**Comparison of different light sources for trapping *Culicoides* biting midges,
mosquitoes and other dipterans**

**Mikel González^a, Pedro María Alarcón-Elbal^b, Javier Valle-Mora^c, Arturo
Goldarazena^d**

^a Centre for Applied Entomology and Parasitology, Institute for Science and Technology in Medicine, Keele University,
Keele, Staffordshire ST5 5BG, United Kingdom. E-mail address: mikel_alexander86@hotmail.com

^b Universidad Agroforestal Fernando Arturo de Meriño, Jarabacoa 41000, Dominican Republic.

^c Departamento de Conservación de la Biodiversidad, El Colegio de la Frontera Sur, Unidad Tapachula. Carr. Antiguo
Aeropuerto km 2.5, Tapachula, Chiapas 30700, Mexico.

^d Université Catholique de Louvain, Earth and Life Institute, Department of Entomology, Croix du Sud, 2 bte L7.05.05 -
B-1348 Louvain-la-Neuve, Belgium.

Corresponding author: Arturo Goldarazena, Université Catholique de Louvain, Earth and Life
Institute, Department of Entomology, Croix du Sud, 2 bte L7.05.05 - B-1348 Louvain-la-Neuve,
Belgium. E-mail address: arturogoldarazena@gmail.com

ABSTRACT

The response of *Culicoides* biting midges, mosquitoes and other dipterans to different wavelengths
was evaluated in a farm meadow in northern Spain. A total of 9449 specimens of 23 species of
Culicoides, 5495 other ceratopogonids (non-biting midges), 602 culicids and 12428 other mixed
dipterans were captured. Centers for Disease Control and Prevention (CDC) suction light traps fitted
with five light emitting diodes (LEDs) (white, green, red, blue, ultraviolet) were run for 15
consecutive nights. Significantly more *Culicoides* were collected in those traps fitted with green,
blue or ultraviolet (UV) lights than in red and white-baited LED traps for the most abundant species
captured: *C. punctatus* (37.5%), *C. cataneii* (26.5%) and *C. obsoletus/C. scoticus* (20.4%). Similar
results were obtained for non-*Culicoides* ceratopogonids, mosquitoes and other mixed dipterans.

Wavelengths in green (570 nm) resulted effective for targeting some *Culicoides* species, culicids and other midges. In a second trial, the effectiveness of 4-watt white and UV tubes was compared to traps fitted with UV LED and a standard incandescent light bulb. More specimens of all taxa were collected with fluorescent black light (UV) traps than with the other light sources, except culicids, which were recovered in high numbers from fluorescent white light traps.

Key words: Diptera, Ceratopogonidae, Culicidae, *Culicoides*, fluorescent traps, LED traps.

1. Introduction

Various trapping devices for insects are commercially available, which are used for nuisance reduction, monitoring or surveillance of Diptera (Lühken et al., 2014). Light traps are one of the most commonly used devices, particularly to attract insects with phototaxis. The use of light traps for sampling dipterans with relevance as disease vectors has been studied by many researchers since the mid-twenties (Odetoynbo, 1969). Among the wide range of light traps developed, CDC-light traps (Centers for Disease Control and Prevention light traps) were introduced originally for arbovirus surveillance and other short-term mosquito investigations. They provide a reliable method for monitoring disease vectors with minimal exposure (Cohntaedt et al., 2008), avoiding unsafe methods such as animal or human bite collection. Since their introduction, several modifications to these traps have been made to improve their effectiveness, being the modern models (CDC miniature trap models 512 and 1212), the most common tools for monitoring *Culicoides* species. These traps have routinely been used in surveillance programs in the USA (Smith and Mullens, 2003), but also in many European countries, including France (Venail et al., 2012), Spain (Pérez et al., 2012; González et al., 2013) or Portugal (Ramilo et al., 2012). Black lights (UV) are superior to white light in terms of specimens and species collected (Venter et al., 2009), depending on the type of trap (design, size and intensity of light source, etc.).

50 In an effort to develop a highly effective visual target for improved surveillance of different
51 economically important vectors, Burket et al. (1998) used for first time a new generation of lighting
52 technology based on super-bright light-emitting diodes (LEDs). These are energy efficient, often
53 producing a greater total photon flux (TPF) than incandescent globes in the visible spectrum (400-
54 780 nm), making them optimal for battery operation (Bishop et al., 2004). LEDs have become
55 widely available and popular substitutes for incandescent light over the past 18 years. Their
56 advantages include greatly reduced power consumption, high efficiency, accuracy in specific
57 wavelength achievement, cool operating temperatures, durability, less prone to shock damage,
58 compact size, excellent colour saturation, and monochromatic light production in a wide variety of
59 possible wavelengths (Hoel et al., 2007).

60 Several recent studies have tested LED colours and whether LEDs can serve as effective
61 substitutes for incandescent lamps in standard CDC mosquito traps for mosquito surveillance as well
62 as to determine the most appropriate colour for attracting these vectors (Tchouassi et al., 2012).
63 Blood-feeding Diptera such as mosquitoes, sand flies and biting midges, often are attracted to
64 specific wavelengths of light: UV, blue and green (Wilton and Fay, 1972; Mellor and Hamilton,
65 2003; Bishop et al., 2004; Burkett and Butler, 2005; Fernández et al., 2015). LED tests on *Culicoides*
66 biting midges have been done in Australia (Bishop et al., 2004, 2006), Africa (Tchouassi et al.,
67 2012), and most recently in South America (Silva et al., 2015) and Europe (Hope et al., 2015). Only
68 a few publications describe the attractiveness of LEDs to different Diptera species.

69 Therefore, the objective of this study was to determine wavelength preference of adult
70 *Culicoides*, culicids, and selected non-target dipterans, using LEDs technology and standard
71 fluorescent and incandescent light sources.

