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Artificial lighting triggers the presence of urban spiders and their webs on historical buildings

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(Article begins on next page)

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Title: Artificial lighting triggers the presence of urban spiders and their webs on historical buildings

Article Type: Research paper

Keywords: urban ecology; digital image analysis; light pollution; Araneae; synanthropic species; aesthetic nuisance

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Abstract: Different spider species living in the urban environment spin their webs on building facades. Due to air pollution, web aggregations entrap dirt particles over time, assuming a brownish-greyish colouration and thus determining an aesthetic impact on buildings and street furniture. In Europe, the most common species causing such an aesthetic nuisance is Brigittea civica (Lucas) (Dictynidae). In spite of the socioeconomical relevance of the problem, the ecological factors driving the proliferation of this species in the urban environment are poorly described and the effectiveness of potential cleaning activities has never been discussed in scientific literature. Over one year, we studied the environmental drivers of B. civica webs in the arcades of the historical down-town district of Turin (NW-Italy). We selected a number of sampling plots on arcade ceilings and we estimated the density of B. civica webs by means of digital image analysis. In parallel, we collected information on a number of potential explanatory variables driving the arcade colonization, namely artificial lighting at night, substrate temperature, distance from the main artificial light sources and distance from the river. Regression analysis showed that the coverage of spider webs increased significantly at plots with higher light intensity, with a major effect related to the presence of historical lampposts with incandescent lamps rather than halogen lamps. We also detected a seasonal variation in the web coverage, with significant higher values in summer. Stemming from our results, we are able to suggest good practices for the containment of this phenomenon.



Università degli Studi di Torino DIPARTIMENTO DI SCIENZE DELLA VITA E BIOLOGIA DEI SISTEMI



Dr. Marco Isaia Department of Life Science and Systems Biology University of Turin Via Accademia Albertina, 13 - 10123 Torino Tel. 0116704519 E-mail: marco.isaia@unito.it

May 07th, 2018

Dear Dr Xiang,

we hereby submit the revised version of manuscript LAND-D-18-00321 entitled "Artificial lighting triggers the presence of urban spiders and their webs, causing an aesthetic damage to historical buildings" intended for publication in *Landascape and Urban Planning*.

We thank you for handling our submission and spending time in evaluating it. In this revision, we have took into account all minor corrections suggested by referee 2 and proof-read it once more.

We confirm that the work is all original research carried out by the authors, all authors agree with the contents of the manuscript and its submission to the journal, no part of the research has been published in any form elsewhere, and the manuscript is not being considered for publication elsewhere.

Yours,

Dr Marco Isaia

On behalf of all co-authors

1	REBUTTAL LETTER FOR					
2						
۲۰۰۲ LAND-D-18-00321						
- 5 6	'Artificial lighting triggers the presence of urban spiders and their webs on historical buildings'					
8 9 10 11 12 13 14 15 16 17 18	Reviewer #2: Landscape and Urban Planning MS 18-0321 This seems to be a respectable contribution suitable for publication. It is a nice combination of science addressing a real world problem. It also is a relatively clean paper. I usually find lots of mistakes in manuscripts that I review but this one had few errors. One caveat is that I have very limited statistical background of the oditor marks of the paper.					
	RESPONSE: Thank you for spending time to review our manuscript and for you very positive attitude toward it.					
19 20 21	There are several instances of misspelling the spider family name as "Dyctinidae" which needs correcting (lines 45, 505, 506)					
22 23 24	RESPONSE: Corrected.					
24 25 26	line 47: cited as Hertel 1969 in the text but 1968 in the reference section					
20	RESPONSE: Corrected – the right one was 1968.					
29	line 217: citation is "XXXXXXX" but is probably Hanggi which is not cited in the paper and is also 2016					
30 31	RESPONSE: Actually, this is not a mistake. From the journal's guidelines (see highlight in colour):					
32 33 34 35 36 37 38 39 40 41 42 43 44 43	"Landscape and Urban Planning uses a double-blind review process, and to ensure anonymity the manuscript file must not include any self-referencing, logos, headers or any other type of information or formatting that might reveal the identify or affiliation of any of the authors. Acknowledgements should not be included in the manuscript file and must be uploaded as a separate file. See Section 3.9.7 below. Self-references that must be included must not be obvious in revealing any authors' identify and should refer to the authors' work only indirectly (e.g., "This work builds upon procedures developed by Smith (2010)"; NOT "I build upon my previous work (Smith, 2010)"). To further ensure anonymity, authors may choose to temporarily remove self-citations from the reference list and mask in-text references (e.g., "(XXX, 2009 masked for blind review)"), then restore the proper citation when the manuscript is accepted. Although such an approach better respects the integrity of the blind review process, authors must weigh the removal of a citation against the need for reviewers to evaluate the credibility of your work."					
46	On the other hand, we now reference the missing reference in the text (Hanggi).					
47 48 49 50 51	line 62: change "environment" to "environments" line 152: insert a space in "Photo#2" line 175: change "generated" to "generate" line 270: change "them" to "themselves"					

