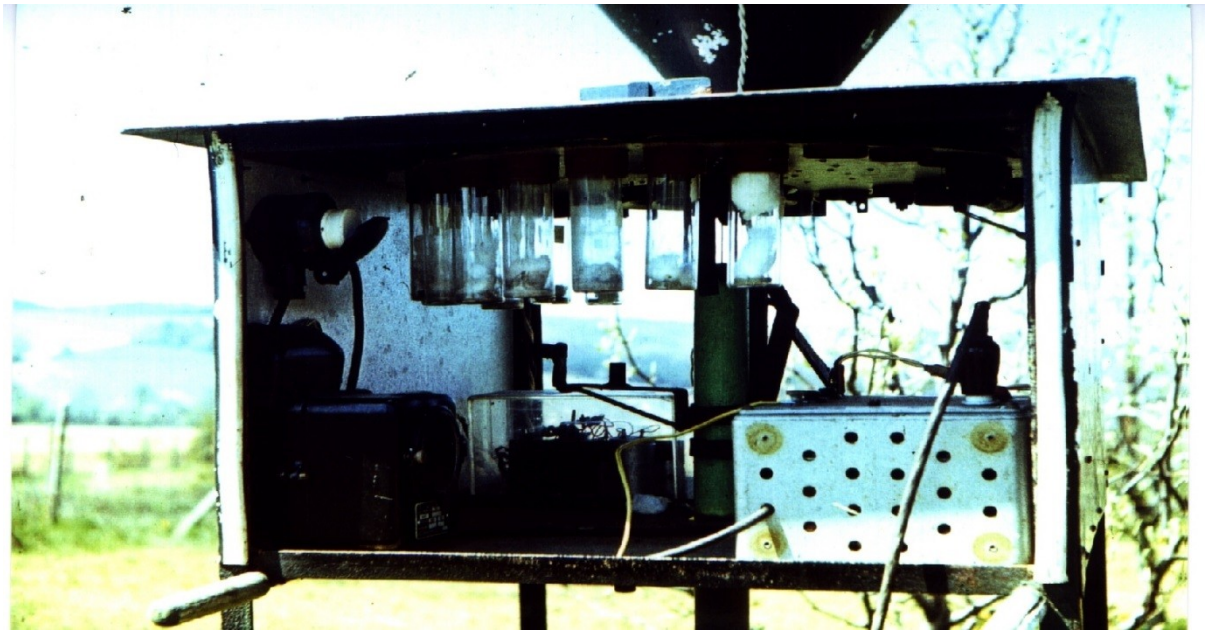
9. SUPPLEMET

Light-trap types used in Hungary

Jermy type light-traps Photo: Dr. Zsuzsanna Kúti PhD

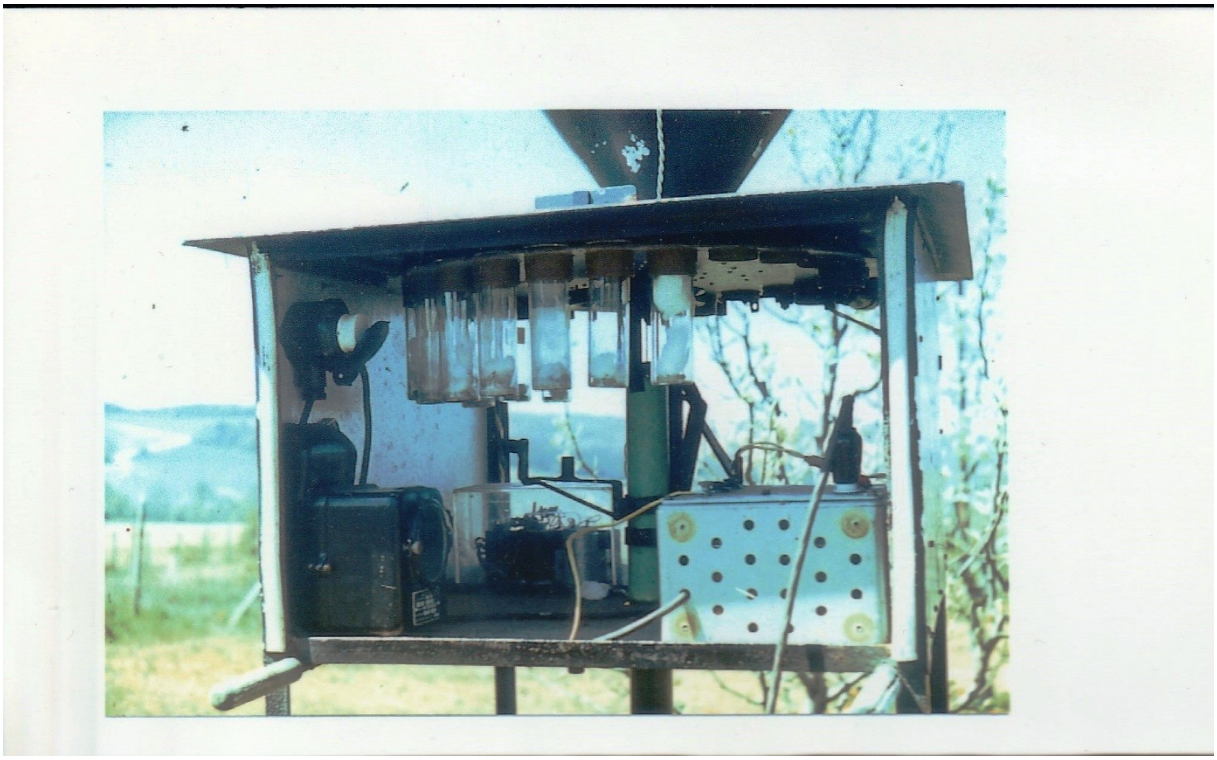


Fractionating light-trap in Julianna farm Photo: Prof. dr. Zoltán Mészáros DSc

Jermy type light-trap in Julianna farm Photo: Prof. dr. Zoltán Mészáros DSc

Járfás type fractionating light-trap in Kecskemét Photo: Prof. dr. József Járfás

Mészáros type light-trap used in Bećej, Serbia



Becse type light-trap Photo: Prof. Dr. Zoltán Mészáros DSc

Rothamsted design light-trap was operated at Stony Rise, Tasmania

The Rothamsted design light-trap that was operated at Stony Rise near Devonport in Tasmania from 1992 to 2019 by Lionel Hill

15 W BL trap was operated at North Carolina and Nebraska States (USA)

BL trap was operated at North Carolina and Nebraska, USA

Conclusions

The results of our factor analysis studies show that some features of the Sun and the Moon influence light trapping of insect collection on all the three continents.
The polarization of the night sky is used by insects for their spatial orientation. Although the polarization of the Moon at night is higher than the polarization of the Sun, there is still a closer relationship between the polarization of the Sun and the efficiency of the light-trap than the Moon produces. Perhaps, the reason for this is that the polarization from the Sun changes much less dramatically from night to night than from the Moon. It therefore provides "more reliable" information for insects.