72

73 **2. Material and methods**

74 *2.1. Study area*

75 Trapping studies were done at Neiker-Tecnalia, Basque Institute for Agricultural Research
76 and Development, Vitoria-Gasteiz, Northern Spain, coordinates: 42° 51' 43'' N; 2° 38' 84'' W,
77 elevation 517 masl. This area consists primarily of extensive sheep farming, with a flat landscape
78 bearing a variety of trees and bushes. Sheep flocks were enclosed at night until the next morning to
79 avoid interferences in the study. Traps were placed in the middle of a meadow (200 m x 150 m),
80 which was occasionally irrigated, creating temporary pools of water that provided suitable conditions
81 for the development of *Culicoides* species as well as other dipterans.

82 2.2. Collection methods

83 The first trial occurred from mid-July to early August 2013 over 15 consecutive nights. Traps
84 were hung 15 m apart in a randomised block design at a height of 1.5 m and separated by 15 m from
85 each other to prevent interference between traps. Five CDC-miniature portable light traps model 512
86 (John W. Hock Company, Florida, U.S.A.) featured five different LED platform arrays (Bioquip,
87 Rancho Dominguez, U.S.A). Different LED bulbs emitted light which was: white between 425 to
88 750 nm, red 660 nm, green 570 nm, blue 430 nm and UV 390 nm. Adapters consisted of eight LED
89 units oriented in all directions (360°). Each day, all traps were rotated to new positions to reduce
90 sampling point specific differences.

91 A second trial was run over 12 nights in mid-August. Traps were hung, rotated and positioned
92 same manner as the first trial. Two CDC standard miniature traps (John W. Hock Company, Florida,
93 U.S.A., model 1212) were used, one equipped with a 4-watt UV light (320-420 nm) and the other
94 with a 4-watt white light (peaks at 450 and 580 nm). The other two CDC-miniature portable traps
95 model 512 were baited with a UV LED array light (390 nm) and with an incandescent bulb. The
96 portable models were connected to the power supply by means of transformers (6 V to 220 V).

97 All traps fitted with the same model of fan and dimensions were operated overnight from
98 dusk till dawn. Dipterans were collected into 500 ml plastic jars containing water and a drop of
99 detergent and were emptied early in the morning. Trapping was repeated during extra nights in case

of strong wind and/or trap failure. Insects collected were stored in 70% ethanol until processing. In total, four Diptera groups we studied: *Culicoides*, other ceratopogonids, culicids referred as mosquitoes and other mixed Diptera. *Culicoides* specimens were identified to species level based on the appropriate keys for northern Spain biting midges (González, 2014). Other common ceratopogonids and culicids were identified at genus level (González and Goldarazena, 2011; Schaffner et al. 2001). For the common members of the subgenus *Avaritia*, *Culicoides obsoletus* and *C. scoticus* (sibling species) were grouped, while *C. chiopterus* and *C. dewulfi* were identified by their characteristic morphological features (Nielsen and Kristensen, 2011). The number of *Culicoides* collected were counted and sexes pooled to simplify the data analysis, as for example *Culicoides* males are relatively rare representing only 0.9% of the total collections.

2.3. Statistical analysis

All data analyses were performed using the program R 3.3.0 (Fox, 2005; R Core Team, 2016) and graphs were prepared with SPSS statistics 23 (IBM corporation, Armonk, U.S.A). Data were analysed with generalized linear models (GLMz) using Poisson response as variables are discrete. Due to data overdispersion, a binomial negative response was applied to compare captures among light traps with the following criteria: if residual deviance was double the degrees of freedom, data were readjusted with negative binomial response (McCullagh and Nelder, 1989). Post-Hoc multiple comparisons of mean trap catches between the different traps were assessed using Tukey's test.

3. Results

A total of 27974 specimens of Diptera was collected over the 27 consecutive nights divided into two independent experiments (15 nights and 12 nights), giving a total of 123 collections. The

majority (53.4%) were ceratopogonids. *Culicoides* midges comprised 33.7% of the total ($n = 9449$), while other ceratopogonids represented 19.6% ($n = 5495$). A total of 22 species/6485 specimens of *Culicoides* biting midges were collected in the first trial and 11 species/2964 specimens in the second trial.

The most abundant species were *Culicoides punctatus* (67.7%; $n = 6400$), *C. cataneii* (13.5%; $n = 1282$) and *C. obsoletus/C. scoticus* (9.6%; $n = 906$). Other species collected in declining order of abundance were: *Culicoides alazanicus* (3.1%; $n = 291$), *C. festivipennis* (1.6%; $n = 148$) and *C. kibunensis* (1.2%; $n = 117$). The remaining 16 species comprised less than 3.2% of the total collections. Non-biting midges within Ceratopogonidae were represented by *Forcipomyia* (92.6%; $n = 5090$), *Dasyhelea* (4.4%; $n = 242$), *Atrichopogon* (2.8%; $n = 154$) and *Stilobezzia* (0.2%; $n = 9$). Culicids comprised a total of 602 specimens (2.2% of the total collections) representing four genera: *Culex*, *Culiseta*, *Anopheles* and *Aedes*. Other mixed Diptera (Nematocera suborder), specially Chironomidae, Sciaridae and Cecidomiidae, were also recorded in a single group which accounted for 12428 individuals (44.4% of the total collections).

In the first trial (Table 1, Fig. 1A), there were significant differences in the total mean numbers of *Culicoides* collected between traps ($X^2 = 194.91$, d.f. = 4, $P < 0.001$). Comparison of the efficacy of different LEDs in *Culicoides* collections indicated that UV-LED traps ($X \pm SD = 159.8 \pm 121.9$) and green-baited LED traps (118.8 ± 74.3) collected significantly higher numbers of *Culicoides* than traps using white (34.7 ± 25.2) and red (21.8 ± 12.5) LEDs. Blue LED-baited traps (96.2 ± 61.3) were not significantly different from each other ($P > 0.05$). Similar patterns were observed for the most common *Culicoides* species: *C. punctatus*, *C. cataneii* and *C. obsoletus/C. scoticus*, but with subtle differences. Green LED light traps showed the highest numbers of captures for the 18 remaining species (10.7 ± 9.3) ahead of UV LED light (7.9 ± 9.3), and significantly different from blue LED (4.1 ± 3.6), red LED (1.3 ± 1.4) and white LED lights (3.7 ± 4.9) ($P < 0.001$). In non-biting ceratopogonids, mean numbers collected with green LED-baited traps ($103.5 \pm$

211.6) was significantly higher than that with white (30.3 ± 56.0) and red (13.8 ± 29.8) LED light traps ($X^2 = 53.25$, d.f. = 4, $P < 0.001$). Similar responses were observed for culicids ($X^2 = 13.05$, d.f. = 4, $P = 0.001$). However, in other Diptera, a major response to blue and green wavelengths was observed ($X^2 = 210.64$, d.f. = 4, $P < 0.001$). Regarding *Culicoides* species richness, only 9 species were trapped using red LED traps, while the other wavelengths attracted between 15 and 19.