- line 270: change them to themselves line 287: I would change "Southern" to "southern" line 350: change "spider" to "spiders" line 352: I would change "Southern" to "southern" line 484: insert a space in "seriesmodel" 53

- line 541: many other citations have a long list of authors, whereas this one just has the first author and et al. line 590s: Vetter paper should be listed before Vitousek line 620: add a space in "typeanalyses"

- 60
- **RESPONSE:** Done.

- 1 Artificial lighting triggers the presence of urban spiders and their webs on historical
- 2 buildings
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1. Spider web aggregations affect the aesthetic value of historical building

2. We studied the ecological factors driving the abundance of spider webs on historical arcade ceilings

3. Web density was estimated using an innovative photographic-based methodology

4. By attracting prey, incandescent artificial lighting is the major factor driving of the increase of spider webs

5. Changing the lighting system type may help in reducing this problem

*Blinded Manuscript with No Author Identifiers Click here to view linked References

- 1 Artificial lighting triggers the presence of urban spiders and their webs on historical
- 2 buildings
- 3
- 4
- 5 Abstract
- 6

Different spider species living in the urban environment spin their webs on building 7 facades. Due to air pollution, web aggregations entrap dirt particles over time, assuming a 8 9 brownish-greyish colouration and thus determining an aesthetic impact on buildings and 10 street furniture. In Europe, the most common species causing such an aesthetic nuisance 11 is Brigittea civica (Lucas) (Dictynidae). In spite of the socio-economical relevance of the 12 problem, the ecological factors driving the proliferation of this species in the urban environment are poorly described and the effectiveness of potential cleaning activities has 13 14 never been discussed in scientific literature. Over one year, we studied the environmental 15 drivers of *B. civica* webs in the arcades of the historical down-town district of Turin (NW-Italy). We selected a number of sampling plots on arcade ceilings and we estimated the 16 17 density of B. civica webs by means of digital image analysis. In parallel, we collected 18 information on a number of potential explanatory variables driving the arcade colonization, namely artificial lighting at night, substrate temperature, distance from the main artificial 19 20 light sources and distance from the river. Regression analysis showed that the coverage of 21 spider webs increased significantly at plots with higher light intensity, with a major effect 22 related to the presence of historical lampposts with incandescent lamps rather than halogen lamps. We also detected a seasonal variation in the web coverage, with 23 24 significant higher values in summer. Stemming from our results, we are able to suggest 25 good practices for the containment of this phenomenon.

26

Keywords: urban ecology; digital image analysis; light pollution; Araneae; synanthropic
species, aesthetic nuisance