It is also proven that the gravitational potential of celestial bodies also influences the efficiency of trapping. In cases where the negative gravity value reaches -500 μJ/kg, the insect does not have to use energy to take off up to 0.051 mm, and the resulting gravitational potential is 0. Above this value, the energy required for take-off is reduced by 5% at 1 mm rise and 0.005% at 1 m rise as the suction effect occurs.
In contrast, with the same positive gravity, when the gravity of the celestial body is added to the gravity of the Earth, it requires the same amount of energy to fly.
We found that the neutral points of the sky that are above the horizon at night are also significantly related to the catch results.
Apart from our own studies, similar results have not been reported by other researchers.
The apparent illumination of the Moon and the phases of the Moon influenced the success of catch on every continent and in all groups of insects, although maximum and minimum catch appeared in different phases of the Moon.
The above mentioned characteristics influenced the efficiency of trapping on all the three continents and in all insect groups, however, other lunar features *(illuminated surface ratio and moonlight)* are not considered to be a widespread modifying factor, although we have not been able to justify their influence only on Australian migratory species. Although the influence of polarized moonlight has been proven by several researchers, our current investigation has only confirmed this in the case of the Australian Microlepidoptera and Macrolepidoptera species.
However, in our opinion, this may be due to the fact that polarized moonlight is not present in the full lunar month. Therefore, its significance lags behind the other characteristics and therefore it was not classified as a significant influencing factor by factor analysis.

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