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ORIGINAL ARTICLE

Assessing the efficiency of UV LEDs as light sources for sampling the diversity of macro-moths (Lepidoptera)

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Abstract. Light trapping is the most widely used tool for determining the diversity of nocturnal Lepidoptera, but UV LEDs have yet to be used as light sources for the large-scale monitoring of Lepidoptera. We assessed the efficiency of this novel light source for sampling moths using a Heath type moth equipped with a strip of 150 high brightness UV LEDs (emission peak 398 nm, ~15 W) powered by a 12 V battery. We compared the number of individuals, the number of species and the Geometridae/Noctuidae ratio recorded for the samples collected using UV LED traps with those collected in two monitoring programs carried out in the same geographic region using two different light sources: a 200 W incandescent lamp (Rothamsted trap) and a 160 W mercury vapour lamp (manual catch). The total catch consisted of 61,120 individuals belonging to 699 species. The species richness rarefaction curves revealed that the Rothamsted trap collected fewer species and individuals than UV LED traps. Furthermore, the median numbers of species and individuals caught by UV LED traps fell within the range of those caught by mercury vapour lamp traps. In addition, the community composition recorded using incandescent lamps and UV LEDs was similar. The data obtained using UV LED traps, in absolute terms and in comparison with the other light sources and different sampling methods, clearly reveal that this light source is suitable for sampling macro-moth communities. For field work UV LEDs have many advantages, as they are resistant to mechanical damage, easily protected from heavy rain and energy efficient.

INTRODUCTION

Light trapping is the most widely used tool for investigating communities of nocturnal Lepidoptera and often used in studies on the effects of environmental changes on biodiversity around the world and in many types of habitats. This sampling method has been used for assessing moth diversity e.g. in species rich tropical rain forests in Malaysia (Barlow & Woiwod, 1989), in the Ecuadorian Andes (Brehm & Fiedler, 2005) and in Costa Rica (Brehm & Axmacher, 2006). In temperate regions it has been used for exploring the relationships between landscape consisting of farms, woodlands and forest and macro-Lepidoptera diversity in Great Britain (Usher & Keiller, 1998) and for studying biodiversity and ecology of deciduous forests in North America and South Korea (Summerville & Crist, 2004; Choi & Miller, 2013). Light trapping has also been used for studying changes in moth communities as a consequence of climate warming in Mediterranean mountains and subarctic forests (Scalercio, 2009; Hunter et al., 2014), and for studying moth diversity in urban areas in North America (Downer & Ebert, 2014).

When the main goal is to obtain the highest possible number of species and specimens in good condition for faunistic studies, moths are manually collected (qualitatively or quantitatively) on the surface of white sheets, gauze and other structures in front of or around artificial light sources (Axmacher & Fiedler, 2004). Automatic light traps are utilized in ecological studies for which it is important to compare samples obtained using a comparable sampling effort (e.g. Holloway et al., 2001; Fiedler & Schulze, 2004; Beck & Linsenmair, 2006; Brehm, 2007). However, there are no universally adopted standards for sampling with light sources and features of the traps are from time to time adapted to different contingent factors. Data obtained with such a variety of collecting methods are not fully comparable because the adopted method affects samples both qualitatively and quantitatively (Taylor & French, 1974; Intachat & Woiwod, 1999; Jonason et al., 2014; Merckx & Slade, 2014). It is possible to identify four main types of traps: Robinson (Robinson & Robinson, 1950), Skinner (designed by Bernard Skinner), Heath (Heath, 1965) and Rothamsted (Williams, 1948). Rothamsted traps are usually used for sampling nocturnal insects at permanent locations (Southwood et al., 2003), while the others are usually positioned in the field for just one or few consecutive nights, as is recorded in all previously cited papers.

Apart from the standard Rothamsted traps, that operate with an incandescent lamp (RIL) having a tungsten filament (according to the Rothamsted Insect Survey – RIS), the most often used light sources are mercury vapour lamps (MVL) and actinic and blacklight tubes with emission spectra including ultraviolet (UV) light. UV radiation is widely regarded as the most attractive for moths. Under laboratory conditions, incandescent lamps only have a lifespan of approx. 1,000 h, they are highly energy demanding, produce high proportions of long wave radiation (including infrared above ca. 700 nm) and low proportions of short wave radiation. Not-self ballasted MVLs usually have a longer lifespan of approx. 6,000–8,000 h while the self-ballasted MVLs have a similar lifespan to the incandescent lamp because they have a tungsten filament in the bulb. They are also highly energy demanding, but produce a considerable amount UV light. Actinic and black light tubes have a lifespan of approx. 5,000 h, are low in energy demand and produce a very high proportion of UV-light. Standard incandescent and MVLs require a high voltage, whereas actinic tubes can work on a low voltage and thus can be operated using batteries. The glass of both, bulbs and tubes are easily damaged during transport and fieldwork, which affects their transportability. Moreover, all tubes and MVLs contain mercury, a heavy metal that is highly toxic to humans and other organisms.

Whichever collecting method is used, a sufficient number of species and individuals are usually collected by the above mentioned devices under favourable meteorological conditions for researchers to infer and draw conclusions. Between 20–40 species and 60–200 individuals per night from May to October are sufficient for carrying out ecological studies in European countries at different latitudes (Usher & Keiller, 1998; Scalercio & Infusino, 2003, 2006; Scalercio et al., 2008; Jonason et al., 2014).