29 **1. INTRODUCTION**

30

Environmental modifications driven by urbanization have a significant effect on biodiversity 31 (Güneralp & Seto, 2013; Seto, Gueneralp, & Hutyra, 2012; Vitousek, 1997), driving large 32 33 changes in species abundances and distributions within the original biological communities 34 (McKinney, 2008). Whilst urbanization is considered to be a major determinant of biodiversity loss (Grimm et al., 2008; Newbold et al., 2015), a number of organisms are 35 36 able to coexist alongside us in urban environments (e.g., Aronson et al., 2014; Bertone et al., 2016; McKinney, 2002). Owing to their high ecological plasticity (Turnbull, 1973), 37 38 several species of spiders are able to dwell in cities, representing an important component 39 of the urban wildlife (McIntyre, 2000; Shochat, Stefanov, Whitehouse, & Faeth, 2004; 40 Taucare-Ríos, Brescovit, & Canals, 2013). With the exception of some species of medical 41 importance (e.g. Isbister et al., 2005; Sams et al., 2001; Vetter & Isbister, 2008), urban 42 spiders usually have little socio-economic impacts and often remain unnoticed. A remarkable exception is found in those spider that due to their webs may cause aesthetic 43 44 alterations to buildings facades — see discussion in Nentwig (2015).

In Europe, one of the most noticeable species causing aesthetic nuisance to 45 buildings is Brigittea civica (Lucas) (Araneae: Dictynidae) (Figure 1A) (Samu, Jozsa, & 46 Csànyi, 2004). This is a small cribellate spider (body length 2.3–3.5 mm; Nentwig, Blick, 47 Gloor, Hänggi, & Kropf, 2018) of South European origin (Hertel, 1968), which spins a 48 49 circular, tangled cribellate cobweb on flat surfaces (Billaudelle, 1957; Krumpálová, 2001). 50 Although being relatively small in size (ca. 5 cm in diameter), cobwebs of *B. civica* may 51 occur at very high density on wall facades and can persist for long periods of time (Figure 52 1B–D). The fact that multiple individuals are able to coexist and spin their cobwebs at a very close distance to one another can be explained in light of the peculiar behaviour of B. 53 54 civica, with different individuals being able to share prey without fighting each other (Billaudelle, 1957). Due to air pollution, these large web aggregations entrap dust and dirt 55

particles over time, assuming a brownish-greyish coloration and thus significantly reducing
the aesthetic value of buildings (Havlová & Hula, 2010; Kostanjšek & Celestina, 2008;
Nedvěd et al., 2011; Novotný, Hula, & Niedobová, 2017; Samu et al., 2004; Figure 1D, E).

59 The factors determining this phenomenon are as yet poorly described, and thus no good practices have been put forward to address this problem and to maximize the 60 effectiveness of potential cleaning activities. To the best of our knowledge, the only study 61 referring to habitat selection by *B. civica* was conducted by Samu et al. (2004) in urban 62 63 environments in Hungary. The authors demonstrated quantitatively how web density is significantly higher in facades with a southern exposure and sheltered to external 64 weathering (especially rain), whereas they found no clear pattern in the selection of 65 different surface-types. 66

Because of its artistic heritage from one side and of its predominantly Mediterranean climate suitable for *B. civica* on the other, Italy is potentially among the most affected countries by this issue. In several Italian heritage cities, webs of this spider are found on churches, arcades, palaces and other historical buildings exploited for touristic purposes, resulting in possible economic impacts connected to the cleaning activities aimed at removing the webs.

73 We conducted a one-year field study to identify the environmental factors driving the 74 proliferation of *B. civica* webs in the arcades of the historical down-town district of Turin 75 (NW-Italy) (Figure 1E). Observations made by the authors during a preliminary site 76 inspection, and similar recorded observations published by Samu et al. (2004), lead to an 77 initial prediction that i) the density of webs is significantly higher in the vicinity of artificial 78 lighting systems and in other areas with high illuminance. Moreover, given that webs of B. 79 civica may last for long time on the surfaces, we further hypothesize that ii) webs are 80 present through the year, but there should be variation in their density connected with the 81 phenology of the species. In particular, increases in the density of webs may be expected

- 82 right after the breeding period for this species, approximately from April to June
- 83 (Kostanjšek & Celestina, 2008; Nentwig et al., 2018; Wiehle, 1953).

