MANUAL VERSUS AUTOMATIC MOTH SAMPLING AT EQUAL LIGHT SOURCES - A COMPARISON OF CATCHES FROM MT. KILIMANJARO

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ABSTRACT. Nocturnal moth ensembles are frequently assessed using either catches from automatic light traps or manually collected samples at artificial light sources. Up to now, few studies have compared the influence of these methodological differences on the samples. We compared such samples, attracted by identical light sources, using geometrid moths in the montane rainforest belt of Mt. Kilimanjaro, Tanzania, as an example. The average number of moths caught manually from 1900 h to 2200 h at a light tower - a reflective gauze cylinder with a lamp placed in the middle - was more than ten times higher than that caught in a light trap, with more than half of all species only recorded at the light tower. With regard to individuals sampled, catches were biased towards the subfamily Ennominae in the traps (51% versus 30%) and towards Larentiinae in the manual samples (68% versus 44%). It remains to be tested whether the relatively higher representation of larger-sized Ennominae in the trap catches is due to later flight activity or some behavioral differences related to body size. Diversity (measured as Fisher's alpha) of light tower catches decreased from clearings (22.4) and secondary forest (21.7) to mature forest (11.0), while in the traps, values increased in the same order (Fisher's alpha: 6.0, 12.0, and 14.2). Species composition of trap samples taken in clearings and secondary forest differed strongly from manual catches, while manual and automatic samples from mature forest were more similar to each other. Manual moth sampling at light towers proved superior to automatic light traps in many ways and is hence recommended as a very useful standard method to record nocturnal insects if sufficient man-power is available.

Additional key words: Geometridae, sampling method, tropical mountain rainforest, diversity assessment.

Nocturnal moths can easily be sampled by attracting them to artificial light sources. Two strategies of obtaining samples are frequently employed. Moths may be collected in light traps. Various types of these traps are commonly used (Taylor & Brown 1972, Taylor & French 1974, Baker & Sadovy 1978, Bowden 1982, Muirhead-Thomson 1991, Leinonen et al. 1998). Many light traps are run stationarily, as they are heavy, bulky and rely on permanent electric power supply, but more recently, light, robust types relying on batteries for power supply have become more widely available. Alternatively, moths may be collected manually from reflective sheets or gauze cylinders set up adjacent to a light (e.g. Beck et al. 2002, Chey 2002, Axmacher 2003, Brehm & Fiedler 2003, Schulze & Fiedler 2003). Both collecting methods yield samples that are amenable to statistical analysis, provided that proper measures are taken to standardize catches (Schulze 2000). Such samples can be used for addressing various ecological questions, such as the response of moth communities to environmental gradients or change (for geometrid moths e.g. Intachat et al. 1997, Intachat et al. 1999a, 1999b, Beck et al. 2002, Thomas 2002, Axmacher 2003, Brehm & Fiedler 2003).

Few studies have attempted to critically compare sampling success and sample composition from the same sites as a function of the sampling method. Many light trap studies employed strong (100-250 W) stationary light sources, while for hand sampling and portable traps, weak fluorescent tubes (8-15 W) are commonly used. It therefore remains difficult to directly compare results from such studies.

The aim of our study is to compare both manual sampling at a light tower and automatic sampling using a portable type of light trap. To facilitate comparisons, identical lamps were used in light towers and traps. Thus effects of different light spectra and intensities on the insects (e.g. Taylor & French 1974, Bowden 1982, Leinonen et al. 1998, Intachat & Woiwod 1999, Southwood & Henderson 2000) were eliminated.

Geometrid moths were selected as our study group since they have been often used as ecological indicators (Holloway 1985, Chey et al. 1997, Intachat et al. 1997, Intachat et al. 1999a, 1999b, Intachat & Woiwod 1999, Willott 1999, Kitching et al. 2000, Beck et al. 2002, Brehm et al. 2003). With about 21,000 known species (Scoble et al. 1995, Scoble 1999), this family is one of the most diverse in the order Lepidoptera.

MATERIAL AND METHODS

Study site. The study was conducted in the montane rainforest on the south western slopes of Mt. Kilimanjaro, Tanzania, in close vicinity to the Machame route at altitudes of about 2100 to 2300 m. Moths were caught in three different habitat types: large clearings (> 2500 m2, 3 sites), secondary forest (3 sites), and mature forest (6 sites).