Light-emitting diodes producing UV light (UV LEDs) have several interesting characteristics compared to traditional light sources, such as an emitted light wavelength similar to actinic tubes, a lower energy demand, a low voltage operation (12 V), a longer life under laboratory conditions (up to 50,000 h), a more constant luminous intensity during their life, and, finally, a greater resistance to mechanical damage and electrical overload. Although the properties of UV LEDs overcome most of the problems associated with the use of conventional light sources, UV LEDs have rarely been used as a light source for the large-scale monitoring of Lepidoptera (Horváth et al., 2016), mainly because commercially available models, such as the "Goodden GemLight", have only recently come onto the market.

Effectiveness of UV LEDs for insect monitoring is demonstrated by a relatively few studies. Phlebotomine sand flies were effectively sampled in North and South America (Cohnstaedt et al., 2008), greenhouse whiteflies in Germany (Stukenberg et al., 2015) and aquatic macroinvertebrates in South Africa (Price & Baker, 2016) and New Zealand (Green et al., 2012). In the last mentioned paper, traps with different light sources were tested, including 8 W actinic fluorescent tubes and approximately 2 W UV/black light (18 LEDs, 395 nm) LEDs. Among other insects, a few Lepidoptera were also caught in this study. UV LED traps captured on average as many specimens of Trichoptera and Coleoptera as actinic lamp traps, but significantly less Lepidoptera, i.e. nocturnally active moths. The authors indicate the low power of the LEDs used and their poor visibility from a water body as the cause of such results. In fact, they hypothesized that a greater number of LEDs spreading the light over 360° could result in catches comparable to those of moths by actinic tubes. This hypothesis seems to be confirmed for *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), which is significantly more attracted by LEDs emitting at 405 nm compared to other wavelengths (Cowan & Gries, 2009) and confirmed by electroretinogram recordings. White et al. (2016) tested the efficiency of traps equipped with 18 UV LEDs for catching moths relative to that of light traps equipped with 12W black light mercury vapour bulbs. They found UV LEDs less effective than the other light source, but evaluated the former more cost-effective.

The aim of this paper was to assess the efficiency of UV LEDs as light sources for sampling moths. We hypothesized that UV LEDs would perform at least as well as other currently used light sources. We sampled moths using traps equipped with UV LEDs and a Rothamsted trap equipped with an incandescent lamp, both located in the same forest in a mountainous area in southern Italy. Species richness and abundance of samples were compared as a measure of light sources performance. Furthermore, we assessed the qualitative composition of the samples and evaluated the similarity of communities and the ratio Geometridae/Noctuidae, the two most speciose moth families with different flight behaviours. Our data were also compared with that in the literature on sampling moths in the same geographic region using MVLs in order to obtain a broader view of the efficiency of UV LEDs for sampling moths.

MATERIAL AND METHODS

The experimental design was based on original and literature data, all collected in Calabria, the southernmost region of the Italian Peninsula. Sampling sites were located in different geomorphological territorial units, with potentially different faunas (Scalercio, 2014a) (Fig. 1). We performed two comparisons: (i) UV LED traps vs. Rothamsted traps, carried out on the Sila Massif; (ii) UV LED traps vs. MVL, carried out in six different territorial units.

We tested the attractive power for moths of high brightness UV LEDs (emission peak 398 nm light angle per LED 120°; EPISTAR Corporation, Taiwan). Light traps were constructed based on the design of Parenzan & De Marzo (1981), which is similar to that of Heath traps, but modified to accommodate the UV LEDs (Fig. 2a). A 2.5 m long strip, with a total of 150 LEDs (~15 W), was wrapped around and glued to a PVC tube and placed above the collection funnel. Traps were positioned at approximately

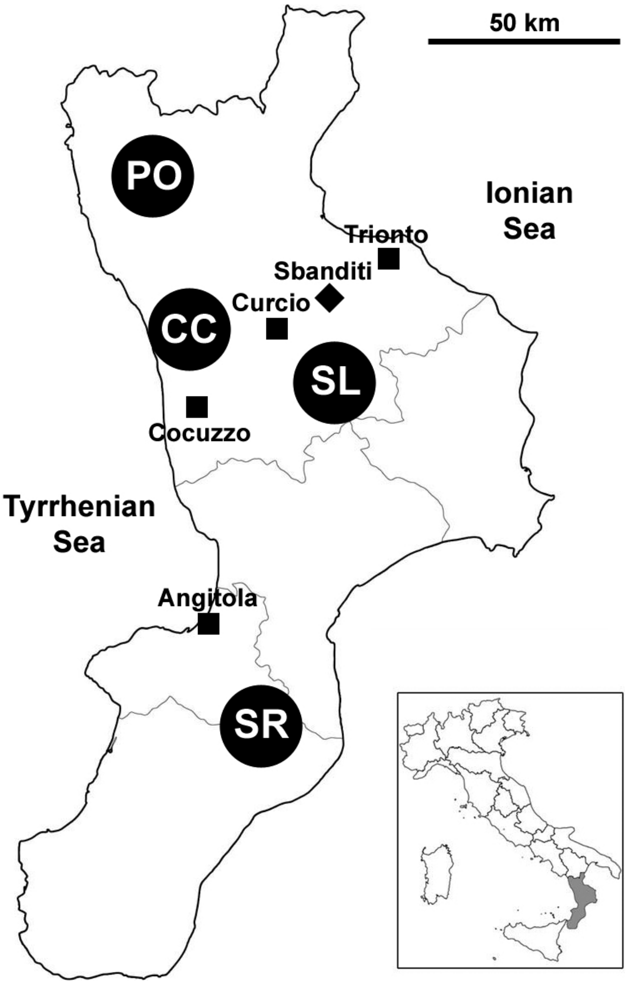

Fig. 1. Location of the areas studied. Black circles indicate geographic areas sampled using UV LED traps (PO – Pollino Mountains; CC – Catena Costiera; SL – Sila Massif; SR – Serre Mountains). Black squares indicate localities sampled using mercury vapour bulbs. The black diamond indicates the location of the Rothamsted trap.