84 2. MATERIAL & METHODS

85

86 **2.1 Study area**

This study was conducted in the municipality of Turin (Torino), NW-Italy (45° 04' N, 7° 42' 87 88 E). The city has a long history, testified by the traditional orthogonal plant of the ancient Roman camps ("castrum"), and the remarkable Baroque architecture, which was 89 90 developed under the Duchy of Savoy (1416–1860). The down-town district of Turin has 18 91 kilometres of historical Baroque arcades ("portici"), mostly interconnected with each other, 92 making it one of the largest pedestrian areas in Europe. Arched ceilings represent suitable habitats to Brigittea civica spiders, being naturally sheltered from rains, direct solar 93 94 irradiation, and air currents (Billaudelle, 1957; Samu et al., 2004). As a result, most arcades ceilings are heavily colonized by *B. civica* cobwebs (Figure 1B–D). In order to 95 improve the aesthetic value of the historical district, the competent authorities promoted 96 97 the cleaning of the arcades in 2006, when the city hosted the XX Olympic Winter Games.

We conducted our study in the heart of the historical down-town district, on the arcades connecting Piazza Vittorio Veneto to Piazza Castello all along Via Po, for approximately 2 kilometres. In this area, arcades are predominantly Serlian-type arches, ranging from 3 to 5 m in height (Figure 1E). The majority of the arcades have vaulted ceilings, with some exceptions (coffered ceilings) along a small stretch of Via Po, which we did not consider in this analysis. At night, arcades are illuminated by historical lampposts with incandescent lights and/or halogen lamps, which are installed at different heights.

105

106 **2.2 Data collection**

We conducted three monitoring sessions over one year (Winter: 10 Dec 2016; Spring: 30 Apr 2017; Summer: 7 Jul 2017), at night. In order to provide a homogeneous coverage of the entire study area, we selected seventy-two arcades as basic sample units,

approximately equidistant. All sampling plots were georeferenced. Within each basic sample unit, at each survey we randomly identified one sampling plot of 1.0 x 0.7 m on a flat area of the ceiling (i.e. avoiding angles and cracks and crevices in the plaster). Using this study design, we were able to control for substrate type (all arcade ceilings are characterized by the same plaster type) and general exposure to external weather (all arcades are protected by rains, direct solar irradiation, and air currents).

116 We conducted the monitoring by means of a photography-based methodology (Figure 2), by taking two photos of each sampling plot in order to estimate the density of 117 Brigittea civica webs (photo #1) and the intensity of artificial lighting illuminating the wall 118 surface of the plot (photo #2). Full details on the calculation of these variables are given in 119 120 the section "Photographic analysis". At each survey, we further measured the substrate 121 temperature with an infrared thermometer at the centre of the sampling plot, and we calculated the linear distance from 1) the closest historical lamppost (incandescent lighting 122 123 system) and/or 2) the closest halogen light (Figure 2). The distance of each sampling plot from the Po River, which is flowing close to the study area (see Figure 3), was further 124 125 calculated in a GIS environment (ArcView 3.3 ESRI). This latter variable was introduced to account for the potential influence of local microclimatic factors related to the proximity of 126 water on web abundance and insect prey availability — e.g. as observed in other web 127 128 weaver spiders (Akamatsu, Toda, & Okino 2004, Gillespie, 1987; Kleinteich, 2010).

129 **2.3 Photographic analysis**

We carried out the photographic analysis in National Instruments[™] LabVIEW environment 130 (Elliott, Vijayakumar, Zink, & Hansen, 2007). In order to obtain a value representing the 131 web coverage of each plot, we acquired a photo of the plot (photo #1) in raw mode with a 132 Nikon D810 camera equipped with a Nikon sb910 flash; the image was then converted to 133 134 16 bit greyscale. Initially we conducted a set of exploratory tests, applying different pixel thresholds for converting the 16 bit greyscale image into a black and white (B/W) image. 135 136 The aim of the B/W conversion was to recolour the pixels depicting webs of Brigittea civica in black and the remaining pixels in white, thus allowing an estimation of the web coverage 137 within the plot. After the preliminary trial, we set the B/W conversion threshold at 49000 138 (where 0 is black and 65535 is white), which proved to be the best trade-off value to 139 140 separate the webs from other features of the surface within the image — i.e. dust particles on the substrate or darker areas due to the natural ruggedness of the ceiling plaster. We 141 142 used this fixed threshold for converting all images into B/W, and we summed up the number of black pixels via an automated function. 143