In the second trial (Table 2, Fig. 1B), proportional representation of *Culicoides* differed significantly between treatments ($X^2 = 294.91$, d.f. = 3, $P < 0.001$). Comparison of the efficacy between UV (tube and LED) and white (tube and incandescent bulb) lights for *Culicoides* collection, showed that the mean number of midges collected with the UV tube traps (136.6 ± 129.8), was nearly double than numbers collected with the white tube trap (73.9 ± 77.2). The mean numbers collected in traps equipped with UV LED lights (21.1 ± 27.5) and white incandescent bulb lights (15.2 ± 16.7) were significantly lower than fluorescent baited traps. Similar tendency was observed for other ceratopogonids, where the mean collections with the UV tube traps were significantly higher than the others ($X^2 = 191.13$, d.f. = 3, $P < 0.001$). However, culicids showed better responses to the fluorescent white light (6.3 ± 5.0) than to the other three light sources ($X^2 = 28.33$, d.f. = 3, $P < 0.001$). In other mixed dipterans, traps equipped with fluorescent wavelengths collected significantly higher numbers than LED traps ($X^2 = 180.44$, d.f. = 3, $P < 0.001$). In relation to the number of *Culicoides* species, the white-baited trap trapped the smallest number of species (6), followed by UV LED (8), white tube (9) and UV tube (11), therefore the latter light trap captured not only a higher mean number of individuals but also higher species diversity.

170

171 **4. Discussion**

172

173 A total of 9449 *Culicoides* midges belonging to 23 species was collected in this study. This
174 represents 44.9% of the *Culicoides* species recorded for the Basque Country region (González, 2014)

175 and 26.8% of the 82 species reported in Spain (Sánchez Murillo et al., 2015). Interestingly, the two
176 most abundant species in the current study, *C. punctatus* and *C. cataneii*, have not been recorded in
177 similar numbers in adjacent regions. At livestock farms, González et al., (2013) recorded mainly *C.*
178 *obsoletus*/*C. scoticus* followed by *C. lupicaris*. Variation in species composition could be attributed
179 to differences in sampling dates and/or habitat and location, as the farm is located next to an urban
180 zone. In fact, *C. punctatus* is the most common species in urban parks in the Basque Country,
181 according to collections done using a battery powered-aspirator (González et al., 2015). This species
182 is of potential interest as it could play a role in the epidemiology of Schmallenberg virus (SBV) and
183 bluetongue virus (BTV) in Europe (Larska et al., 2013).

184 *Culicoides* species exhibited a similar response to green, blue and UV LEDs, but seemed to
185 respond poorly to red (Bishop et al., 2004; Hope et al., 2015). Only 9 species were collected using
186 red lights while the other wavelengths attracted more than 15 species. White light also was less
187 attractive to *Culicoides* midges, although it could collect a large number of species.

188 It is interesting to point out that the most powerful LED light for *C. obsoletus*/*C. scoticus*, the
189 main relevant BTV vectors across Europe (Purse et al., 2005), was green, which agrees with Hope et
190 al. (2015) observations, where *C. obsoletus*/*C. scoticus* and *C. brunnicans* were collected in higher
191 numbers using the same colour LED traps. Notwithstanding the lower numbers collected, *C.*
192 *brunnicans*, *C. kibunensis*, *C. alazanicus* and *C. festivipennis* seemed to be highly attracted to green
193 LED traps. This is in line with studies from Australia, where *Culicoides* midges are routinely
194 collected with green light sources (Bishop et al., 2006; Eagles et al., 2014; Melville et al., 2015).
195 Silva et al. (2015) reported that traps emitting green light captured the most Brazilian *Culicoides*
196 (53.9%), followed by incandescent (34.9%) and blue light (11.2%), but they did not include any UV
197 light source in their comparisons. These results suggest a spectral sensitivity for *Culicoides* females
198 around 570 nm with decreasing sensibility in wavelengths toward the red spectrum. Regarding
199 fluorescent lights, previous studies using Onderstepoort traps fitted with bright black light (8W) have

200 highlighted its superiority for collecting *Culicoides* compared to other trap designs and light sources
201 (del Río et al., 2013; Venter et al., 2009; Probst et al., 2015). Our results with CDC traps showed the
202 superiority of the UV tube baited traps in comparison to UV LEDs, incandescent bulb and white tube
203 lights for the collection of *Culicoides* midges. This can be clearly observed when all light sources
204 are deployed simultaneously, as traps equipped with UV tubes collected six times more *Culicoides*
205 midges than did UV LEDs. Similarly, white tube light traps were five times more efficient than the
206 incandescent bulb. Fluorescent UV light was up to two times more efficient than white light in
207 collecting *Culicoides*, while this difference was three times with South African traps (Venter and
208 Hermanides, 2006).

209 Predaceous, nectar and haemolymph-feeding ceratopogonids are usually sampled by means
210 of a wide variety of trapping methods including light traps (Tóthóva et al., 2005), but often, are
211 accidentally collected in UV light traps used for monitoring *Culicoides* biting midges (González et
212 al., 2014). Nonetheless, there is little wavelength-specific information, as many members of this
213 family are not studied due to their limited sanitary interest. The specimens mostly taken using green,
214 blue and UV LED traps for the four genera studied, except *Dasyhelea*, which was trapped well with
215 white sources as well. Some species of *Forcipomyia* of medical interest such as *F. taiwana*, are
216 monitored with blue light, 405 nm (Liu et al., 2009). In general, fluorescent lights were more
217 attractive than LED lights within this genus.