1.30 m above ground level, powered by a portable lead battery (45 Ah, 12 V), which did not provide a constant current source, using ethyl acetate as the killing agent (Fig. 2b). This trap has several advantages under field conditions; long battery life and high resistance to heavy rain. Under indoor conditions, the battery provided power for more than 70 h and a little bit less under field conditions, allowing us to re-utilize the same battery for at least three consecutive sampling sessions. We found that a lighter battery (7.6 Ah, 12 V) was sufficient for a single sample (data not shown). Therefore, their use did not require frequent recharging, connection to an electricity grid or portable power generators. Finally, a simple cover was sufficient to protect traps from heavy rain that sometimes occurred in spring and autumn during this study. In the MVL, we used an Osram 160 W bulb, which is self-ballasted with a filament. It had a an higher effective power uptake (190 W). The Rothamsted trap had a 200 W incandescent lamp (with filament).

Emission measurements and spectral analysis

We measured the emission spectra of the irradiance from three different types of lamp (UV-LED, MVL, RIL) used in the field using a Specbos 1211 UV broadband spectroradiometer at a distance of 50 cm in the laboratory.

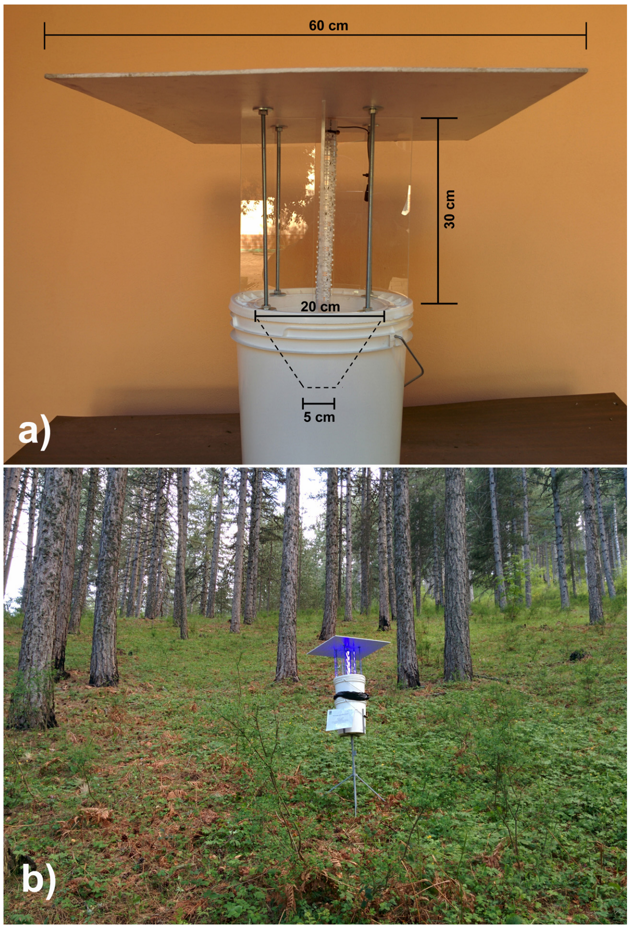

Fig. 2. Trap used in this study: a – close-up photograph of the trap and it's dimensions; b – trap in the field.

Experimental design

UV LED traps vs. Rothamsted trap

We compared the samples obtained using UV LED traps (UV LEDs), as described above, with those obtained using a Rothamsted trap with a 200 W incandescent lamp (RIL) (Williams, 1948). Moths were sampled from May to October 2015. These months are generally regarded as the best for monitoring moths in temperate and sub-arctic climates (Highland et al., 2013; Hunter et al., 2014; Jonason et al., 2014).

We positioned six traps at three localities on the Sila Massif (Table 1), i.e. two traps per locality at a minimum distance of 300 m apart to prevent interference between traps (Merckx & Slade, 2014). The localities were located within a radius of 7.5 km of one another (min. distance: 8 km; max. distance: 15 km). Traps ran for one night per month from sunset to sunrise, resulting in 12 samples per locality (2 traps × 6 nights) at the end of the sampling season. The Rothamsted trap was located at Vivaio Sbanditi, Sila Massif (Fig. 1; Table 1), 12 km from the nearest UV LEDs trap, but in the same habitat and at the same altitude. It was turned on one night per week from May to October 2015, resulting in 26 samples. On the Sila Massif, UV LEDs and RIL traps were used in the same year and contemporaneously for one night per month, which allowed us to compare those samples both qualitatively and quantitatively.