Despite the evaluation of the light intensity that reaches a surface is normally 144 performed directly using a photoradiometer, in our case this resulted highly impractical due 145 146 to the height of the arcades and the number of plots. Starting from the assumption that the 147 intensity of the light reflected by a surface is correlated with the intensity of the lighting 148 source, we used an evaluation method based on the acquisition of the reflected light with a 149 camera. By choosing surfaces having more or less the same colour and the same surface 150 morphology, and by setting up a fixed exposure time and no flash, it is possible to use the acquired image as an indirect measure of the light intensity of the plot. Consequently, 151 images with low values of R, G and B channels correspond to low values of light intensity 152 153 reaching the surface, while high values of R, G and B channels correspond to high values of light intensity. For this calculation, we acquired a second image of the plot (photo #2) 154

focusing on a web-free surface (Figure 2). Photo #2 was taken in raw mode with a Nikon 155 156 D3X camera without flash and using a fixed exposure. We converted the digital image to a 16 bit RGB, and we derived the histogram representing the distribution of the overall pixel 157 values (range 0 – 65535). We used the modal value — i.e., the most recurrent value in the 158 image — as an indirect measure of the artificial light intensity that illuminated the 159 photographed surface. We repeated the same operation for each of the RGB channels in 160 161 order to explore possible relationships between the web coverage and different colours of light. 162

163

164 **2.4 Regression analysis**

We studied the relation between environmental factors and Brigittea civica web coverage 165 by performing a regression-type analysis (Zuur & leno, 2016) in R (R core team, 2017). 166 We expressed the dependent variable as the counts of black pixels (i.e. pixel covered with 167 webs) within photo #1 — hereinafter "web coverage" (WEB). We selected the following 168 covariates (explanatory variables) as potential drivers of the web coverage in the sampled 169 plots: distance from the river (Dst; continuous variable), substrate temperature (T°; 170 continuous variable), sampling session (Sampling; categorical variable of three levels), 171 artificial light intensity (ILL; continuous variable calculated from photo #2), Red, Green and 172 Blue light components (R, G, B, respectively; continuous variables calculated from photo 173 #2), distance from the nearest historical lamppost (Dst lamp; continuous variable) and 174 175 distance from halogen light sources (Dst halo; continuous variable). In order to account for potential density-dependent effects in driving the web coverage (i.e. spatial relationships 176 among webs), we further included a variable reflecting the intercrossed distance of each 177 plot from the others (InterDst; continuous variables). To generate this variable, we 178 179 calculated the distance matrix of each sampling plot using the spatial coordinates of the 180 plots, and derived the mean distance of each plot from the others. We tested for spatial

autocorrelation in web coverage *via* Moran's I test in the *ape* R package (Paradis, Claude,
& Strimmer, 2004), using the Gittleman and Kot (1990) method.

We initially explored the dataset using the standard protocol described by Zuur, leno, and Elphick (2010). We constructed Cleveland' dotplots to assess the presence of outliers within the dataset. We investigated multi-collinearity among explanatory variables by means of scatterplots, Pearson correlation tests (*r*), by setting the threshold for collinearity at *r*>|0.7| (Zuur, leno, Walker, Savaliev, & Smith, 2009). Boxplots were also constructed to graphically assess collinearity between continuous and categorical variables.

To model the response of the web coverage to the explanatory variables, we initially 190 191 fitted a Poisson generalised linear model (GLM), including all non-collinear covariates of 192 interest. In order to test for the potential effect of the different light source illuminating the plot, we allowed for interactions between the artificial light intensity and the distance from 193 194 the different light sources (Dst_lamp * ILL; Dst_halo * ILL). The Poisson GLM was highly over-dispersed [dispersion statistic (DS)=600.95], and thus a negative binomial GLM was 195 considered (Zuur et al., 2010). We fitted the negative binomial GLM in the MASS R 196 package (Venables & Ripley, 2002). Over-dispersion in the negative binomial GLM was 197 minimal (DS=1.62), so we chose this error distribution in all subsequent analysis. 198