218 Regarding culicids, trapping is usually conducted with a combination of light traps and
219 chemical attractants, e.g., BG-Sentinel traps or CDC traps baited with CO₂ and/or 1-octen-3-ol, (Roiz
220 et al., 2012; Lühken et al., 2014). Mosquitoes wavelength preferences seems to be in the blue-green
221 range (400-600 nm), with a decrease in attraction as wavelengths increase (> 600 nm) (Burkett et al.,
222 1998). Using LED technology, green and UV light traps collected the highest numbers of culicids,
223 followed by blue colour, which agrees with Silva et al. (2014). Similarly, Bentley et al. (2009)
224 suggested that, in the absence of host stimuli, wavelengths in the lower green (502 nm) spectral

range would be optimal for targeting a broad range of mosquitoes. However, when fluorescent lights are run with LEDs, the responses in culicids were greater with a white fluorescent tube according to other similar studies (Hoel, 2005). This suggests that incandescent bulbs are less attractive to culicids than fluorescent tubes. However, giving the accuracy in trapping considerable host-seeking mosquitoes, LEDs can be used as an alternative trapping system thereby eliminating the cost of heavy tanks, volatile chemicals or where access or equipment is limited (Bentley et al., 2009).

Finally, regarding other mixed Diptera, our results showed a preference to blue light, followed by green and UV light, and to a lesser extent white and red. It is documented that UV and blue light are usually most attractive to arthropods, although the degree of attraction varies among families (Longcore et al., 2015). Small collections in red spectrum agree with (Li et al., 2015), as members of the Diptera order, including mosquitoes, tend not to be attracted to light wavelengths > 580 nm.

5. Conclusion

The use of green LED lights is quite promising in collecting *Culicoides* midges and other dipterans. We suggest further studies be done using green fluorescent lights (4 to 8 watt tubes) instead of LEDs technology and this should be compared with standard UV lamps for *Culicoides*. The investigation of green light as a new light source in surveillance and monitoring trapping programs might have important implications, particularly for *C. obsoletus*/*C. scoticus* species, as these species are the most abundant across Europe. Fluorescent lamps are powerful lures for the collection of huge numbers and species richness. However, LED array technology could be used as an alternative suitable for monitoring blood-sucking dipterans in areas where external power supply is not available or where the weight of batteries is prohibitive. The expected results will have potential for use by ecologists and epidemiologists for improving collection efficiency of certain

250 species of biting midges, obtaining greater sample sizes, higher species biodiversity and saving time
251 and money.

252

253 **Acknowledgments**

254

255 We thank Prof. Dr. Bradley Mullens (University of California Riverside) for critical
256 comments of an early version of the manuscript. We are grateful to the anonymous reviewers for
257 their careful reading and improvement of the readability of our paper. The authors express their
258 sincere gratitude to the personnel of Neiker-Tecnalia for allowing us to undertake trapping on their
259 properties and to the farmers and technicians for supporting fieldwork. The equipment used was
260 funded by the Department of Agriculture, Fisheries and Food of the Basque Country
261 (CULCONTROL-DST2007013).

262

263 **Conflict of interest**

264

265 The authors disclose no conflicts of interest in this work.

266

267 **References**

268

- 269 Bentley, M.T., Kaufman, P.E., Kline, D.L., Hoqsette, J.A., 2009. Response of adult mosquitoes to
270 light-emitting diodes placed in resting boxes and in the field. *J. Am. Mosq. Control Assoc.* 25
271 (3), 285–291.
- 272 Bishop, A.L., Worral, R., Spohr, L.J., Mckenzie, H.J., Barchia, I.M., 2004. Response of *Culicoides*
273 spp. (Diptera: Ceratopogonidae) to light emitting diodes. *Aust. J. Entomol.* 43 (2), 184–188.

274 Bishop, A.L., Bellis, G.A., McKenzie, H.J., Spohr, L.J., Worrall, R.J., Harris, A.M., Melville, L.,
275 2006. Light trapping of biting midges *Culicoides* spp. (Diptera: Ceratopogonidae) with green
276 light-emitting diodes. Aust. J. Entomol. 45 (3), 202–205.

277 Burkett, D.A., Butler, J.F., Kline, D.L., 1998. Field evaluation of colored light-emitting diodes as
278 attractants for woodland mosquitoes and other diptera in north central Florida. J. Am. Mosq.
279 Control Assoc. 14 (2), 186–195.

280 Burkett, D.A., Butler, J.F., 2005. Laboratory evaluation of colored light as an attractant for female
281 *Aedes aegypti*, *Aedes albopictus*, *Anopheles quadrimaculatus*, and *Culex nigripalpus*. Fla.
282 Entomol. 88 (4), 383–389.

283 Cohnstaedt, L., Gillen, J.I., Munstermann, L.E., 2008. Light-emitting diode technology improves
284 insect trapping. J. Am. Mosq. Control Assoc. 24 (2), 331–334.

285 Del Río, R., Moneris, M., Miquel, M., Borràs, D., Calvete, D., Estrada, R., Lucientes, J., Miranda,
286 M.A., 2013. Collection of *Culicoides* spp. with four light trap models during different seasons
287 in the Balearic Islands. Vet. Parasitol. 195 (1–2), 150–156.

288 Eagles, D., Melville, L., Weir, R., Davis, S., Bellis, G., Zalucki, M.P., Walker, P.J., Durr, P.A., 2014.
289 Long-distance aerial dispersal modelling of *Culicoides* biting midges: case studies of
290 incursions into Australia. BMC Vet. Res. 10, 135.

291 Fernández, M.A., Martínez, M.F., Pérez, A.A., Santini, M.S., Gould, I.T., Salomón, O.D., 2015.
292 Performance of light-emitting diode traps for collectiong sand flies in entomological surveys in
293 Argentina. J. Vector. Eco. 40 (2), 373–378.

294 Fox, J., 2005. The R Commander: A Basic Statistics Graphical User Interface to R. Journal of
295 Statistical Software, 14 (9), 142.