UV LED traps vs. MVLs

This comparison was done using samples collected in six different territorial units in Calabria. UV LEDs were located in the Pollino Mountains (PO), the Catena Costiera (CC), on the Sila

Massif (SL) and in the Serre Mountains (SR) (Fig. 1, Table 1). Within each territorial unit we followed the same sampling procedure as described for the UV LEDs/RIL comparison carried out on the Sila Massif, resulting at the end of the sampling season with 12 UV LEDs samples per locality (2 traps × 6 nights) and a total of 144 samples (12 samples × 12 localities).

Data for the MVLs were obtained from a moth monitoring program carried out from 1999 to 2003 (Scalercio & Infusino, 2003, 2006; Scalercio et al., 2008; Scalercio, 2014b). One 160 W MVL was located at each of four sites in four different territorial units, the Catena Costiera (CC), on the Sila Massif (SL), the Ionian Coast (IC) and the Tyrrhenian Coast (TC) (Fig. 1, Table 1). Two operators collected moths manually and by nets around the lamps, positioned 1.30 m above the ground in front of a reflecting white sheet. MVLs ran for four hours after sunset. Each site was sampled for two years resulting in four samples per month, i.e. a total of 24 MVL samples per site from May to October, or a total of 96 samples (24 samples × 4 localities).

Data analyses

The efficiency of the light sources tested was compared in terms of species richness and abundance, the two measures most frequently used in the analysis of animal communities. Detailed comparisons between UV LEDs and RIL were carried out because samples were obtained within the same territorial unit, in the same habitat and at the same time. A descriptive approach was used to compare UV LEDs and MVLs because in only two cases were the samples obtained from the same territorial unit, always in different habitats and in different years.

UV LED traps vs. Rothamsted trap

Box and Whisker plots of species richness and abundance were used to describe the results obtained using the different light sources. These were based on raw data, i.e. number of species and number of individuals collected during any trap/night, plotting (i) their maximum and minimum values, (ii) their 25–75% intervals and (iii) their medians.

We used sample-based and abundance-based rarefaction curves to compare the total species richness recorded at the four sites used for this comparison. We used this method because it allows species richness of samples to be compared even if sample sizes are different (Jonason et al., 2014), as in this study (12 samples for each UV LED site and 26 for the RIL site). They were computed after 100 randomizations running EstimateS 9.1.0 (Colwell, 2013).

We used the Bray-Curtis quantitative index (B–C) to measure the similarity among communities. B–C varies between 0 and 1, 0 indicates no similarity, 1 complete similarity. This index was also computed by running EstimateS 9.1.0 (Colwell, 2013).

In order to evaluate the effect of trapping methods on catchability of taxa with different flight behaviours, we computed the Geometridae/Noctuidae ratio (G/N) for samples collected contemporaneously by the Sila Massif's RIL and UV LEDs. Many species of Noctuidae are considered to be good flyers and generally spend the daytime on the ground. Geometridae are generally weaker flyers than Noctuidae and usually rest on vegetation (Intachat & Woiwod, 1999; Steiner & Häuser, 2010).

UV LED traps vs. MVLs

This comparison was only descriptive due to the potentially different faunas at the sites sampled. Nevertheless, it is useful to carry out this type of analysis because it can provide additional information on the relative efficiency of UV LEDs. Data are arranged and plotted in Box and Whisker plots of species richness and abundance as described for the UV LEDs/RIL data analysis.

RESULTS

Lamp emission and spectral analysis

The three types of lamp differ considerably in the power required, total emission (Table 2) and emission spectra (Fig. 3). The UV LED has the lowest power requirement and the lowest total emission. However, the emitted radiation falls within the range that is thought to be visible to moths (ca. 300–650 nm, Table 2). In contrast, a large percentage of the emission of the other lamps consisted of

Table 1. Description and location of the sites sampled. Territorial unit: Pollino Mountains (PO); Catena Costiera (CC); Sila Massif (SL); Serre Mountains (SR); Tyrrhenian Coast (TC); Ionian Coast (IC). Light sources: UV LED – ultraviolet light emitting diode; MVL – mercury vapour lamp; RIL – Rothamsted incandescent lamp.

Site	Territorial unit	Light source	Altitude (m a.s.l.)	Habitat type
Serrapaolo	PO	UV LED	990–1010	Beech forest
Novacco	PO	UV LED	1315–1370	Beech forest
Magara	PO	UV LED	1460–1465	Beech forest
San Fili	CC	UV LED	720–740	Chestnut forest
Greco	CC	UV LED	620–630	Chestnut forest
Parantoro	CC	UV LED	550–565	Chestnut forest
Covelli	SL	UV LED	1294–1380	Black pine forest
Arvo	SL	UV LED	1310–1382	Black pine forest
Colle Macchie	SL	UV LED	1436–1453	Black pine forest
Santa Maria	SR	UV LED	840–847	Silver fir forest
Cattarinella	SR	UV LED	940–970	Silver fir forest
Archiforo	SR	UV LED	1080–1120	Silver fir forest
Angitola	TC	MVL	44	Riparian wood
Trionto	IC	MVL	90	Xerothermic wood
Cocuzzo	CC	MVL	1150	Mixed forest
Curcio	SL	MVL	1690	Beech forest
Sbanditi	SL	RIL	1350	Black pine forest

