Chapter 16

Recording insects by light-traps

by

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Abstract

Light-trapping is a general term which covers all methods of attracting and/or capturing nocturnal insects with lamps that usually have a strong emission in the ultraviolet range of the spectrum, *e.g.* mercury vapour lamps, black light lamps or fluorescent tubes. Nocturnal Lepidoptera (moths), Trichoptera and Ephemeroptera are the insect groups which can be collected most efficiently by light-trapping but many nocturnal species in several other orders are rarely recorded with other methods, *e.g.* some Coleoptera. There are various light-trap designs in common use, but they are all based on two general construction types. The advantages, limitations and performances of different trap types in relation to target group, study area, vegetation and weather conditions are briefly discussed with reference to relevant literature, and general recommendations for operations are given.

Keywords: monitoring, light trap design, light trap efficiency, abiotic factors, Lepidoptera

1. Introduction

The attraction of moths and other nocturnal insects to light is a well-known phenomenon and has been used for collecting nocturnal insects since the beginnings of scientific entomology in the 18th century. Light-trapping has become a general term which refers to all methods of attracting nocturnal insects with lamps or artificial light sources, whether they are actually connected to a trap or just being operated in front of walls or other reflective surfaces where incoming insects are then recorded or collected manually. The first purpose built devices which could be termed actual light-traps were used by the Romans in the 1st century AD (Morge, 1973; Steiner, 1991; Beavis, 1995).

While the physiological background of the attraction to light is still under discussion (see *e.g.* Hsiao, 1972, 1973; Baker & Sadovy, 1978; Sotthibandhu & Baker, 1979), attracting nocturnal insects with ultraviolet light is now in general use and presents the most effective collecting method for nocturnal species of the orders Lepidoptera, Trichoptera, and Ephemeroptera, but also for many species of Coleoptera, Hymenoptera, Diptera, Neuroptera s.l., Orthoptera, and some other insect groups. Automatic light traps have also become standard equipment for insect pest control and pest management but will not be considered here further, as these devices are purely designed to kill or even destroy the insects attracted and thereby preclude any scientific application.

The main advantage of light-trapping is the large number of species which can be recorded during a relatively short period. In Europe, for example, this can amount to 200 or more species of Lepidoptera in a single night under favourable conditions with the number of individuals running into the thousands. In the tropics the total count both of individuals and of species can be even much higher, often exceeding the available capacity for recording or collecting. On the other hand, light-trapping is still a selective method and not all taxa of a given group (family, genus) are attracted to light with the same efficiency, and females of many species are less attracted than males or not at all. For ecological studies it is sometimes seen as a drawback that light-trapping is an attraction method and it is thus not possible to directly link the species recorded to their respective (larval) habitats.

Overall there are two main approaches in the use of light traps. The qualitative approach aims at maximizing record and/or catch efficiency. For faunistic purposes, and for inventorying or assessing larger areas, it is usually preferable to use high-powered lights (*e.g.* 125 W lamps) and to chose sampling sites for maximum effect and across habitat-types, such as ridge tops, forest edges, etc. For ecological and habitat-related studies which require standardized comparisons and often target habitat- or niche-specific species it is better to use low-powered lamps (*e.g.* 8 W fluorescent tubes) placed well inside the target habitats (Wirooks, 2005).

2. Lamp types

While insects are attracted in a lesser degree to open fire, oil lamps, paraffin lamps, kerosene lamps and other light sources, the most effective lamps are those with a high emittance in the UV part of the spectrum. For most nocturnal insects the attractive part of the light spectrum lies in the ultraviolet range, somewhere between 350 nm and 550 nm (Cleve, 1954; Dufay, 1964, 1965; Mikkola, 1972; Hartstack, 1979) though spectral sensitivity varies from species to species; in a number of nocturnal Lepidoptera taxa Eguchi *et al.* (1982) reported peak sensitivities especially around 440-480 nm, and around 500-540 nm.

For field work, however, the choice of lamp type is more often determined by the actual field conditions than purely by scientific considerations. If there is access to the electricity network or if a portable generator is available, mercury vapour lamps, black-light lamps or blended (mixed light) lamps are usually the best choice because their emittance in the UV range is higher than that of standard household light bulbs (tungsten bulbs). If weight and size are an issue or in field situations without a mains power supply, fluorescent tubes are a perfect alternative which can be run from rechargeable 12 V batteries.

2.1. Mercury vapour and other UV lamps

High pressure mercury vapour lamps come in several sizes of which the 80 W and 125 W versions are those most used by entomologists. A larger 250 W version (which is no longer manufactured) is even more effective but also more trying for the human eye. All of those lamps require a separate electronic ballast (choke) to be inserted between the lamp and the power outlet. There are also 80 W versions which can be run without a ballast. The so-called black-light bulbs (125 W) produce almost no visible light; for the human eye they seem dark blue. They are thus suitable for situations where bright light is undesirable, *e.g.* in residential areas. For many groups, the 160 W blended (mixed light) lamps are less effective than the 125 W mercury vapour lamps but require no external ballast. There is also a 160 W black light bulb available, which does not need a ballast. Details can be obtained from manufacturers or from entomological suppliers via the internet.

2.2. Fluorescent tubes

The low pressure fluorescent tubes or neon tubes generally produce a bluish light and are available in a range of sizes in different lengths: 6 W (22.5 cm), 8 W (30 cm), 15 W (45 cm), 20 W (60 cm). Two special types emitting UV light are commonly used for light-trapping: the so-called "super actinic" tubes producing pale blue light, and "black light" tubes which are comparable to the black-light bulbs and are virtually invisible from a distance. While fluorescent tubes can also be operated with a voltage converter from a generator or mains power supply, in the field they are best directly run from 12 V rechargeable batteries.