Moth sampling. A small, robust type of automatic light trap (Fritz Weber, Germany, slightly modified,

Fig. 1) was used. The automatic light trap was arranged with the sampling bag just above the soil surface in order to avoid intrusion of army ants (Dorylus spp.). A total of seven traps were operated during the whole night from dusk to dawn (~1900 h to 0600 h), with 29 catches performed on clearings, 26 catches at secondary forest sites and 39 catches in mature forest.

Additionally, moths were sampled manually at three light towers (cylinder of reflective gauze, Fritz Weber, Germany, Fig. 2). On light towers, all geometrid moths were manually sampled from 1900 h to 2200 h. Twenty-two catches were performed on clearings, 16 in secondary forest and 11 in mature forest. Five nights before to four nights after full moon, sampling with both methods was stopped as the attractiveness of artificial light sources is reduced during this period (McGeachie 1989, Yela & Holyoak 1997, Schulze 2000, Brehm 2002).

FIG. 2: Sketch of the light tower. Moths settle on the reflective gauze cylinder where they can be easily and selectively sampled.

Automatic light traps and light towers were equipped with a 15W-blacklight tube each (Sylvania Blacklight-Blue, F 15 W / BLB-TB) run on a 12V dry battery pack. This weak light source was aimed to ensure that moths were only attracted from a short radius, so that habitat-specific sampling was possible also in habitat mosaics. Earlier studies with the same equipment revealed that indeed such moth samples have a high spatial resolution (Schulze & Fiedler 2003, Fiedler & Schulze in press).

To avoid possible effects of seasonality on the comparison of the sampling techniques, for both methods only catches from the rainy seasons (1st March to 30th May and 1st -26th November) are considered in this study. Furthermore, samples were generally taken simultaneously at all three habitat types to make results more easily comparable. Site selection within the same habitat type was performed at random. To allow for meaningful statistical analyses, samples from different sites belonging to the same habitat type were pooled. Moths were sorted to morphospecies level and further determined as far as possible at the Zoologische Staatssammlung, Munich, where vouchers of all species will be deposited. A complete list of our specimens has been published (Axmacher 2003) and can also be obtained directly from the corresponding author.

Statistical analysis. χ^2-tests were employed to compare the effect of the sampling technique on the proportion of the subfamilies in the overall catches. Fisher's alpha (Fisher et al. 1943) was used to assess the
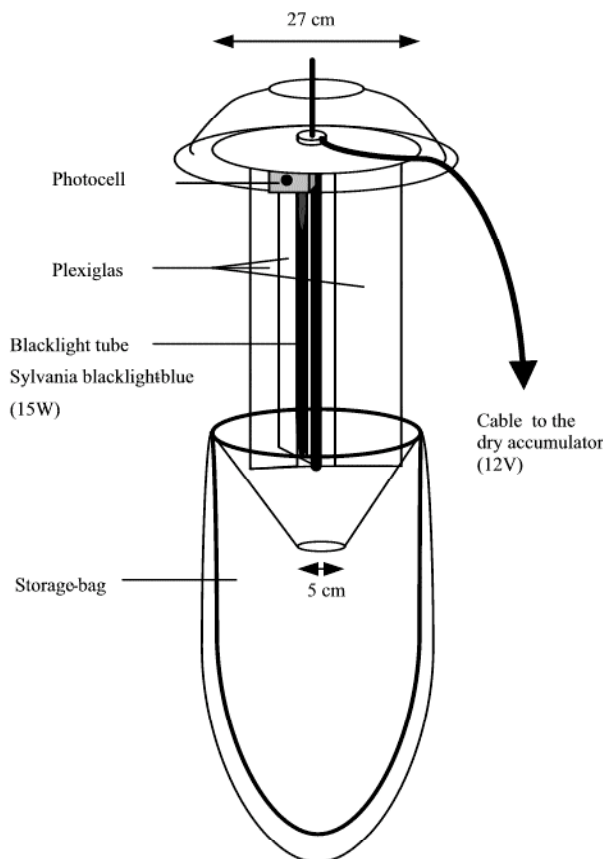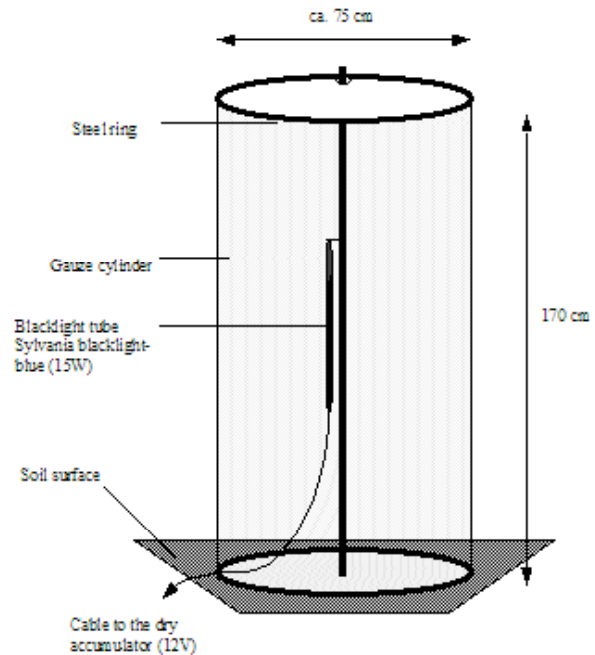