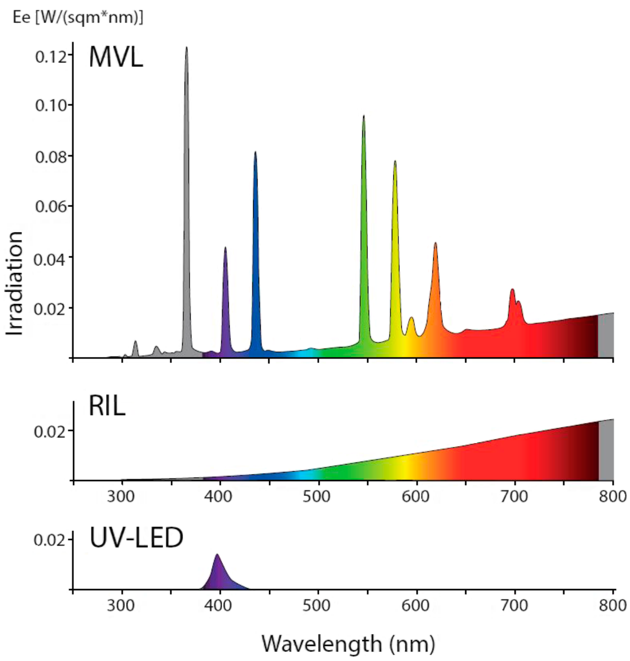

Fig. 3. Emission spectra and irradiation recorded at a distance of 50 cm from an Osram 160 W mercury vapour lamp (MVL), UV LEDs (15 W) and a 200 W incandescent lamp (RIL) used to sample moths measured using a Specbos 1211 UV broadband spectroradiometer.

Table 2. Power required and total emission of the different types of lamps used.

	UV LED	MVL	RIL
Effective power uptake	15 W	190 W	200 W
Emission Ee [W/(sqm*nm)] 300–1000 nm	0.234	10.156	9.940
300–400 nm	0.129 (55.2%)	0.694 (6.8%)	0.035 (0.3%)
401–650 nm	0.104 (44.8%)	3.132 (30.8%)	1.54 (15.5%)
651–1000 nm	0 (0%)	6.330 (62.3%)	8.36 (84.1%)

relatively long wave radiation (650–1000 nm). More than 60% of the emission was >650 nm for the MVL and even more than 80% was >650 nm for the RIL. Spectral analysis of the UV LEDs revealed a single peak at 398 nm (Fig. 3). The MVL had the typical spectrum of lamps containing mercury vapour, with narrow peaks of emission at 365, 405, 436, 546 and 578 nm. The MVL also produced a large amount of long wave radiation from the filament glow in the bulb, which ranged into the infrared (Fig. 3). The RIL had only the latter (Fig. 3).

Species and individuals

The total sample consisted of 61,120 individuals belonging to 699 species. The number of species collected at each site varied from 142 to 274 and the number of specimens from 1,098 to 14,405 (Table 3). The lowest number of species (S = 142) was recorded for a site with a UV LED trap, but the second most species rich site (S = 261) was also one with the same kind of trap. Furthermore, both the most and the least numerous samples were recorded at sites with UV LED traps (Table 3).

UV LED traps vs. Rothamsted trap

RIL traps collected fewer species and individuals per night than UV LED traps located in the same type of habitat on the same massif (Fig. 4). Sample-based rarefaction curves of species richness indicated that the UV LED samples were composed of a similar number of species, which is higher than those recorded in RIL samples (Fig. 5). Abundance-based rarefaction curves of species richness showed that RIL and UV LED samples were very similar when samples with more than ca. 1,500 specimens were compared (Fig. 5). These patterns indicate that RIL collected less individuals per species than UV LEDs, and that UV LEDs were more efficient for describing the diversity and abundance patterns of moths.

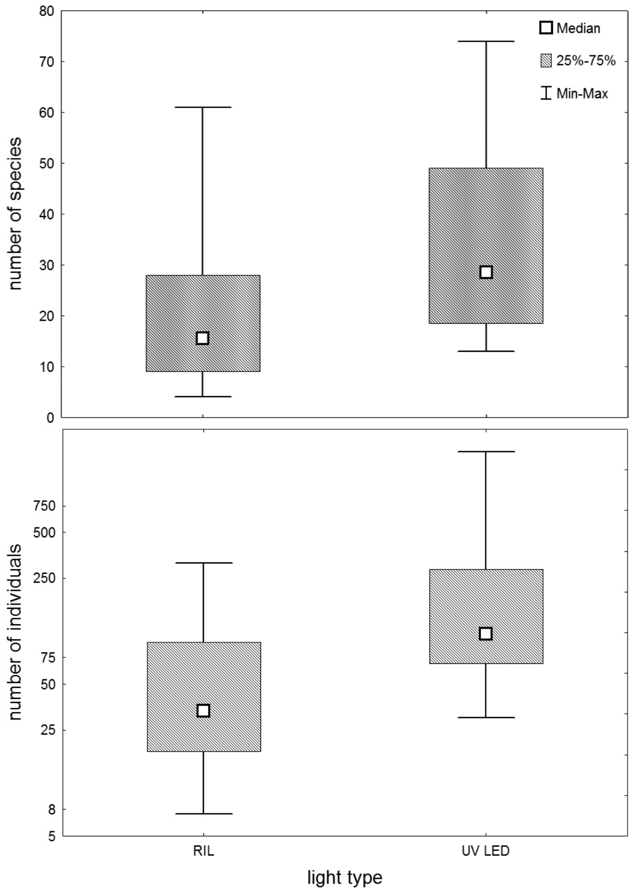

Fig. 4. Box and Whisker plot of the numbers of species and individuals collected using Rothamsted incandescent lamp (RIL) and UV LEDs on the Sila Massif (26 trap*night samples collected using RIL; 144 trap*night samples collected using UV LEDs).