296 González, M., Goldarazena, A., 2011. El género *Culicoides* en el País Vasco: guía práctica para su
 297 identificación y control. Servicio Central de Publicaciones del Gobierno Vasco, Vitoria,
 298 España, 247 pp. (in Spanish).
 299 González, M., López, S., Romón, P., Baldet, T., Delécolle, J.C., Goldarazena, A., 2013. Monitoring
 300 of *Culicoides* Latreille (Diptera: Ceratopogonidae) after BTV outbreaks in sheep farms and in
 301 natural habitats from the Basque Country (N Spain). *Pro. Entomol. Soc. Wash.* 115 (1), 48–69.
 302 González, M. 2014. The genus *Culicoides* (Diptera: Ceratopogonidae) in the Basque Country. Ph.D
 303 Thesis. University of the Basque Country, Spain.
 304 González, M., López, S., Romón, P., Iturrondobeitia, J.C., Goldarazena, A., 2014. Phenology,
 305 ecology and diversity of the family Ceratopogonidae (Diptera: Nematocera), excluding the
 306 genus *Culicoides*, in the Basque Country region (Iberian Peninsula). *Bol. SEA.* 55, 205–215.
 307 González, M., López, S., Alarcón-Elbal, P.M., 2015. Blood-feeding Diptera (Culicidae and
 308 Ceratopogonidae) in an urban park of the city of Vitoria-Gasteiz (Basque Country, Spain). *J.*
 309 *Europ. Mosq. Control Assoc.* 33, 10–14.
 310 Hoel, D.F., 2005. Response of *Aedes albopictus* (Diptera: Culicidae) to traps, attractants, and
 311 adulticides in north central Florida. Ph.D Thesis. University of Florida, USA.
 312 Hoel, D.F., Butler, J.F., Fawaz, E.Y., Watany, N., El-Hossary, S.S., Villinski, J., 2007. Response of
 313 phlebotomine sand flies to light-emitting diode-modified light traps in southern Egypt. *J.*
 314 *Vector. Eco.* 32 (2), 302–308.
 315 Hope, A., Gubbins, S., Sanders, C., Denison, E., Barber, J., Stubbins, F., Baylis, M., Carpenter, S.,
 316 2015. A comparison of commercial light-emitting diode baited suction traps for surveillance of
 317 *Culicoides* in northern Europe. *Parasit Vectors.* 8, 239.
 318
 319

320 Larska, M., Lechowski, L., Grochowska, M., Żmudziński, J.F., 2013. Detection of the
 321 Schmallenberg virus in nulliparous *Culicoides obsoletus/scoticus* complex and *C. punctatus* -
 322 the possibility of transovarial virus transmission in the midge population and of a new vector.
 323 Vet. Microbiol. 166 (3–4), 467–473.

324 Li, C.X., Smith, M.L., Fulcher, A., Kaufman, P.E., Zhao, T.Y., Xue, R.D., 2015. Field evaluation of
 325 three new mosquito light traps against two standard light traps to collect mosquitoes (Diptera:
 326 Culicidae) and non-target insects in Northeast Florida. Fla. Entomol. 98 (1), 114117.

327 Liu, W.Y., Lee, S.J., Yang, E.C., 2009. Evaluation for attractiveness of four chemicals to the biting
 328 midge, *Forcipomyia taiwana* (Diptera: Ceratopogonidae). J. Am. Mosq. Control Assoc. 25 (4),
 329 448–455.

330 Longcore, T., Aldern, H.L., Eggers, J.F., Flores, S., Franco, L., Hirshfield-Yamanishi, E., Petrinec,
 331 L.N., Yan, W.A., Barroso, A.M., 2015. Tuning the white light spectrum of light emitting diode
 332 lamps to reduce attraction of nocturnal arthropods. Phil. Trans. R. Soc. B. 370, 20140125.

333 Lühken, R., Pfitzner, W.P., Börstler, J., Garms, R., Huber, K., Schork, N., Steinke, S., Kiel, E.,
 334 Becker, N., Tannich, E., Krüger, A., 2014. Field evaluation of four widely used mosquito traps
 335 in Central Europe. Parasit Vectors 7, 268.

336 McCullagh, P., Nelder, J.A., 1989. Generalized Linear Models, 2nd Ed. London: Chapman and Hall.

337 Mellor, H.E., Hamilton, J.G.C., 2003. Navigation of *Lutzomyia longipalpis* (Diptera: Psychodidae)
 338 under dusk or starlight conditions. Bull. Entomol. Res. 93 (4), 315–322.

339 Melville, L., Weir, R., Hunt, N., Davis, S., Walsh, S., 2015. Forty years continuous monitoring for
 340 bluetongue virus at an Australian site of high arbovirus activity. What have we achieved? Vet.
 341 Ital. 51 (4), 263–267.

342 Nielsen, S.A., Kristensen, M., 2011. Morphological and molecular identification of species of the
 343 Obsoletus group (Diptera: Ceratopogonidae) in Scandinavia. Parasitol. Res. 109 (4), 1133–
 344 1141.

345 Odetoyinbo, J.A. 1969. Preliminary investigation on the use of a light-trap for sampling malaria
 346 vectors in the Gambia. Bull. Word. Health. Organ. 40 (4), 547–560.

347 Pérez, J.M., García-Ballester, J.A., López-Olvera, J.R., Serrano, E., 2012. Monitoring bluetongue
 348 virus vectors in Andalusia (SW Europe): *Culicoides* species composition and factors affecting
 349 capture rates of the biting midge *Culicoides imicola*. Parasitol. Res. 111 (3), 1267–1275.

350 Probst, C., Gethmann, J.M., Kampen, H., Werner, D., Conraths, F.J., 2015. A comparison of four
 351 light traps for collecting *Culicoides* biting midges. Parasitol. Res. 114 (12), 4717–4724.

352 Purse, B.V., Mellor, P.S., Rogers, D.J., Samuel, A.R., Mertens, P.P.C., Baylis, M., 2005. Climate
 353 change and the recent emergence of bluetongue in Europe. Nat. Rev. Microbiol. 3 (2), 171–
 354 181.

355 R Core Team, 2016. R: A language and environment for statistical computing. R Foundation for
 356 Statistical Computing, Vienna, Austria. Available in: <https://www.R-project.org/>

357 Ramilo, D.W., Diaz, S., Pereirada Fonseca, I., Delécolle, J.C., Wilson, A., Meireles, J., Lucientes, J.,
 358 Ribeiro, R., Boinas, F., 2012. First report of 13 species of *Culicoides* (Diptera:
 359 Ceratopogonidae) in mainland Portugal and Azores by morphological and molecular
 360 characterization. PLoS One 7 (4), e3496.