A number of studies have compared the relative performance of different lamp types and their attraction on various insect orders (Williams, 1951; Bretherton, 1954; Williams *et al.*, 1955; Cleve, 1954, 1966, 1967; Lam and Stewart, 1969; Mikkola, 1972; Taylor and Brown, 1972; Taylor and French, 1974; Blomberg *et al.*, 1976; Walker and Galbreath, 1979; Leinonen *et al.*, 1998).

3. Trap design

In general, all lamps can be used without any trap or collecting vessel and incoming insects can be recorded or collected manually (Figs 1-5). This is often practised for faunistic studies and in cases when only particular species or specimens are of interest, especially if higher numbers of insects are likely to be attracted which would unnecessarily be collected by a trap or damage the desired specimens inside the collecting container. The lamp is best placed in front of a vertical white sheet, a wall or any other substrate which serves as a good reflector and also allows insects to settle near the lamp. Placing the lamp inside a larger gauze cylinder has the advantage that insects can be similarly attracted from all directions and that the lamp cannot be reached directly by incoming insects (see Figs 4 & 5). The simplest method is still to hang the lamp above a sheet lying on the ground

Fig. 1. Personal light-trapping. The sheet method. A white linen sheet mounted on a frame of aluminium poles, with two battery-powered 15 W fluorescent tubes, one actinic, one black.(Photo by A. Steiner).

Fig. 2. Personal light-trapping. A 125 W mercury vapour lamp and a sheet in a tropical rainforest. Note necessity of rain protection. (Photo by A. Steiner).

Fig. 3. Personal light-trapping. A simple set-up: A black-light bulb in a wire-frame housing at the white wall of a house. (Photo by A. Steiner).

Fig. 4. Personal light-trapping. Two battery-powered 15 W fluorescent tubes in a gauze cylinder ("tower"). (Photo by A. Steiner).

Fig. 5. Personal light-trapping. A combination of a 125 W mercury vapour lamp and two 15 W actinic fluorescent tubes in a gauze cylinder. (Photo by A. Steiner).

For actual light traps, there is a variety of individual designs in use and a vast literature available about the subject. Most designs, however, are based on the following components.

Basic features:

- Lamp
- Funnel
- Collecting container or receptacle

Additional features:

- Rain protection for light bulb
- Rain drainage
- Baffles or deflector shields
- Photoelectric switch
- Anaesthetic or killing agent

The lamp is the attractant. It is placed above or in front of a funnel which directs the insects into a collecting container, jar or receptacle. In addition, the trap can be provided with a range of useful features like a roof structure to protect the light bulb from rain and to prevent leaves, twigs, etc. from falling into the funnel. Alternately or additionally a rain drainage system can be installed, usually consisting of a small drainage funnel below the main funnel entry. A simple hole in the bottom of the trap collecting container covered with fine gauze is sometimes useful, but if a killing agent heavier than air is used the opening of the drainage funnel has to be raised above the bottom of the container.

A number of deflecting shields or baffles - usually two to four - made from Plexiglas, plastic or metal can be arranged around the lamp so that at least the larger, heavier, and faster-flying specimens fall into the funnel when hitting the baffles while circling the lamp.

Nowadays a photoelectric cell is an almost universal component of light traps. It allows the trap to be brought into the field at any time of day; the light-sensitive cell (the sensitivity can be regulated) switches the light on at dusk and off at dawn.

An anaesthetic or killing agent is often used inside the trap container to avoid damage of the specimens. Chemicals like chloroform ($CHCl_3$) or tetrachloroethane (1,1,2,2-tetrachloroethane, $C_2H_2Cl_4$) are left to evaporate from a vial or small bottle by means of a wick, whereas the often used ethyl-acetate is much less useful as it evaporates too quickly. Note that openings at the bottom of the trap have to be avoided (see caution about rain drains above).

Special features:

- Fan
- Wire mesh trays for separating insects according to size

When the trap is run without an anaesthetic it can be helpful to place a small fan inside the trap container to simulate wind which keeps the specimens inactive. Some trap designs include wire mesh or trays for automatically sorting specimens by size so that smaller insects reach the bottom trays and are less susceptible to damage by larger specimens (Common & Upton 1964; Vaishampayan, 1985a, b).

Fig. 6. Trichoptera and Lepidoptera at a gauze cylinder (Photo by A. Steiner).

Figures 7-8 illustrate two different trap designs. More information about specific designs including detailed drawings can be obtained from the literature, *e.g.* Muirhead-Thomson (1991), Fry & Waring (2001), or from individual supplier websites. For some examples of individual trap designs: Rothamsted light trap (Williams 1936, 1948; Taylor & Brown, 1972); Robinson light trap (Robinson & Robinson, 1950); Jermy trap (Jermy, 1961); Common trap (Common, 1960; Common & Upton, 1964); Heath trap (Heath, 1965). In all light traps, design significantly influences the catch especially with regard to the relative composition of different taxa, which can also be used to collect selectively specific target taxa (*e.g.*, Denmark, 1964; Lam & Stewart, 1969; Farrow, 1974; Sutton, 1979; Intachat & Woiwod, 1999).

Fig. 7. A hanging light-trap without rain-cover, showing three baffles around a 6 W actinic tube, a collapsible funnel made of thick plastic film, and a bucket as container. (Photo by A. Steiner).