Quantitative comparisons of communities revealed low B–C values, even among UV LEDs. Pairwise RIL/UV LED had similarity values one or two decimals constantly lower than those recorded only for UV LED traps (Table 4).

The Geometridae/Noctuidae species ratio (G/N) was more consistent and higher for UV LEDs than for RIL samples (Table 4). This pattern was mainly due to the low numbers of species of Noctuidae in the RIL sample. This was not the case for the G/N based on the number of individuals, which were similar (Table 5).

UV LED traps vs. MVLs

The numbers of species and individuals collected per night/trap strongly differed across sites, whichever light source was used (Fig. 6). The highest median of species and individuals was recorded for the MVL site at Angitola,

Table 3. Raw data recorded at the sites sampled. Light source: 15 W ultraviolet light emitting diode (UV LED); 160 W mercury vapour lamp (MVL); 200 W Rothamsted incandescent lamp (RIL). Number of species recorded (Sobs). Total number of specimens (N).

Site	Light source	Collecting method	Samples	Sobs	N
Serrapaolo	UV LED	2 Traps	12	261	14,405
Novacco	UV LED	2 Traps	12	171	2,973
Magara	UV LED	2 Traps	12	143	3,026
San Fili	UV LED	2 Traps	12	185	1,984
Greco	UV LED	2 Traps	12	211	2,233
Parantoro	UV LED	2 Traps	12	194	2,183
Covelli	UV LED	2 Traps	12	202	3,616
Arvo	UV LED	2 Traps	12	179	2,188
Colle Macchie	UV LED	2 Traps	12	176	2,869
Santa Maria	UV LED	2 Traps	12	178	1,394
Cattarinella	UV LED	2 Traps	12	142	1,098
Archiforo	UV LED	2 Traps	12	143	1,759
Angitola	MVL	2 Operators	24	243	8,206
Trionto	MVL	2 Operators	24	177	3,432
Cocuzzo	MVL	2 Operators	24	274	4,817
Curcio	MVL	2 Operators	24	201	3,311
Sbanditi	RIL	1 Trap	26	167	1,626

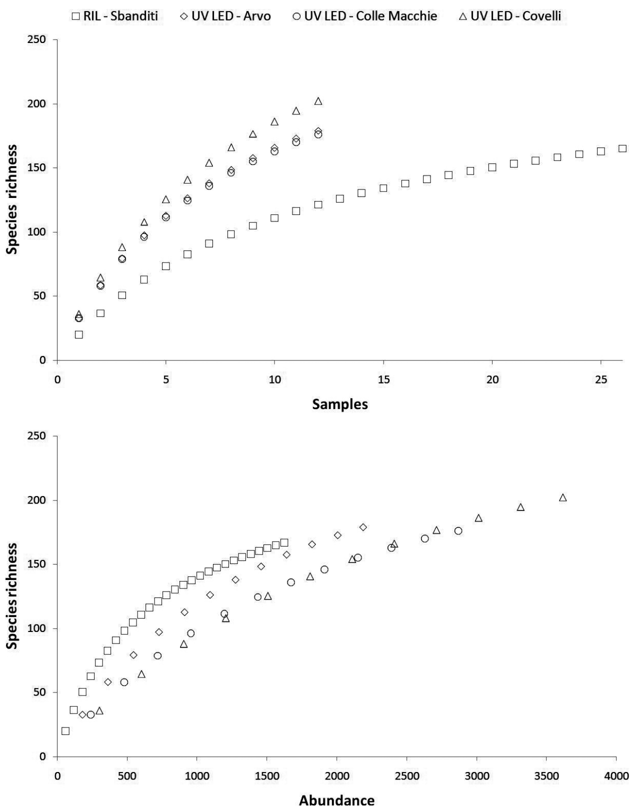

Fig. 5. Sample-based and Abundance-based rarefaction curves of the complete dataset available for the Sila Massif sites sampled using UV LED (UV LEDs) and Rothamsted incandescent lamp (RIL) traps.

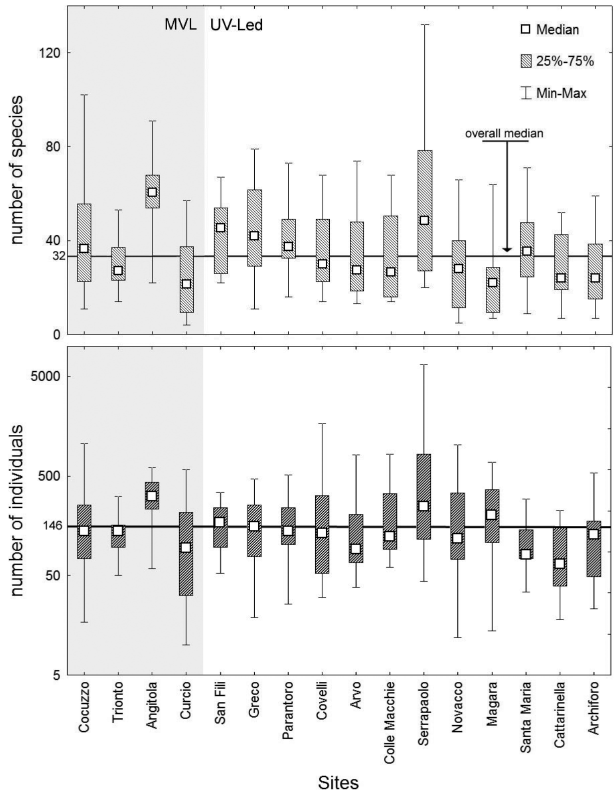

Fig. 6. Box and Whisker plot of the numbers of species and individuals recorded at different collecting sites (24 trap*nights per site for mercury vapour lamps, MVL; 12 trap*nights per site for UV LEDs).