FIG. 1: Sketch of the light trap used in this study. Moths circle around the lamp until they collide with the Plexiglass and fall through the funnel into the storage bag below. For rain protection, a plastic bowl was fixed above the lamp, and the storage bag was put into a plastic bag (dotted lines). The storage bag was partly filled with leaves and twigs among which the moths could rest. A photoelectric element was used to ensure the operation of the lamp from dusk until dawn.

diversity of moths in different habitat types (with pooled samples exceeding 150 individuals in all cases) according to sampling methods. To evaluate the similarity between the pooled samples for each habitat type and for each sampling method, the chord-normalized expected species shared (CNESS) index (Trueblood et al. 1994) was employed. This index gives an approximation of the expected similarity of samples of an equal sample size (m) which can be varied from 1 to the smallest common maximal sample size. Setting $m=1$ strongly emphasises the most dominant species, while an intermediate level ($m=50$) and high values ($m=100$) give an increasingly strong emphasis to rare species. Based on the CNESS dissimilarity matrices, samples were ordinated using non-metric two-dimensional scaling for different values of the sample size parameter m (Brehm & Fiedler 2004). The software packages EstimateS 6.5 (Colwell 2000), COMPAH 96 (Gallagher 1999) and STATISTICA (Statsoft, Tulsa, UK) were used for analyses.

RESULTS

Effectiveness of methods. In the study area, 49 nightly manual catches at the light tower resulted in 2123 specimens representing 109 species of geometrid moths, while 94 nights of automatic light trapping yielded a total of 372 specimens representing 49 species. The average number of individuals caught in light traps was 4.0 specimens/night, whereas the light towers yielded approximately 43 specimens/3 h period (Table 1). Thus, manual samples of moths at light towers were on average more than ten times larger than trap catches. The maximum number of individuals found in a single trap was 20, while the minimum was 1. At the tower, the maximum number of geometrids recorded in a single, 3 h period was 239, the minimum 6. While between-habitat variation for sampling success of light traps was negligible, the effectiveness of light towers strongly increased from clearings and secondary to mature forest.

A comparison of species caught with the two methods showed that 42 species (36%) were present in both samples from light towers and light traps. Sixty-seven species (57%) were only found at the light towers, while 8 species (7%) were exclusively recorded in traps.

Subfamilial sample composition. Depending on the collecting method, samples differed strongly with regard to subfamily composition (Fig. 3 (A)). Larentiinae comprised 68% of all individuals caught at the light tower, compared to only 44% in the traps ($\chi^2=79.1$; p<0.01; df=1). Conversely, the proportion of Ennominae specimens was 30% at the tower and 51% in the traps ($\chi^2=62.8$; p<0.01; df=1). Geometrinae

accounted for a slightly higher proportion in the traps than at the tower, while Sterrhinae occurred rarely at the light tower as well as in the traps. Desmobathrinae (overall very rare on the study sites) were never caught in the traps. When comparing the number of species belonging to different subfamilies (Fig. 3 (B)), the differences were much less pronounced. Larentiinae in both cases accounted for slightly more than half of the species, while Ennominae had a higher proportion in the traps, and there were proportionally more species of Geometrinae encountered at the light towers.

Two species of Larentiinae (*Mimoclystia corticearia* Aurivillius and *Chloroclystis derasata* Bastelberger) and the Ennomine *Darisodes oritropha* Fletcher were the three most dominant species at the light towers. These species were also among the four most dominant species in the traps, but they accounted for smaller proportions in the traps (17%, 10% and 9% respectively), than in the manual catches (26%, 9% and 20% respectively). In the trap catches, the Ennominae *Rhodophthitus arichannaria* Fletcher reached abundance rank two (44 individuals) whereas it was rarely encountered at light towers (12 individuals, rank 20).