Fig. 8. The same trap, disassembled. Top right: container. Right: actinic tube inside a Plexiglas cover with cable. The electronics are housed in the black top cap. Left: Plexiglas baffles and lower part of funnel. Centre: collapsible funnel with stabilising ring, screws for fastening baffles to tube housing, rubber ring for fastening lower part of funnel to container lid. (Photo by A. Steiner).

Fig. 9. A ground light-trap with a rain cover and three baffles around an 8 W black-light tube. The container is a commercially available plastic box. The black dot on the small grey box containing the electronics is the photoelectric cell. (Photo by A. Steiner).

4. Distance of light-response in nocturnal insects

In the past there was much difference of opinion about the effective range of attraction of light sources. More or less speculative values were given from around 1 m to 50 m (Daniel, 1952) or even up to 1.000 m (Koch, 1958). Various experimental studies – with different light sources and different study groups – have yielded effective distances of 3 m to 250 m (Bowden, 1982; Muirhead-Thomson, 1991). An unresolved question is whether specimens which obviously came from far outside the sampling habitat were attracted directly over a great distance or were on a dispersal flight and at some point entered the effective range of the lamp and only then became attracted (which is more probable).

- Mark-release-recapture experiments of Sphingidae (Lepidoptera) around a 125 W mercury vapour lamp in tropical ecosystems (Borneo) suggested attraction radii (for 50% return rate within 5 minutes) of generally below 30 m (Beck & Linsenmair, 2006).
- Experiments with caged moths showed that a 15 W black light tube at a distance of 6.1 m caused 75% of *Heliothis zea* moths (Lepidoptera: Noctuidae) to move towards the light. At a distance of 69 m this response was shown by 10% of the moths. By extrapolation the maximal range of attraction was determined as 60-90 m. In *Manduca sexta* (Lepidoptera: Sphingidae) 48% of individuals showed a positive response at a distance of 4.6 m from the light source; the maximal range of attraction was determined as 120-135 m (Stewart *et al.*, 1967).
- In a similar experimental setup the threshold of attraction was calculated to be 200-250 m for *Spodoptera littoralis* (Lepidoptera: Noctuidae) (Plaut, 1971).
- Physiological studies on the eyes of *Heliothis zea* and *Heliothis virescens* (Lepidoptera: Noctuidae) showed that 15 W blacklight tubes can trigger sensory responses from distances between 31 m and 250 m (Agee, 1972).
- Under the assumption that nocturnal insects react to wavelengths of 500-600 nm, Bowden & Church (1973) calculated the radius around a 125 W mercury vapour lamp within which the brightness of the light source is higher than the background brightness. They obtained values between 35 m (in full moon nights) and 520 m (without moonlight). On a similar basis Dufay (1964) reached results of 50 m to 700 m for another type of 125 W MV lamp, while Nowinszky *et al*. (1979) calculated distances of between 20 m (full moon) and 300 m (no moon) for a 100 W Argon bulb.

5. The role of abiotic factors

There is an abundant literature on the many abiotic and other factors which influence light trap efficiency and sample size. We can only give a basic overview and provide references of more detailed studies.

5.1. Temperature

Ambient air temperature seems to be the most important single factor influencing insect flight activity and thus the catch (Williams, 1940; Daniel, 1952; Hosny, 1959; Taylor, 1963; Pulliainen, 1965; Hanna & Atries, 1969a; Persson, 1971, 1976; Kurtze, 1974; Hanna & Hamad, 1975b; Blomberg *et al.*, 1978; Morton *et al.*, 1981; Dent & Pawar, 1988; McGeachie, 1989). Generally speaking, the higher the temperature the more insects are active, which usually translates into highest activity rates during the first hours after sunset. Rapid cooling during the night will cause inactivity sooner than slow cooling. In temperate climates cloud cover at night means less rapid cooling and thus a longer activity period of insects. Temperature dependency, of course, varies with the climate zone a species inhabits: boreal and alpine species are adapted to lower temperatures than thermophilic, subtropical or tropical species, and specialist species having their peak activity during periods of comparatively low temperature can be found in all biomes, including the famous "winter moths" and "winter midges" of northern hemispheres.

5.2. Moonlight and starlight

Lunar periodicity plays an important role in catch efficiency and has been the subject of numerous studies (Williams, 1936; Williams & Singh, 1951; Hosny, 1959; Dufay, 1964, 1965; Hanna & Atries, 1969b; Persson, 1971, 1976; Bowden, 1973, 1981, 1982, 1984; Bowden & Church 1973; Hartstack *et al.*, 1973; Kurtze, 1974; Bowden & Morris, 1975; Hanna & Hamad, 1975a; Douthwaite, 1978; Nowinszky *et al.*, 1979; Morton *et al.*, 1981; Vaishamapayan and Verma 1982; Danthanarayana, 1986; Taylor, 1986; Dent & Pawar, 1988; McGeachie, 1989; Nag & Nath 1991). In short, the stronger the moonlight is, the less attraction a lamp has to insects. The ratio between catch in new moon nights and catch in full moon nights has been given as 2,67: 1 (Williams, 1940; a 4-year study in England) and as 2.59: 1 (Nowinszky *et al.*, 1979; 14 years of light-trapping in Hungary). While it was once suspected that insect activity in general might be lower in moon nights, it has since been shown that lamp attraction is weaker. In fact insect activity seems to be higher in bright, moonlit nights as indicated by comparisons of light-trapping with other methods such as suction traps (Bowden, 1981) and pheromone traps (Dent & Pawar, 1988). When insect activity actually diminishes in moon nights this is usually due to other negative weather factors, especially rapidly falling temperatures as commonly observed in clear nights. In subarctic regions, however, the naturally bright summer nights make lamps less attractive to insects (Blomberg *et al.*, 1978).