followed by the UV LED site at Serrapaolo. Two out of four MVL sites and 5 out of 12 UV LED sites recorded a median number of species higher than the overall median. Patterns of abundances did not clearly differ from those of species richness.

We recorded a median of 31 species and 131 individuals per night using UV LEDs, and a median of 37 species and 158 individuals using MVLs (Fig. 7). Furthermore, minimum values of number of species and individuals were very similar (4–5 and 10–12 respectively), whilst the maximum value recorded for UV LED was higher than that recorded for MVL traps (species: 132 vs. 102; individuals: 6,559 vs. 1,068) (Fig. 7).

DISCUSSION

The main question addressed in this paper is: are UV LEDs an effective light source for sampling moth communities? Our results clearly indicate that UV LEDs (peak 398 nm) were very effective for sampling moths when their catches were compared with those collected at different places in different years, using different methods. Moreover, our results are based on a good sample of the regional fauna, in fact more than the 80% of species recorded in this area (Parenzan & Porcelli, 2006).

It is reassuring that the results are very similar despite the fact that the three types of lamps compared in this study differed greatly in their emission spectra (Fig. 3, Table 2). The power required ranged from 15 W to 200 W, and emissions varied from a single UV peak (UV LEDs) to various narrow peaks (MVL) and a spectrum dominated

Table 4. Results of pairwise comparisons of individual samples from the Sila Massif. The quantitative Bray-Curtis index was used as a measure of similarity.

	UV LEDs						RIL
	Covelli 01	Covelli 02	Arvo 01	Arvo 02	Colle Macchie 01	Colle Macchie 02	Sbanditi
Covelli 01	1	0,413	0,494	0,455	0,621	0,462	0,328
Covelli 02		1	0,422	0,309	0,434	0,551	0,206
Arvo 01			1	0,451	0,503	0,551	0,348
Arvo 02				1	0,488	0,451	0,305
Colle Macchie 01					1	0,643	0,308
Colle Macchie 02						1	0.253
Sbanditi							1

Table 5. Comparison of species richness (S) and abundance (N) of Geometridae and Noctuidae and their ratio (G/N) recorded for UV LEDs and RIL samples collected on the same nights on the Sila Massif.

	Light source	Geometridae		Noctuidae		G/N	
		S	N	S	N	S	N
Covelli 01	UV LED	67	729	53	231	1.26	3.16
Covelli 02	UV LED	65	2001	73	271	0.89	7.38
Arvo 01	UV LED	68	925	46	246	1.48	3.76
Arvo 02	UV LED	55	449	59	297	0.93	1.51
Colle Macchie 01	UV LED	64	685	58	322	1.10	2.13
Colle Macchie 02	UV LED	69	1225	59	352	1.17	3.48
Sbanditi	RIL	63	344	29	101	2.17	3.40

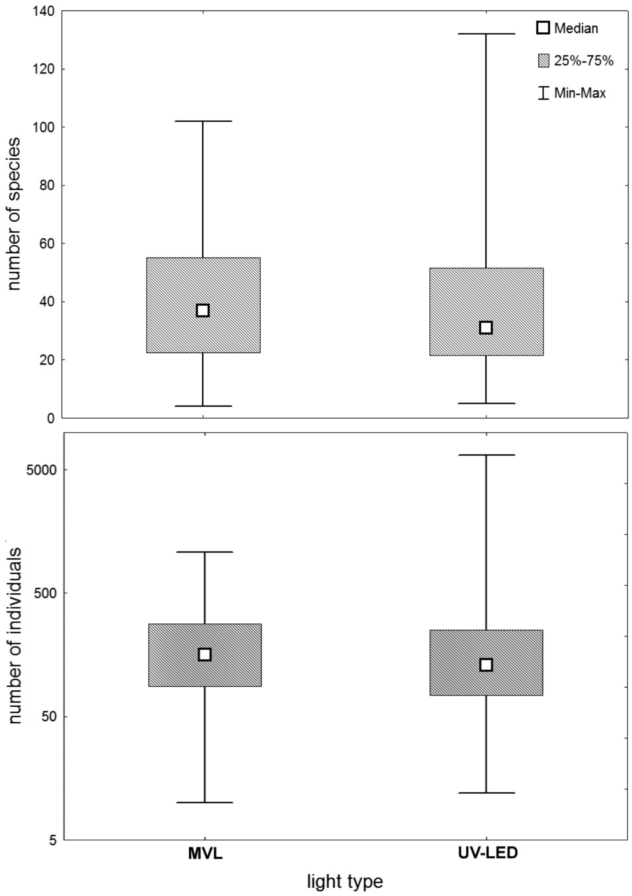

Fig. 7. Box and Whisker plot of the numbers of species and individuals recorded using mercury vapour lamps (MVL) and UV LEDs (96 trap*nights for MVL; 144 trap*nights for UV LEDs).