Once we fitted the initial negative binomial GLM including all the covariates and interactions of interest, we performed model selection in order to select which variables should be included in the final model (Johnson & Omland, 2004). We used a stepwise backward elimination procedure, whereby we progressively excluded variables and interactions from the model according to the corrected Akaike information criterion for finite sample size (AICc values; Burnham & Anderson, 2002; Hurvich & Tsai, 1989). We reiterated the procedure until we obtained a Minimum Adequate Model (MAM) including

206 only significant variables. We conducted model selection using the *MuMIn* R package 207 (Bartoń, 2017).

Model validation was conducted on the MAM (Zuur et al., 2009). In particular, we tested it for over-dispersion, we constructed standard validation plots using model residuals and we investigated the existence of possible non-linear responses of our covariates by means of generalized additive models (GAMs). GAMs were fitted with the *gam* R package (Hastie, 2013), using the same model structure identified during model selection.

214

215 **2.5 GIS analysis**

For each sampling plot, we predicted the value of web coverage using the most 216 217 appropriate model structure supported by the observations derived from the model selection. In order to provide a graphical representation of the investigated phenomenon in 218 219 the study area, we interpolated these predicted values in a GIS environment using the methodology detailed in Mammola and Isaia (2016). For this analysis, we drew the vector 220 221 layer of the arcades on the raster topographical map of the study area, and we 222 interpolated the projected values for each sampling plot relative to each sampling session. 223 For the interpolation, we used an Inverse Distance Weighted function (IDW) using a 224 sample of 12 plots (power 2) to estimate cell values and obtain the renderings of the model 225 prediction.

226 **3. RESULTS**

227

Following the initial data exploration (Zuur et al., 2010), we dropped R, B and G light components from the GLM analysis, being collinear with artificial light intensity (all Pearson r>0.9). Moreover, we dropped the distance from the river (Dst), being collinear with the inter-plot crossed distance (InterDst) and we excluded substrate temperature (T°) from the analysis, being collinear with the sampling session. We further applied a logtransformation to artificial light intensity to achieve homogenization of its distribution (Zuur et al., 2009), and removed one outlier from the dataset.

235 According to model selection (Table 1), the MAM had the following structure: WEB ~ log(ILL) x Dst lamp + Sampling. Specifically, we found a positive and significant 236 237 interaction between the artificial light intensity and the distance from the historical 238 lamppost, whereby higher web coverage was predicted at higher values of light intensity and in the vicinity of historical lamppost. The effect of this interaction can be visualized in 239 Figure 4. We also detected a pattern of seasonal variation in the density of webs on the 240 241 arcades, with significantly higher predicted values in summer with respect to spring (reference category). Coverage in winter was not significantly different from the reference 242 category (Figure 4). Estimated regression parameters and p values are reported in Table 243 244 2, and a graphical representation of the model prediction is shown in Figure 3.

There was a significant spatial association in the web coverage among plots (Moran's I test, observed= -0.022; expected= -0.006; sd= 0.005 p < 0.05). However, this effect was not recovered in the regression analysis, given that the variable InterDST was not significant and thus dropped from the model during the backward elimination model selection procedure. Spatial association of webs can be visualized graphically in Figure 3 (note the conditional size of the dots representing the plots).

251 4. DISCUSSION

252

The two strongest predictors of the web coverage of *Brigittea civica* in the historical 253 254 arcades of Turin were the intensity of artificial light and the distance from the nearest 255 historical (incandescent) lampost. Moreover, we found a variation in the web coverage with respect to the sampling session (Figure 3). It is well demonstrated that artificial 256 257 illuminance plays an important ecological role in urban settings (e.g., Gaston & Bennie, 258 2014; Gaston, Bennie, Davies, & Hopkins 2013; Sanders & Gaston, 2018) and other 259 studies have reported about the significant association between different urban species and artificial lighting (e.g. Frank, 2009; Heiling, 1999; but see Voss, Main, & Dadour, 260 261 2007). As far as *Brigittea civica* is concerned, Samu et al. (2004) reported that (p. 355): "[...] casual observation [...] showed that [B. civica] webs were aggregated around artificial 262 lights." Our work provides statistical support to this observation, as we demonstrated that 263 the web coverage of the plots was significantly higher in the plots where artificial light was 264 more intense. 265