The relationship of background brightness (light emitted by moon and stars) and catch efficiency has been expressed in the formula:

$$\text{catch} = \text{constant x} \sqrt{\text{W/I}}$$

where W represents lamp brightness and I is background brightness. With a constant lamp brightness there is:

$$\text{catch} = \text{constant x} \sqrt{1/\text{I}}$$

Other weather factors can significantly influence this ratio (Bowden & Church, 1973; Bowden, 1981, 1982), while cloud cover mitigates the competing effects of moon light.

5.3. Wind

Wind speed is another important factor affecting insect activity and especially flight (Hosny, 1955, 1959; Williams, 1961; Dufay, 1964, 1965; Brown, 1970; Persson, 1971, 1976; Kurtze, 1974; Hanna & Hamad, 1975b; Douthwaite, 1978; Morton *et al.*, 1981; Tucker, 1983; Dent & Pawar, 1988; McGeachie, 1989). In stronger wind there is less insect activity: most species cease flying as soon as they cannot any longer maintain a directional flight. The critical wind speed varies according to size and strength: larger moths (Noctuidae) cease flying to lamps at wind speeds of 10.8-13.8 m/s, smaller Diptera, Tipulidae, Limnobiidae, and Chironomidae at 8.0-10.7 m/s, Psychodidae and Trichoceridae at 6.7-9.4 m/s, and Ceratopogonidae and Cecidomyiidae at 3.4-5.4 m/s (Kurtze, 1974). A marked reduction of catch occurs at 3-4 m/s (Douthwaite, 1978) and at 4 m/s (Dent & Pawar, 1988). The highest catch rates, however, are not recorded at calm but at wind speeds between 1 and 3 m/s (Hosny, 1955; Douthwaite, 1978; Dent & Pawar 1988).

5.4. Precipitation, air humidity, and fog

Strong rainfall can reduce or prevent insect activity, especially for smaller species, while most insects are usually indifferent to light rain (drizzle, spray) unless it coincides with a drop in ambient temperature. Under certain conditions, *e.g.* in dry or semiarid areas but also in tropical regions with a pronounced rainfall seasonality, rain can induce eclosion and stimulate activity (Williams, 1940; Daniel, 1952; Hosny, 1955, 1959; Pulliainen, 1965; Harling, 1968; Brown *et al.*, 1969; Persson, 1971; Kurtze, 1974; Douthwaite, 1978; Tucker, 1983). In the tropics rain often considerably increases light trap attractivity, often leading to unusual and rare records. For running a light during tropical rain, the lamp or trap is best protected by a larger roof, which can be easily constructed with some canvas or tarpaulin (Malicky, 2002; see also Fig. 2). In addition, some drainage provisions around the position of the trap are often a helpful measure (*e.g.*, Diehl, 2001).

In temperate conditions, high air humidity can also promote insect activity unless combined with cooling. Fog in combination with falling temperatures or fog which forms in valley bottoms, basins, and wetlands, strongly reduces insect activity. Dewfall is usually a result of cooling and coincides with reduced activity. Drifting clouds and fog on slopes or in the mountains need not to lead to negative results; in certain situations they actually seem to intensify the attraction of light traps (Daniel, 1952; Hosny, 1955, 1959; Hanna & Atries, 1969a; Kurtze, 1974; Hanna & Hamad, 1975b; Esche, 1992).

5.5. Air pressure

It is sometimes said that falling air pressure improves general insect activity, *e.g.* before thunderstorms (Haase, 1929; Allan, 1947; Hosny, 1955; Lederer, 1959) while other studies claim there is no recognisable influence of air pressure (Dufay, 1964, 1965). Without quantitative studies or experimental evidence at hand, however, we also have experienced many times the highest attraction of light traps at times just before the onset of thunderstorms or heavy rainfall, both in temperate and especially under tropical conditions; whether it is specifically air pressure or other factors related to the imminent change of weather conditions which lead to high levels of insect activity remains unclear, but such situations are usually always advantageous for light-trapping.

In addition to climate and weather related factors, several locality-related conditions also play an important role in determining the most productive sites for light traps.

Forest vs. open country

Inside forests the negative effect of moonlight is less dramatic. Bowden (1982) studying trapping data from Rothamsted (England, U.K.) noted a catch ratio of *Noctua pronuba* (Lepidoptera: Noctuidae) between open habitats and forests of 1 : 3.7. Temperature change, especially nocturnal cooling is often less marked in forests, and winds are weaker. On the other hand light has a larger radius in open areas (Hosny 1955, 1959; Bowden, 1982), and results are significantly different between light traps placed in the understorey and in the forest canopy, especially in the tropics (Schulze *et al.*, 2001; Beck & Linsenmair, 2006).

Wind direction

Most insects prefer to fly against the wind when looking for food or locating females. Exceptions are migrating specimens which use wind currents and fly with the wind (Brown *et al.*, 1969; Brown, 1970). When smaller areas are to be studied it is thus advantageous to place traps at their windward side.