Within-habitat diversity. Values of Fisher's alpha for different habitats differed significantly for both sampling methods, but the trends diverged strongly relative to the sampling method (Fig. 4). On clearings, samples attained at light towers showed the highest values for Fisher's alpha, whereas trap samples had the lowest values of all habitats investigated. Diversity was intermediate in secondary forest for both methods and peaked in mature forest when evaluated with light traps, while there was an overall decrease in diversity from clearings across secondary forest to mature forest for the catches at light towers.

Species composition. Ordinations using CNESS distances were performed for three different values of the sample size parameter m (Fig. 5). There is a general division between trap samples from secondary forest and clearings, and the remaining samples along the first dimension. Only trap catches in mature forest show a stronger similarity with the respective tower catches. This dissimilarity increases with an increasing sample size parameter m. The stress value of the ordinations as a measure of goodness of fit was <<0.01 in all cases, indicating that the ordinations precisely depict the original dissimilarity matrices.

DISCUSSION

Comparisons of samples attained with sampling at light towers and with light traps show that there are substantial differences in abundance and composition of

TABLE 1: Average number of Geometridae individuals, species, and individuals per catch recorded by nightly automatic light trap catches and manual 3 h catches in the different habitat types on Mt. Kilimanjaro, Tanzania.

Light trap	Catches	Individuals	Species	Individuals per catch
clearing	29	139	19	4.79
secondary forest	26	102	27	3.92
mature forest	39	131	33	3.45
all habitats	94	372	49	3.96

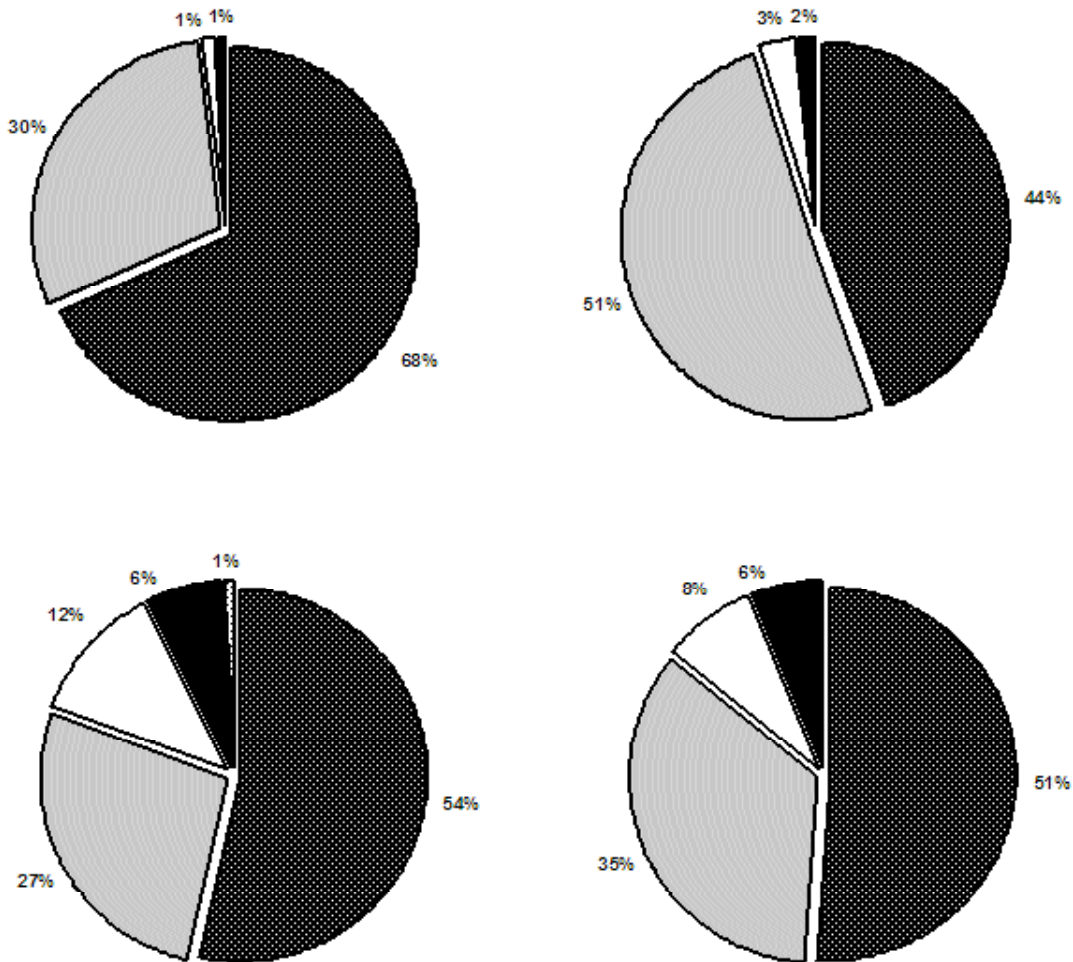| **Light tower**	Catches	Individuals	Species	Individuals per catch
clearing	22	534	72	24.27
secondary forest	16	578	71	36.13
mature forest	11	1011	50	91.91
all habitats	49	2123	109	43.33