361 Roiz, D., Roussel, M., Muñoz, J., Ruiz, S., Soriguer, R., Figuerola, J., 2012. Efficacy of mosquito
 362 traps for collecting potential West Nile mosquito vectors in a natural Mediterranean wetland.
 363 Am. J. Trop. Med. Hyg. 86 (4), 642–648.

364 Sánchez Murillo, J.M., González, M., Martínez Díaz, M.M., Reyes Galán, A., Alarcón-Elbal, P.M.,
 365 2015. First record of *Culicoides paradoxalis* Ramilo & Delécolle, 2013 (Diptera,
 366 Ceratopogonidae) in Spain. Graellsia 71 (2), e033.

367 Schaffner, F., Angel, G., Geoffreoy, B., Hervy, J.P., Rhaïem, A., Brunhes, J., 2001. The mosquitoes
 368 of Europe/Les moustiques d'Europe [CD-ROM]. IRD Éditions -EID Méditerranée,
 369 Montpellier, France.

370 Silva, J.S., Souto Couri, M., de Leão Giupponi, A.P., Alencar, J., 2014. Mosquito fauna of the
371 Guapiaçu Ecological Reserve, Cachoeiras de Macacu, Rio de Janeiro, Brazil, collected under
372 the influence of different color CDC light traps. J. Vector. Ecol. 39 (2), 384–394.

373 Silva, F.S., Brito, J.M., Costa-Neta, B.M., 2015. Field evaluation of light-emitting diode as attractant
374 for blood-sucking midges of the genus *Culicoides* Latreille (Diptera: Culicomorpha,
375 Ceratopogonidae) in the Brazilian Savanna. Entomol. News. 125 (1), 1–6.

376 Smith, H., Mullens, B.A., 2003. Seasonal activity, size, and parity of *Culicoides occidentalis*
377 (Diptera: Ceratopogonidae) in a coastal southern California salt marsh. J. Med. Entomol. 40,
378 352–355.

379 Tchouassi, D.P., Sang, R., Sole, C.L., Bastos, A.D.S., Cohnstaedt, L.W., Torto, B., 2012. Trapping
380 of Rift Valley Fever (RVF) vectors using light emitting diode (LED) CDC traps in two
381 arboviral disease hot spots in Kenya. Parasit Vectors 5, 94.

382 Tóthová, A., Knoz, J., Országh, I., Barták, M., 2005. Genus *Culicoides* (Diptera: Ceratopogonidae)
383 collected by non-light traps in South Moravia. Stud. Dipterol. 12, 49–55.

384 Venail, R., Balenghien, T., Guis, H., Tran, A., Setier-Rio, M.L., Delécolle, J.C., Mathieu, B., Cêtre-
385 Sossah, C., Martinez, D., Languill, E.J., Baldet, T., Garros, C., 2012. Assessing diversity and
386 abundance of vector populations at a national scale: Example of *Culicoides* surveillance in
387 France after bluetongue virus emergence. In: Mehlhorn, H. (Eds.), Arthropods as Vectors of
388 Emerging Diseases, Heidelberg: Springer, Parasitology Research Monographs, Germany, pp.
389 77–102.

390 Venter, G.J., Hermanides, K.G., 2006. Comparison of black and white light for collecting
391 *Culicoides imicola* and other livestock-associated *Culicoides* species in South Africa. Vet.
392 Parasitol. 142 (3-4), 383–385.

393 Venter, G.J., Labuschagne, K., Hermanides, K.G., Boikanyo, S.N.B., Majatladi, D.M., Morey, L.,
394 2009. Comparison of the efficiency of five suction light traps under field conditions in South

395 Africa for the collection of *Culicoides* species. Vet. Parasitol. 166 (3–4), 299–307. Wilkerson,
396 R.C., Linton, Y.M., Fonseca, D.M., Schultz, T.R., Price, D.C., Strickman, D.A., 2015. Making
397 mosquito taxonomy useful: A stable classification of tribe *Aedini* that balances utility with
398 current knowledge of evolutionary relationships. PLoS One 10 (7), e0133602.
399 Wilton, D.P., Fay, R.W., 1972. Responses of adult *Anopheles stephensi* to light of various
400 wavelengths. J. Med. Entomol. 9, 301–304.

401

402

403

404

405

406

407

408

409

410

411

412

413

414

415

416

417

418

419 **Table 1.** Summary of dipterans collected with five different LED lights between mid-July to the beginning
420 of August 2013 over 15 consecutive nights at a meadow in the Basque Country, Spain.