Terrain structure and landscape

Many insects prefer to fly upslope, also at night. Lights placed on slopes or hilltops may control a larger area; even considering that a lamp's direct effective range of attraction may be quite small, there is a higher chance that more specimens reach the neighbourhood of the trap. The landscape (and vegetation) surroundings of the light trap location also greatly influence the results, *e.g.* by offering protection from or providing exposure to local wind currents and other weather factors, and through different local microclimatic conditions, including varying albedo properties. Cold air often accumulates in even small depressions and valley bottoms, while certain terrain structures such as bare rocks can absorb heat during the day and emit part of that radiation at night. Selecting the exact placement of a light trap should also take these factors into account.

6. Concluding remarks

For any new light-trapping project, the choice of the equipment to be used is clearly an important initial step. Aside from the relevant technical and biological parameters that different lamps and trap constructions entail, the final choice should also consider more practical criteria, such as weight and transportability, durability under field conditions, and availability and cost of spare parts or repairs. It should be kept in mind that there exists no overall most effective or "best" lamp type nor "standard" light trap construction or design; all types and makes of light traps are differently selective in one way or another, and the final choice should be determined by the exact question(s) and goals to be pursued by the study. Although most equipment discussed here works well for most insect taxa and many different habitats, no one type of light trap will equally attract all taxa. For aiming at a comprehensive inventory such as an ATBI of a local fauna or a community of different taxa, it is therefore advisable to employ a number of different lights and trap designs, if at all possible.

With standardization of methods being a requirement for many scientific approaches in order to allow for comparable and/or repeatable collection of data, especially from ecology, light-trapping provides a clear method of choice for many entomological studies. While standardization can be easily achieved for the equipment and light-trapping regime, other factors relevant for the results are much more difficult to compare or even standardize, even if the availability of fully automatic light traps allows reducing the influence of the "human factor" to a certain degree. Apart from the important effects of weather, moonlight and other factors discussed above, the exact placement of a trap in the field remains the overall most difficult and perhaps still influential parameter in making light-trapping data fully comparable, especially for highly structured habitats and landscapes such as forests and mountains. As indicated above and experienced many times, the precise placement of the light in relation to its surroundings greatly impacts the results, with sometimes a few feet or meters distance already leading to noticeably different catches. Especially for manually operated lights, finding the "best" precise location is almost always the biggest challenge in the field, for which personal experience often still provides the best guidance. All these methodological challenges should provide additional incentives for the precise recording and documenting any light-trapping session, especially for exact geographic coordinates, time, and weather conditions, which should be a common standard under all light-trapping circumstances.

7. Tips and hints – some "do-s and don't-s"

- The higher a lamp/trap is placed above the ground, the larger is the area it controls. Be sure to have sufficient possibilities to raise the light and/or trap above ground on site (*e.g.*, by carrying poles or other equipment).
- Stronger light generally means higher attraction (more specimens/species), but some species prefer to settle at some distance from bright lamps. It is often helpful to carefully check the perimeter around such a lamp to find those species.
- Small moths and other insects with a gentle flight often come to rest on the baffles of a trap or in the vegetation nearby and do not enter the collecting container. Traps should therefore be checked well before sunrise, before these specimens fly away or are eaten by birds and other predators. It is helpful to place the trap on a large white sheet or a similar background that makes it easier to find those specimens.
- Before placing light traps for longer-term studies in the field, check and record the microclimatic conditions at night at the exact location, particularly with regard to air temperature, wind strength, and wind direction.
- When using a trap without a killing agent, the container needs to be filled with materials to provide sufficient resting space for the specimens. Many authors

recommend using egg cartons, which however we find very difficult to extract resting specimens from. Instead, we recommend using rough, slightly crumpled paper, because this is easier to handle and can be more readily straightened to box specimens.

- When running light traps with a killing agent especially for specific, limited questions, try to ensure that the by-catch is also kept for / used by other researchers; all specimens collected with accurate data can be of value!
- Do not look directly into a mercury vapour lamp. Although the UV radiation from MV lamps is considered not harmful for the human eye, individual sensitivity varies and emission from strong MV lamps can be irritating.
- When going into the field, always carry sufficient torches and other additional light sources along; if for no other reason, setting up and taking down light trap equipment at night can be quite difficult without sufficient torches at hand.
- Always take some basic tool kit (screwdriver, pincer, small knife, electrical tape) along when light-trapping; equipment gets easily damaged under field conditions, and it is advantageous to be able to do basic repairs on site.

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9. References

AGEE, H.R. 1972. Sensory response of the compound eye of adult *Heliothis zea* and *H. virescens* to ultraviolet stimuli. *Annals of the Entomological Society of America* 65: 701-705.

ALLEN, P.B.M. 1947. *A Moth-Hunter's Gossip.* London (Watkins & Doncaster): 269 pp.

BAKER, R.R. & SADOVY, Y. 1978. The distance and nature of the light-trap response of moths. *Nature* 276: 818-821.

BEAVIS, I.C. 1995. The first light trap, 1st century AD. *The Entomologist's Record and Journal of Variation* 197: 155.

BECK, J.F. & LINSENMAIR, K.E. 2006. Feasibility of light-trapping in community research on moths: Attraction radius of light, completeness of samples, nightly flight times and seasonality of Southeast-Asian hawkmoths (Lepidoptera: Sphingidae). *Journal of Research on the Lepidoptera* 39: 18-37.

BLOMBERG, O., ITÄMIES, J. & KUUSELA, K. 1978. The influence of weather factors on insect catches in traps equipped with different lamps in northern Finland. *Annales Entomologici Fennici* 44: 56-62.

BOWDEN, J. 1973. The influence of moonlight on catches of insects in light-traps in Africa. Part I. The moon and moonlight. *Bulletin of Entomological Research* 63: 113-128.