FIG. 3: Comparison of sampling methods with regard to subfamily spectra of (A) individuals and (B) species.
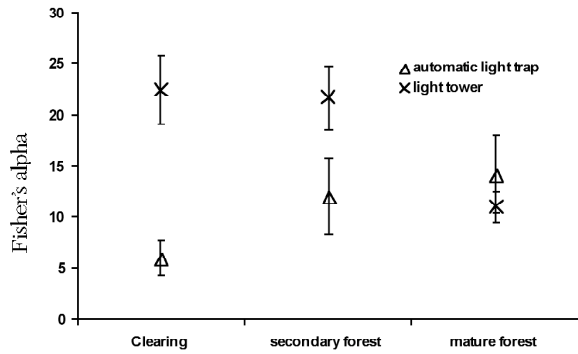
FIG. 4: Values of Fisher's alpha for the different habitats attained with light traps and at light towers. Whiskers show the 95% confidence interval. Pooled sample sizes exceed 100 individuals for each habitat.

such catches, even when identical light sources are used in the same habitats. Manual samples taken at light towers over 3 h intervals were on average ten times l a rger than automatic trap samples assembled over 11 h.

Overall, diversity and abundance of geometrid moths on Mt. Kilimanjaro is very low in comparison to other t ropical forest ecosystems (Axmacher et al. 1994, in p ress). Nevertheless, the same tendency is obvious in other geographical regions. In Southeast Asia, light trap catches - mostly employing powerful types of lamps (125-250 W) - ranged from 10 to 31 geometrid moths per night (Barlow & Woiwod 1989, Intachat et al. 1997, Intachat & Woiwod 1999, Intachat & Holloway 2000). Trap catches in Australian tropical rainforest (8 W lamp) yielded an even lower average of only 6 geometrid moths per night (Kitching et al. 2000), which is in the same range as the catches on Mt. Kilimanjaro. In contrast, at light towers equipped with the same weak type of blacklight lamp as employed on Mt. Kilimanjaro, an average of 34 geometrid moths were caught on Borneo during 2.5 h nightly sampling periods (Beck et al. 2002). In the Ecuadorian Andes, the average number of geometrid individuals caught at light towers (with 2 x 15 W tubes) even exceeded 200 individuals during 3 h nightly catches (Brehm & Fiedler 2003).

Quantitative samples from temperate regions reveal the same diffe rences. Here, the number of individuals caught in traps varies from less than 5 to 27 (Usher & Keiller 1998, Ricketts et al. 2002, Thomas 2002), whereas at light towers, an average of 50 geometrid moths were caught during 3 h sampling periods (Mühlenberg 1999). It can therefore be concluded that manual catches using light towers, albeit more laborious, generally result in a higher number of specimens caught per unit time than comparable light traps.