It was observed that spiders thriving in urban habitats may benefit from increased 266 trophic resources in cities (Lowe, Wilder, & Hochuli, 2016; Trubl, Gburek, Miles, & 267 Johnson, 2012; Voss et al., 2007). Based upon this premise, the relationship between web 268 269 coverage and artificial light that we observed, could be explained as a function of the 270 higher prey availability found in the nearby of light sources (Heiling, 1999). The attraction of aerial and terrestrial arthropods to artificial lighting is indeed a well-documented 271 phenomenon (Davies, Bennie, & Gaston, 2012; Eisenbeis, 2006; Frank, 2006; Shimoda & 272 273 Honda, 2013). It has been shown that *B. civica* is able to feed upon a wide range of small 274 flying insects — including dipterans, but also flying ants, small lepidopterans and aphids. 275 Also, if previously starved of food, these spiders are able to feed upon prey nearly three

times bigger than themselves (Billaudelle, 1957). This wide range of potential prey is
expected to be available in the areas surrounding street lights (Davies et al., 2012).

Our data also demonstrate that the type of light source is important in explaining the 278 coverage of webs. In particular, spider webs were more abundant in the vicinity of 279 incandescent historical lampposts (Figure 3) rather than halogen lamps. We assume that 280 281 the light emitted by lampposts has its greater effects on attracting spiders due to its higher 282 potential of attracting insect prey. It is well-documented that nocturnal insects are able to see ultraviolet radiation, being often attracted to light sources that emit large amounts of 283 UV radiation (Shimoda & Honda, 2013). At the same time, different light spectra have 284 different attraction potential to nocturnal arthropods (e.g. Longcore et al., 2015), with 285 286 incandescent lights often attracting most nocturnal insects (Justice & Justice, 2016). This 287 would convincingly explain the interaction we observed between light intensity and the distance from the incandescent light sources. 288

One could argue that the incandescent artificial lighting system may affect the distribution of the spiders because of the general influence on thermal conditions, rather than because of its light spectrum. In fact, there should be higher ambient temperature in the vicinity of lights, offering a more favourable habitat for a southern European species such as *B. civica*. However, we rejected this alternative explanation given that the temperature of the substrate was only limitedly anti-correlated with the distance from the incandescent artificial lighting system (r=-0.26).

There is evidence indicating that spiders may be able to recognise the quality of foraging patches and change web site on the basis of prey availability (e.g., Enders, 1977; Gillespie & Caraco, 1987; Harwood, Sunderland, & Symondson, 2001; but see Vollrath, 1985). Conversely, it may also be that habitat patches with higher light intensity, and thus higher prey availability, are not actively selected by the spiders, but simply support larger colonies of spiders, due to their more favourable condition. It stands to reason that the

individual fitness of a spider should be higher in a prey-rich rather than in prey-poor habitat patch. However, further studies are needed to determine whether the optimal patches are actively selected by the spiders, or if the higher web coverage found in the vicinity of incandescent lampposts is the actual results of a higher persistence of the local population.

It is likely that the effect of artificial lighting was particularly clear-cut in our case 307 because, through the design of the study, we were able to exclude other confounding 308 factors. It has been shown that *B. civica* avoids areas exposed to rains, winds and direct 309 solar irradiation (Billaudelle, 1957; Samu et al., 2004). By using our study design (all plot in 310 sheltered arcades), we were able to exclude these factors from the analysis. Moreover, we 311 312 deliberately avoided plots with significant cracks and crevices in the plaster, which are 313 preferentially selected as supporting framework for the construction of webs and may thus influence the fine distribution of this species. 314