BOWDEN, J. 1981. The relationship between light- and suction-trap catches of *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), and the adjustment of light-trap catches to allow for variation in moonlight. *Bulletin of Entomological Research* 71: 621-629.

BOWDEN, J. 1982. An analysis of factors affecting catches of insects in light-traps. *Bulletin of Entomological Research* 72: 535-556.

BOWDEN, J. 1984. Latitudinal and seasonal changes of nocturnal illumination with a hypothesis about their effect on catches of insects in light-traps. *Bulletin of Entomological Research* 74: 279-298.

BOWDEN, J. & CHURCH, B.M. 1973. The influence of moonlight on catches of insects in light-traps in Africa. Part II. The effect of moon phase on light-trap catches. *Bulletin of Entomological Research* 63: 129-142.

BOWDEN, J. & MORRIS, M.G. 1975. The influence of moonlight on catches of insects in light-traps in Africa. III. The effective radius of a mercury-vapour light-trap and the analysis of catches using effective radius. *Bulletin of Entomological Research* 65: 303-348.

BRETHERTON, R.F. 1954. Moth traps and their lamps: an attempt at comparative analysis. *Entomologist's Gazette* 5: 145-154.

BROWN, E.S. 1970. Nocturnal insect flight direction in relation to the wind. *Proceedings of the Royal Entomological Society of London, Series A*, 45: 39-43.

BROWN, E.S., BETTS, E. & RAINEY, R.C. 1969. Seasonal changes in distribution of the African armyworm, *Spodoptera exempta* (Wlk.) (Lep., Noctuidae), with special reference to eastern Africa. *Bulletin of Entomological Research* 58: 661-728.

CLEVE, K. 1954. Einfluß der Wellenlänge des Lichtes auf den Lichtfang der Schmetterlinge. *In:* TITSCHAK, E. (Ed.). *Deutscher Entomologentag in Hamburg 30. Juli bis 3. August 1953*, Jena (Fischer): 107-113.

CLEVE, K. 1966. Das Sternenlicht und dessen vermutliche Wahrnehmung durch nachts fliegende Schmetterlinge. *Deutsche Entomologische Zeitschrift N. F.* 13: 359-375.

CLEVE, K. 1967. Das spektrale Wahrnehmungsvermögen nachts fliegender Schmetterlinge (Lep.). *Nachrichtenblatt der Bayerischen Entomologen* 16: 33-53.

COMMON, I.F.B. 1960. A transparent light trap for the field collection of Lepidoptera. *Journal of the Lepidopterists' Society* 13: 57-61.

COMMON, I.F.B. & UPTON, M.S. 1964. A weather-resistant light trap for the collection of Lepidoptera. *Journal of the Lepidopterists' Society* 18: 79-83.

DANIEL, F. 1952. Praxis des Nachtfangs mit Licht. *Nachrichtenblatt der Bayerischen Entomologen* 1: 44-46, 51-54, 61-63, 67-68.

DANTHANARAYANA, W. 1986. Lunar periodicity of insect flight. *In:* DANTHANARAYANA, W (Ed.). *Insect Flight: Dispersal and Migration*. Springer: 88-119.

DENMARK, H.A. 1964. Evaluation of an insect light trap designed to separate beetles and moths. *Journal of the Lepidopterists' Society* 18: 1-10.

DENT, D.R. & PAWAR, C.S. 1988. The influence of moonlight and weather on catches of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) in light and pheromone traps. *Bulletin of Entomological Research* 78: 365-377.

DIEHL, E.W. 2001. Moderner Lichtfang unter besonderer Berücksichtigung tropischer Verhältnisse. *Entomologische Zeitschrift* 111: 308-311.

DOUTHWAITE, R.J. 1978. Some effects of weather and moonlight on light-trap catches of the army-worm, *Spodoptera exempta* (Walker) (Lepidoptera: Noctuidae), at Muguga, Kenya. *Bulletin of Entomological Research* 68: 533-542.

DUFAY, C. 1964. Contribution à l'étude du phototropisme des lépidoptères noctuides. *Annales des Sciences Naturelles - Zoologie et Biologie Animale, Paris, 12e série* 6: 281-406.

DUFAY, C. 1965. Étude du phototropisme des Lépidoptères Noctuides. Applications aux chasses à la lumière. *Alexanor* 4: 81-88, 131-136.

EGUCHI, E., WATANABE, K., HARIYAMA, T. & YAMAMOTO, K. 1982. A comparison of electrophysiologically determined spectral responses in 35 species of Lepidoptera. *Journal of Insect Physiology* 28: 675-682.

ESCHE, TH. 1992. Konkurrieren Nachtschmetterlinge um Blüten? Untersuchungen zu Nischentrennung und Bestäubungseffektivität. Dissertation. University of Freiburg: 194 pp.

FARROW, R.A. 1974. A modified light trap for obtaining large samples of night-flying locusts and grasshoppers. *Journal of the Australian Entomological Society* 13: 357-360.

FRY, R. & WARING, P. 2001. A Guide to Moth Traps and their Use. *The Amateur Entomologist* 24: iv, 1-68.

HAASE, J. 1929. Die Lichtfalle, ein Hilfsmittel zur Erforschung der Lokalfauna. *Internationale Entomologische Zeitschrift [Guben]* 23: 89-107.

HANNA, H.M. & ATRIES, I.E. 1969a. The flight activity of certain nocturnal Lepidoptera in relation to temperature and humidity. *Bulletin de la Société Entomologique d'Egypte* 53: 1-6.