Species	LIGHT EMITTING DIODES (LEDs)						% species
	WHITE	RED	GREEN	BLUE	UV	TOTAL	
<i>Culicoides a</i>							
<i>C. punctatus</i>	417 (27.8 ± 19.1) b	257 (17.1 ± 10.4) b	1411 (94.1 ± 60.5) a	1254 (83.6 ± 54.9) a	1927 (128.4 ± 90.6) a	5266	81.1
<i>C. cataneii</i>	20 (1.3 ± 2.3) c	32 (2.1 ± 1.6) c	113 (7.5 ± 5.6) b	63 (4.2 ± 2.8) b	262 (17.4 ± 28.7) a	490	7.5
<i>C. obsoletus/scoticus</i>	28 (1.9 ± 2.0) bc	19 (1.3 ± 1.7) c	98 (6.5 ± 8.5) a	65 (4.3 ± 5.2) ab	89 (5.9 ± 6.0) a	299	4.6
<i>C. kibunensis</i>	6	5	31	16	30	88	1.4
<i>C. alazanicus</i>	9	5	28	13	24	79	1.2
<i>C. circumscriptus</i>	19	6	13	7	28	73	1.1
<i>C. brunnicans</i>	3	0	34	3	12	52	0.8
<i>C. festipennis</i>	2	1	17	1	7	28	0.4
<i>C. lupicaris</i>	3	0	8	3	10	24	0.4
<i>C. achrayi</i>	1	0	9	4	5	19	0.3
<i>C. fascipennis</i>	2	0	7	5	1	15	0.2
<i>C. duddingstoni</i>	3	2	0	0	9	14	0.2
<i>C. picturatus</i>	3	0	6	4	0	13	0.2
<i>C. poperinghensis</i>	1	0	5	0	1	7	0.1
<i>C. simulator</i>	0	0	1	2	3	6	0.1
<i>C. dewulfi</i>	0	0	4	0	0	4	0.1
<i>C. tauricus</i>	1	0	1	0	0	2	0.0
<i>C. vexans</i>	1	0	0	1	0	2	0.0
<i>C. parroti</i>	0	0	2	0	0	2	0.0
<i>C. furcillatus</i>	1	0	0	0	0	1	0.0
<i>C. pulicaris</i>	1	0	0	0	0	1	0.0
Total (other species) b	56 (3.7 ± 4.9)c	19 (1.3 ± 1.4)d	166 (10.7 ± 9.3)a	59 (4.1 ± 3.6)bc	130 (7.9 ± 9.3)ab	430	
Total <i>Culicoides</i>	521	327	1788	1441	2408	6485	100
Species collected	19	9	18	15	15	22	
Mean collected	34.7 ± 25.2 b	21.8 ± 12.5 b	118.8 ± 74.3 a	96.2 ± 61.3 ab	159.8 ± 121.9 a		
Other Ceratopogonidae							
<i>Forcipomyia</i>	403	207	1457	1347	1355	4769	95.0
<i>Dasyhelea</i>	44	9	47	30	44	174	3.4
<i>Atrichopogon</i>	8	1	47	10	7	73	1.4
<i>Stilobezzia</i>	0	0	2	4	0	6	0.1
Total " other Ceratopogonidae "	455	217	1553	1391	1406	5022	100
Mean collected	30.3 ± 56.0 cd	13.8 ± 29.8 d	103.5 ± 211.6 a	92.7 ± 228.9 bc	93.7 ± 189.0 ab		
Culicidae							
<i>Culex</i>	54	42	109	67	59	331	78.3
<i>Culiseta</i>	19	9	13	11	21	73	17.3
<i>Anopheles</i>	1	2	2	7	3	15	3.5
<i>Aedes</i>	1	1	1	1	0	4	0.9
Total Culicidae	75	54	125	86	83	423	100
Mean collected	5.0 ± 3.8 ab	3.6 ± 2.6 b	8.3 ± 8.0 a	5.7 ± 5.4 ab	5.5 ± 7.0 ab		
Other Diptera							
Total " other Diptera "	714	504	2810	3227	1473	8728	100
Mean collected	47.6 ± 32.2 c	33.6 ± 27.5 c	187.3 ± 107.4 a	215.1 ± 129.8 a	98.2 ± 84.4 b		

^a In brackets, mean ± SD for the most abundant *Culicoides* species. ^b Includes the remaining species. Different letters in bold denote statistically differences at the 5% level according to Tukey's comparison test. *Aedes* spp. and *Ochlerotatus* spp. were pooled as *Aedes* spp. according to the criteria of Wilkerson et al. (2015).

Table 2. Summary of dipterans collected with different light sources in mid-August over 12 nights at a meadow in the Basque Country, Spain.

Species	BULB	WHITE-TUBE	UV-LED	UV-TUBE	TOTAL	% species
<i>Culicoides a</i>						
<i>C. punctatus</i>	56 (4.7 ± 4.9)c	362 (30.1 ± 32.3)b	81 (6.7 ± 12.4)c	635 (52.9 ± 52.7)a	1134	38.3
<i>C. cataneii</i>	97 (8.1 ± 9.9)c	221 (18.4 ± 18.2)b	71 (5.9 ± 6.3)c	403 (33.6 ± 33.1)a	792	26.8
<i>C. obsoletus/scoticus</i>	6 (0.5 ± 1.2)c	174 (14.5 ± 17.1)b	19 (1.6 ± 2.1)c	408 (34.0 ± 31.5)a	607	20.5
<i>C. alazanicus</i>	10	50	41	111	212	7.1
<i>C. festivipennis</i>	13	36	32	39	120	4.1
<i>C. kibunensis</i>	0	13	4	12	29	0.9
<i>C. kibunensis</i>	0	20	5	19	44	1.5
<i>C. circumscriptus</i>	0	14	0	6	20	0.7
<i>C. duddingstoni</i>	0	0	0	5	5	0.2
<i>C. nubeculosus</i>	0	0	0	1	1	0.0
Total (other species) b	23 (1.9 ± 2.6) d	133 (10.8 ± 12.4) b	82 (6.8 ± 8.7) c	193 (16.2 ± 16.8) a	431	14.5
Total <i>Culicoides</i>	182	890	253	1639	2964	100
Species collected	6	9	8	11	11	
Mean collected	15.2 ± 16.7 c	73.9 ± 77.2 b	21.1 ± 27.5 c	136.6 ± 129.8 a		
Other Ceratopogonidae						
<i>Forcipomyia</i>	37	122	34	129	321	68.0
<i>Atrichopogon</i>	2	11	8	61	81	17.1
<i>Dasyhelea</i>	5	12	15	36	68	14.3
<i>Stilobezzia</i>	0	0	0	3	3	0.6
Total "other Ceratopogonidae "	44	145	57	229	473	100
Mean collected	3.6 ± 4.2 c	12.1 ± 16.3 b	4.7 ± 5.2 c	19.1 ± 24.0 a		
Culicidae						
Total Culicidae	28	76	34	41	179	100
Mean collected	2.3 ± 2.2 b	6.3 ± 5.0 a	2.8 ± 2.0 b	3.4 ± 3.2 b		
Other Diptera						
Total "other Diptera"	510	1319	445	1426	3700	100
Mean collected	42.5 ± 28.4 b	109.9 ± 81.4 a	37.1 ± 22.8 b	118.8 ± 75.5 a		

^a In brackets, mean ± SD for the most abundant *Culicoides* species. ^b Includes the remaining species. Different letters in bold denote statistically differences at the 5% level according to Tukey's comparison test. Culicidae was pooled due to the low numbers collected.