by long wave and infrared radiation (MVL and RIL). 15 W-UV LEDs, despite the far lower power required, tended to sample even more species and individuals than 200 W incandescent lamps, clearly showing that the total quantity of radiation alone does not positively affect the number of moths caught. One likely reason for this pattern is that incandescent lamps largely emit long wave radiation that is less attractive to most nocturnal moths than short wave radiation (van Langevelde et al., 2011; van Grunsven et al., 2014). Moreover, strong (and hot) light sources could even be counterproductive and prevent moths from landing directly on a trap. Our results show that single-peak light sources at 398 nm can be recommended for use in studies on moth biodiversity. However, further study is required to determine whether similar results are obtained, either by single peak light sources at other wavelengths, or by a combination of UV, blue and green LEDs that correspond to the sensitivity maxima of most insect eyes (Price & Baker, 2016).

There are many studies describing richness and abundance of European moth communities. During a study involving 225 trap nights carried out in an agricultural landscape in Germany 29,953 individuals belonging to 334 species and 19,519 individuals belonging to 299 species were collected by traps equipped with a 250 W MVL and a 40 W actinic tubes, respectively (Jonason et al., 2014). Usher & Keiller (1998) collected between 67 and 129 species during 24 trap nights in 18 forested habitats in Great Britain using Heath traps powered by 15 W actinic lamps. In a riparian habitat in Central Italy from the beginning of August to mid-September, between 714 and 1,488 individuals belonging to 93–151 species were collected using 8 W blacklight tubes (Dapporto et al., 2005). In a Sicilian coastal wetland, 121 species over 24 nights were manually collected using a 160 W MVL as a light source (Bella et al., 1999). Although collected in different geographic areas with different ecological characteristics, using different lights and methods, the above mentioned data are comparable with our UV LED samples, obtained over only 12 nights of trapping, of 142 and 261 species, and between 1,098 and 14,405 individuals. These samples give us an idea of how many species and individuals can be collected during entire monitoring programs.

A more appropriate comparison among data should be done using single night samples, but such well resolved data are rarely available in the literature. In order to compare our results with those obtained by other authors, we extrapolated data from Jonason et al. (2014). They record a median of 27 species per night using a 250 W MVL and a median of 19 species using a 40 W actinic tube. It is not surprising that we recorded a higher median of species (37) using a 160 W mercury vapour lamp in Mediterranean habitats than Jonason et al. (2014) in Central Germany, but it is much more interesting that we recorded a median of 31 species using 15 W UV LEDs, a number nearer to those recorded by MVLs than actinic tubes. Furthermore, on an extremely favourable night we caught a maximum of 132 species in a single trap using UV LEDs, whilst the maximum richness reported by Jonason et al. (2014) is 79 species. Despite these results being obtained in very different places and habitats this comparison confirms the efficacy of this novel light source for sampling moths.

Our data indicate that abundance and richness of moth communities depend more on type of habitat than on the method of collection and light sources used for monitoring. At the MVL site in Angitola more species and individuals per night were recorded than at sites sampled using UV LED traps, but this was also recorded when compared with other MVL sites (Scalercio & Infusino, 2003, 2006; Scalercio et al., 2008; Scalercio, 2014b). Although the combination of manual sampling and MVLs is regarded as the most effective method for monitoring moths (Axmacher & Fiedler, 2004; Scalercio et al., 2009; Jonason et al., 2014), the traps equipped with 15 W UV LEDs collected a comparable number of species and individuals, and even a higher number of species and individuals during the most favorable meteorological conditions. Furthermore, MVLs are currently being phased out in many countries as it is no longer an easily available light source (Bates et al., 2013), which is one more reason for clarifying whether the light sources available in the future will be as effective in attracting moths as those traditionally used.

Another question we address in this paper is: are species and abundance composition of moth samples affected by the type of light source? Detailed analyses of the structures of the communities in the Calabrian black pine forests on the Sila Massif, using Rothamsted and UV LED traps over the the same period in the same habitat revealed that the UV LED traps collected a slightly higher fraction of Geometridae than the 0.85 reported for the European fauna (Karsholt & Razowski, 1996).This is most likely due to the greater affinity of Geometridae for forested habitats (Usher & Keiller, 1998; Brehm & Fiedler, 2005). The Rothamsted trap recorded the highest Geometridae/Noctuidae ratio, probably due to the design of the trap, which is less suited to intercept Noctuidae because of the lack of baffles around the light bulb. The lower efficiency of Rothamsted traps in catching Noctuidae may explain the low similarity of the ratios recorded by UV LEDs and RIL traps. The patterns in the Geometridae/Noctuidae ratios and similarity analyses confirmed that the composition of moth communities was not dramatically changed by using UV LEDs as a light source.

The data obtained using UV LEDs, both in absolute terms and in comparison with other light sources and different methods of sampling, clearly show that they are suitable for sampling macro-moth communities. No significant loss of data was recorded. As discussed in this paper, several collecting methods and light sources are used to study the biodiversity and community structure of nocturnal Lepidoptera, the choice of which was mainly based on the preferences and experiences of individual researchers. The use of a standard method is advisable in order to make data more comparable and homogenous. The effectiveness of UV LEDs as light sources for trapping moths and the benefits they offer in terms of greater resistance to damage, lower power consumption and portability, make this light source a good candidate for this purpose.

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