HANNA, H.M. & ATRIES, I.E. 1969b. The effect of moonlight on certain nocturnal Lepidoptera. *Bulletin de la Société Entomologique d'Egypte* 53: 7-12.

HANNA, H.M. & HAMAD, N.E.F. 1975a. Lunar periodicity and flight activity of nocturnal Lepidoptera at different levels. *Bulletin de la Société Entomologique d'Egypte* 59: 17-27.

HANNA, H.M. & HAMAD, N.E.F. 1975b. Effect of climatic factors on flight activity of moths of certain cotton pests. *Bulletin de la Société Entomologique d'Egypte* 59: 39-47.

HARLING, J. 1968. Meteorological factors affecting the activity of night-flying Macro-Lepidoptera. *The Entomologist* 101: 83-93.

HARTSTACK, A.W. 1979. Light sources, trap design and other factors affecting moth catch. *In*: RABB, R.L. & KENNEDY, G.G. (Eds). *Movement of highly mobile insects: concepts and methodology in research*. Raleigh: 232-241.

HEATH, J. 1965. A genuinely portable MV light trap. *The Entomologist's Record and Journal of Variation* 77: 236-238.

HOSNY, M.M. 1955. Notes on the effect of some secondary environmental conditions on the activity of nocturnal Macrolepidoptera. *Bulletin de la Société Entomologique d'Egypte* 39: 297-314.

HOSNY, M.M. 1959. A review of results and a complete list of Macrolepidoptera caught in two ultra-violet light traps during 24 months, at Rothamsted, Hertfordshire. *Entomologist's Monthly Magazine* 95: 226-237.

HSIAO, H.S. 1972. *Attraction of moths to light and to infrared radiation*. San Francisco Press: 89 pp.

HSIAO, H.S. 1973. Flight paths of night-flying moths to light. *Journal of Insect Physiology* 19: 1971-1976.

INTACHAT, J. & WOIWOD, I.P. 1999. Trap design for monitoring moth biodiversity in tropical rainforests. *Bulletin of Entomological Research* 89: 153-163.

JERMY, T. 1961. Kártevö rovarok rajzásának vizsgálata fénycsapdákkal. *A Növényvédelem Idöszerü Kérdései* 2: 53-60.

KOCH, M. 1958. *Wir bestimmen Schmetterlinge*. Vol. 3. Neumann Radebeul/Berlin: 291 pp., 24 pls.

KURTZE, W. 1974. Synökologische und experimentelle Untersuchungen zur Nachtaktivität von Insekten. Synecological and experimental investigations on the night-activity of insects. *Zoologische Jahrbücher, Abteilung für Systematik* 101: 297-344.

LAM, J.J. & STEWART, P.A. 1969. Modified traps using blacklight lamps to capture nocturnal tobacco insects. *Journal of Economic Entomology* 62: 1378-1381.

LEDERER, G. 1959. Nahrungssuche und Nahrungsaufnahme der in der Dämmerung und in der Nacht fliegenden Lepidopteren. Grundlagen und Anleitung für das Köder- und Blütenfangverfahren. *Entomologische Zeitschrift* 69: 25-40, 42-56, 67-80, 94-100, 109-124, 126-132, 136-144.

LEINONEN, R., SÖDERMAN, G., ITÄMIES, J., RYTKÖNEN, S. RUTANEN, I. 1998. Intercalibration of different light-traps and bulbs used in moth monitoring in northern Europe. *Entomologica Fennica* 9: 37-51.

MALICKY, H. 2002. Ein Regendach für den Lichtfang. *Entomologische Zeitschrift* 112: 2-4.

McGEACHIE, W.J. 1989. The effects of moonlight illuminance temperature and wind speed on light-trap catches of moths. *Bulletin of Entomological Research* 79: 185-192.

MIKKOLA, K. 1972. Behavioural and electrophysiological responses of night-flying insects, especially Lepidoptera, to near-ultraviolet and visible light. *Annales Zoologici Fennici* 9: 225-254.

MORGE, G. 1973. Entomology in the western world in antiquity and in medieval times. *In:* SMITH, R.F., MITTLER, T.E. & SMITH, C.N. (Eds). *History of Entomology*. Annual Reviews Inc. Palo Alto, CA: 37-80.

MORTON, R., TUART, L.D. & WARDHAUGH, K.G. 1981. The analysis and standardisation of light-trap catches of *Heliothis armiger* (Hübner) and *H. punctiger* Wallengren (Lepidoptera: Noctuidae). *Bulletin of Entomological Research* 71: 207-225.

MUIRHEAD-THOMSON, R.C. 1991. Trap responses of flying insects. The influence of trap design on capture efficiency. Academic Press London: xii + 287 pp.

NAG, A. & NATH, P. 1991. Effect of moon light and lunar periodicity on the light trap catches of cutworm *Agrotis ipsilon* (Hufn.) moths. *Journal of Applied Entomology* 111: 358-360.

NOWINSZKY, L., SZABÓ, S., TÓTH, G., EKK, I. & KISS, M. 1979. The effect of the moon phases and of the intensity of polarized moonlight on the light-trap catches. *Zeitschrift für Angewandte Entomologie* 88: 337-353.

PERSSON, B. 1971. Influence of light on flight activity of noctuids (Lepidoptera) in south Sweden. *Entomologica Scandinavica* 2: 215-232.

PERSSON, B. 1976. Influence of weather and nocturnal illumination on the activity and abundance of populations of Noctuids (Lepidoptera) in south coastal Queensland. *Bulletin of Entomological Research* 66: 33-63.