438 **Figure 1.** Numbers of *Culicoides* midges collected with suction light traps at a sheep meadow in the
 439 Basque Country, Spain: (A) LEDs trial (white, red, green, blue and UV lights) and (B) mixed light
 440 sources trial (incandescent bulb, white tube, UV LED and UV tube).

441

442

443 Bars represent means confidence interval $\pm$ SD and different letters between boxes denote statistically significant differences ($p <$
 444 0.05).

Table1

Species	LIGHT EMITTING DIODES (LEDs)			
	WHITE	RED	GREEN	BLUE
<i>Culicoides a</i>				
<i>C. punctatus</i>	417 (27.8 ± 19.1) b	257 (17.1 ± 10.4) b	1411 (94.1 ± 60.5) a	1254 (83.6 ± 54.9) a
<i>C. cataneii</i>	20 (1.3 ± 2.3) c	32 (2.1 ± 1.6) c	113 (7.5 ± 5.6) b	63 (4.2 ± 2.8) b
<i>C. obsoletus/scoticus</i>	28 (1.9 ± 2.0) bc	19 (1.3 ± 1.7) c	98 (6.5 ± 8.5) a	65 (4.3 ± 5.2) ab
<i>C. kibunensis</i>	6	5	31	16
<i>C. alazanicus</i>	9	5	28	13
<i>C. circumscriptus</i>	19	6	13	7
<i>C. brunnicans</i>	3	0	34	3
<i>C. festivipennis</i>	2	1	17	1
<i>C. lupicaris</i>	3	0	8	3
<i>C. achrayi</i>	1	0	9	4
<i>C. fascipennis</i>	2	0	7	5
<i>C. duddingstoni</i>	3	2	0	0
<i>C. picturatus</i>	3	0	6	4
<i>C. poperinghensis</i>	1	0	5	0
<i>C. simulator</i>	0	0	1	2
<i>C. dewulfi</i>	0	0	4	0
<i>C. tauricus</i>	1	0	1	0
<i>C. vexans</i>	1	0	0	1
<i>C. parroti</i>	0	0	2	0
<i>C. furcillatus</i>	1	0	0	0
<i>C. pulicaris</i>	1	0	0	0
Total (other species) b	56 (3.7 ± 4.9)c	19 (1.3 ± 1.4)d	166 (10.7 ± 9.3)a	59 (4.1 ± 3.6)bc
Total <i>Culicoides</i>	521	327	1788	1441
Species collected	19	9	18	15
Mean collected	34.7 ± 25.2 b	21.8 ± 12.5 b	118.8 ± 74.3 a	96.2 ± 61.3 ab
Other Ceratopogonidae				
<i>Forcipomyia</i>	403	207	1457	1347
<i>Dasyhelea</i>	44	9	47	30
<i>Atrichopogon</i>	8	1	47	10
<i>Stilobezzia</i>	0	0	2	4
Total " other Ceratopogonidae "	455	217	1553	1391
Mean collected	30.3 ± 56.0 cd	13.8 ± 29.8 d	103.5 ± 211.6 a	92.7 ± 228.9 bc
Culicidae				
<i>Culex</i>	54	42	109	67
<i>Culiseta</i>	19	9	13	11
<i>Anopheles</i>	1	2	2	7
<i>Aedes</i>	1	1	1	1
Total Culicidae	75	54	125	86
Mean collected	5.0 ± 3.8 ab	3.6 ± 2.6 b	8.3 ± 8.0 a	5.7 ± 5.4 ab
Other Diptera				
Total " other Diptera "	714	504	2810	3227
Mean collected	47.6 ± 32.2 c	33.6 ± 27.5 c	187.3 ± 107.4 a	215.1 ± 129.8 a

Table2

Species	BULB	WHITE-TUBE	UV-LED	UV-TUBE
<i>Culicoides a</i>				
<i>C. punctatus</i>	56 (4.7 ± 4.9)c	362 (30.1 ± 32.3)b	81 (6.7 ± 12.4)c	635 (52.9 ± 52.7)a
<i>C. cataneii</i>	97 (8.1 ± 9.9)c	221 (18.4 ± 18.2)b	71 (5.9 ± 6.3)c	403 (33.6 ± 33.1)a
<i>C. obsoletus/scoticus</i>	6 (0.5 ± 1.2)c	174 (14.5 ± 17.1)b	19 (1.6 ± 2.1)c	408 (34.0 ± 31.5)a
<i>C. alazanicus</i>	10	50	41	111
<i>C. festivipennis</i>	13	36	32	39
<i>C. kibunensis</i>	0	13	4	12
<i>C. kibunensis</i>	0	20	5	19
<i>C. circumscriptus</i>	0	14	0	6
<i>C. duddingstoni</i>	0	0	0	5
<i>C. nubeculosus</i>	0	0	0	1
Total (other species) b	23 (1.9 ± 2.6) d	133 (10.8 ± 12.4) b	82 (6.8 ± 8.7) c	193 (16.2 ± 16.8) a
Total <i>Culicoides</i>	182	890	253	1639
Species collected	6	9	8	11
Mean collected	15.2 ± 16.7 c	73.9 ± 77.2 b	21.1 ± 27.5 c	136.6 ± 129.8 a
Other Ceratopogonidae				
<i>Forcipomyia</i>	37	122	34	129
<i>Atrichopogon</i>	2	11	8	61
<i>Dasyhelea</i>	5	12	15	36
<i>Stilobezzia</i>	0	0	0	3
Total " other Ceratopogonidae "	44	145	57	229
Mean collected	3.6 ± 4.2 c	12.1 ± 16.3 b	4.7 ± 5.2 c	19.1 ± 24.0 a
Culicidae				
Total Culicidae	28	76	34	41
Mean collected	2.3 ± 2.2 b	6.3 ± 5.0 a	2.8 ± 2.0 b	3.4 ± 3.2 b
Other Diptera				
Total "other Diptera"	510	1319	445	1426
Mean collected	42.5 ± 28.4 b	109.9 ± 81.4 a	37.1 ± 22.8 b	118.8 ± 75.5 a