In our study, the number of moths arriving on the gauze of the tower decreased strongly after 2100 h. It is
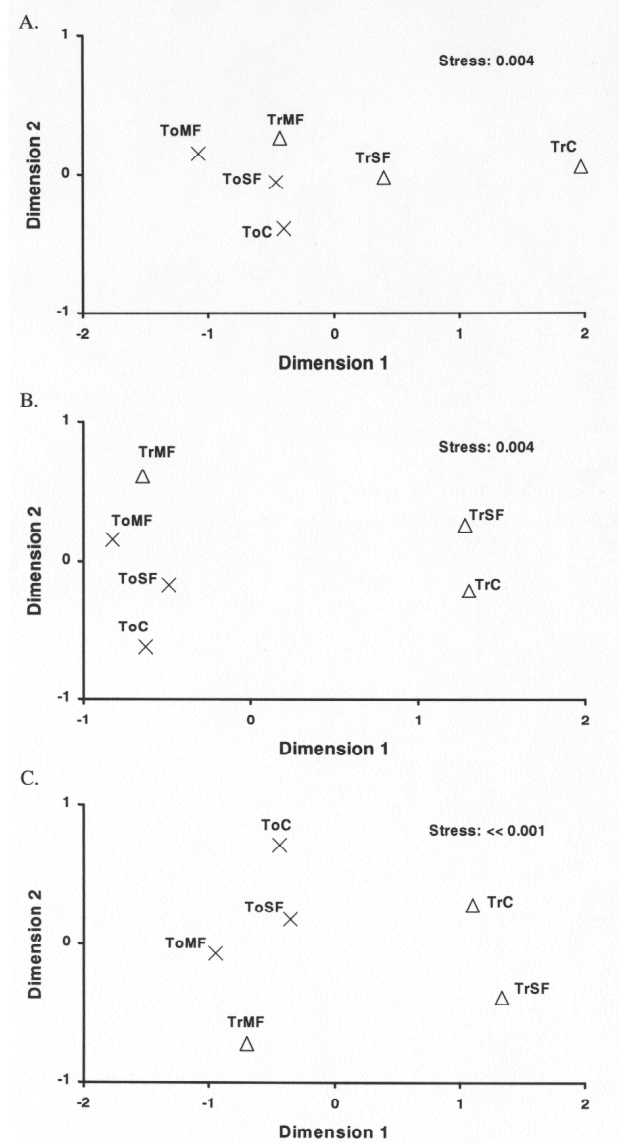

FIG. 5: Ordination diagrams (non-linear two-dimensional scaling) of moth samples based on CNESS distances (A: m=1, B: m=50, C: m=100, To: light tower, Tr: light trap, C: clearing, SF: secondary forest, MF: mature forest).

therefore likely that most geometrid species in the montane forest belt of Mt. Kilimanjaro show highest activity between 1900 h and 2100 h. The vast majority of species collected with the traps were also present in the catches at the light tower, which further supports this presumption. Therefore, a qualitative species inventory in an area is possible with light towers as they were operated in this study.

A few species were much more strongly represented in trap samples (e.g. *Rhodophthitus arichannaria*, *Xanthisthisa fulva* Wa rren, *X. tarsispina* Wa rren, *Cleora* c.f. *thyris* (all Ennominae); *Pingasa distensaria* Walker

(Geometrinae)). There are two possibilities to explain this phenomenon. These species may have later peaks of flight activity, reducing their likelihood of being sampled in the first 3 h of darkness. Remarkably, these species are all relatively large geometrid moths (wingspan: 2.9-5.5 cm). In contrast, Larentiinae moths (which are generally smaller than Ennominae, e.g. Brehm & Fiedler 2004a) were more strongly represented in the manual catches. Thus, an alternative explanation for differences between manual and automatic samples could be a systematic bias of the trap samples to larger-sized geometrids, perhaps due to characteristics in flight and behavior which are related to body size and design. This idea should be experimentally tested, since if true it would strongly challenge the representativeness of automatic trap samples with regard to species composition and diversity.

The much wider spectrum of species caught manually at the tower shows that only about half of all species of Geometridae attracted to the lamps used in this study were recorded in the light traps. Although this might also be partly related to differences in the size of the samples, also sample-size independent estimators of local diversity (such as Fisher's alpha) show that automatic light-trap samples tend to underestimate species diversity. Furthermore, with regard to species composition the smaller trap samples are not just impoverished subsets of the larger manual ones. Rather, as indicated by ordination results, the communities amenable to sampling by the two methods are not identical.

Our findings demonstrate that not only different light quality and trap types (Taylor & Brown 1972, Taylor & French 1974, Muirhead-Thomson 1991, Leinonen et al. 1998), but also the method of sampling itself has a major impact on species number, diversity and composition of light trap samples. This makes comparisons between different studies more complicated. Moreover, our results raise doubts whether with automatic light traps - at least among the Geometridae - important fractions of the fauna (e.g. small-bodied Larentiinae) are generally strongly under-sampled.

For the future, it therefore seems advisable to standardize methods of recording nocturnal insects. In this regard, light towers proved not only to be a robust and flexible equipment, but also very effective albeit labor intensive and catching a wider spectrum of species than the traps. Especially when effectiveness of the sampling is central, e.g. when studying remote areas or habitats slated for destruction, we strongly propose manual sampling. Finally, when equipped with weak light sources such manual samples also allow for an assessment of moth ensembles with a high spatial or temporal resolution (Schulze et al. 2001, Beck et al. 2002, Axmacher 2003, Schulze & Fiedler 2003).

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