PLAUT, H.N. 1971. Distance of attraction of moths of *Spodoptera littoralis* to BL radiation, and recapture of moths released at different distances of an ESA blacklight standard trap. *Journal of Economic Entomology* 64: 1402-1404.

PULLIAINEN, E. 1965. Tutkimuksia yökkösten (Lep., Noctuidae) aktiivisuudesta ja Varkauden (PS) seudun yökkösfaunasta [Studies on the activity of noctuids (Lep., Noctuidae) and on the noctuid fauna in the vicinity of Varkaus in north Savo]. *Savotar* 5: 215-255.

ROBINSON, H.S. & ROBINSON, P.J.M. 1950. Some notes on the observed behaviour of Lepidoptera in flight in the vicinity of light sources, together with a description of a light trap designed to take entomological samples. *Entomologist's Gazette* 1: 3-20.

SCHULZE, C.H., LINSENMAIR, K.E. & FIEDLER, K. 2001. Understorey versus canopy: patterns of vertical stratification and diversity among Lepidoptera in a Bornean rain forest. *Plant Ecology* 153: 1533-1552.

SOTTHIBANDHU, S. & BAKER, R.R. 1979. Celestial orientation by the large yellow underwing moth, *Noctua pronuba* L. *Animal Behaviour* 27: 786-800.

STEINER, A. 1991. Der Einsatz von Lichtfallen bei der Schädlingsbekämpfung in der römischen Kaiserzeit, 1. Jahrhundert v. Chr. - 4. Jahrhundert n. Chr. (Insecta, Lepidoptera, Pyralidae). *Beiträge zur Entomologie* 41: 405-410.

STEWART, P.A., LAM, J.J. & HOFFMAN, J.D. 1967. Activity of tobacco hornworm and corn earworm moths as determined by traps equipped with blacklight lamps. *Journal of Economic Entomology* 60: 1520-1522.

SUTTON, S.L. 1979. A portable light trap for studying insects of the upper canopy. *Brunei Museum Journal* 4: 156-160.

TAYLOR, L.R. 1963. Analysis of the effect of temperature on insects in flight. *Journal of Animal Ecology* 32: 99-117.

TAYLOR, L.R. & BROWN, E.S. 1972. Effects of light-trap design and illumination on samples of moths in the Kenya highlands. *Bulletin of Entomological Research* 62: 91-112.

TAYLOR, L.R. & FRENCH, R.A. 1974. Effects of light-trap design and illumination on samples of moths in an English woodland. *Bulletin of Entomological Research* 63: 583-594.

TAYLOR, R.A.J. 1986. Time series analysis of numbers of Lepidoptera caught at light traps in East Africa, and the effect of moonlight on trap efficiency. *Bulletin of Entomological Research* 76: 593-606.

TUCKER, M.R. 1983. Light-trap catches of African armyworm moths, *Spodoptera exempta* (Walker) (Lepidoptera: Noctuidae), in relation to rain and wind. *Bulletin of Entomological Research* 73: 315-319.

VAISHAMPAYAN, S.M. 1985a. Factors affecting the light trap catches of insects with emphasis on design aspects. *In*: *Use of traps for pest/vector research and control*. Mohanpur, West Bengal (Proc. Nat. Seminar): 62-67.

VAISHAMPAYAN, S.M. 1985b. JNKVV trap SM-model-light trap for survey of insect pests and vectors. *In*: *Use of traps for pest/vector research and control*. Mohanpur, West Bengal (Proc. Nat. Seminar): 152-155.

VAISHAMPAYAN, S.M. & VERMA, R. 1982. Influence of moon light and lunar periodicity on the light trap catches of gram pod borer, *Heliothis armigera* (Hübner) moths. *Indian Journal of Entomology* 44: 206-212.

WALKER, A.K. & GALBREATH, R.A. 1979. Collecting insects at lights: a test of four types of lamp. *New Zealand Entomologist* 7: 83-85.

WILLIAMS, C.B. 1936. The influence of moonlight on the activity of certain nocturnal insects, particularly of the family Noctuidae, as indicated by a light-trap. *Philosophical Transactions of the Royal Society of London, Series B* 226: 357-389.

WILLIAMS, C.B. 1940. An analysis of four years captures of insects in a light-trap. Part II: The effect of weather conditions on insect activity; and the estimation and forecasting of changes in the insect populations. *Philosophical Transactions of the Royal Entomological Society of London, Series B* 90: 227-306.

WILLIAMS, C.B. 1948. The Rothamsted light trap. *Philosophical Transactions of the Royal Entomological Society of London, Series A* 23: 80-85.

WILLIAMS, C.B. 1951. Comparing the efficiency of insect traps. *Bulletin of Entomological Research* 42: 513-517.

WILLIAMS, C.B. 1961. Studies in the effect of weather conditions on the activity and abundance of insect populations. *Philosophical Transactions of the Royal Society of London, Series B* 244: 331-378.

WILLIAMS, C.B., FRENCH, R.A. & HOSNI SIC M.M. 1955. A second experiment on testing the relative efficiency of insect traps. *Bulletin Entomological Research* 46: 193-204.

WILLIAMS, C.B. & SINGH, B.P. 1951. The effect of moonlight on insect activity. *Nature* 167: 853.

WIROOKS, L. 2005. Die ökologische Aussagekraft des Lichtfangs. Eine Studie zur Habitatbindung und kleinräumigen Verteilung von Nachtfaltern und ihren Raupen. Havixbeck-Hohenholte Verlag Wolf & Kreuels: 320 pp.