315

316 **4.1 Management implications**

It has been argued that there is not an easy solution to the contamination of urban wall 317 318 surfaces by spider webs of Brigittea civica, mainly because this species does not show a selective preference for a particular wall material or painting (Samu et al., 2004). As far as 319 320 we are aware, the only method so far implemented to deal with this issue is the 321 mechanical removal of the spider webs from the wall surfaces. Whilst the mechanical 322 removal is certainly effective, such methodology is rather costly, time consuming and 323 problematic, especially in the case of high buildings. Secondly, the mechanical removal only represents a temporary remedy to the problem, needing to be reiterated over time. 324

There are three general findings relevant to the management of building surfaces arising from this work. First, the timing of the mechanical cleaning can be important. Whilst this may seem self-evident, we suggest that it is important to consider carefully the

phenology of the species when planning the cleaning activities. We documented a higher prevalence of webs during the warm seasons (Figure 4). In particular, a higher web coverage was observed in summer, at the end of the breeding season of *B. civica* (Kostanjšek & Celestina, 2008; Nentwig et al., 2018; Wiehle, 1953). This observation suggests that, in order to maximise the effect of the mechanical removal of the webs, one should perform the cleaning after the summer peak of density.

Second, we showed that the incandescent artificial lighting systems illuminating 334 335 most of the arcades in our study area is the main trigger of the increase of the web coverage (Figure 4). Thus, a renovation of the artificial lighting illuminating in the down-336 town districts of heritage cities towards halogen or light emitting diode (LED) lights may 337 provide a near-permanent solution to this problem, or it may at least contribute to mitigate 338 the contamination. According to our results, arcades and building facades should become 339 a less attractive habitats for spiders, thereby reducing the aesthetic nuisance caused by 340 341 the webs.

Third, casual observations during this study revealed that cracks and crevices in the plaster are preferentially used as supporting framework for the construction of webs. Maintaining an intact plaster, at least in the touristic areas, will likely help in reducing the intensity of the phenomenon.

Ultimately, it can be argued that heavy traffic exacerbates the phenomenon, given 346 that webs became more visible due to air pollution — see argumentation in Samu et al. 347 348 (2004). Pedestrian areas have been introduced in most of the historical down-town 349 districts of cities all around the world, with the aim of increasing commercial and touristic activities, meanwhile reducing pollution to preserve historical sites (Pagliaria & Biggiero, 350 2013). Accordingly, an increase of pedestrian areas associated to a reduction of the local 351 352 air pollution in down-town districts will, in turn, limit the aesthetic impact associated with B. 353 civica webs.

355 **4.2 Significance statement**

356 One may argue that the results of this study might not be applied to spiders more widely and that Brigittea civica might represent only a very specific case. Still, it is worth noting 357 that, despite being of southern European origin, this species has been spreading 358 359 northward during the last few years. Currently, B. civica reaches central Siberia and central Asia (Buchar & Růžička, 2002; Zamani & Mozaffarian, 2017). Recent evidence indicate 360 that the species is much more common than was previously known; for instance, in 361 Central Europe it is likely that its presence has been underestimated (data from Czech 362 Republic; Novotný et al., 2017; see also discussions in Hänggi & Straub, 2016). Moreover, 363 the spider was recently found in North America (World Spider Catalog, 2018) and South 364 Africa (Foord, 2014), which poses additional concerns in light of the potential economic 365 importance of the potential aesthetic damage caused by this species. 366

367 Moreover, this study exemplifies a methodological approach that is efficient and inexpensive, and thus that can be easily reproduced in other cases. More studies similar to 368 this one would be useful when considering other species which are known to have 369 potentially negative aesthetic impacts, or that may even cause potential structural 370 371 damages. For instance, the photography-based methodology herein described can be 372 easily used to estimate the density of other organisms which may occur at high densities - even forming biofilms - on wall surfaces, especially lichens, mosses, and fungi (e.g. de 373 374 los Ríos et al., 2009 Gaylarde & Morton, 1999; Lisci, Monte, & Pacini, 2003).

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TABLES

- 649 Table 1. Model selection according to the corrected Akaike criterion for finite sample size (AICc; Burnham &
- Anderson, 2002; Hurvich & Tsai, 1989). Models are ordered from the most to the least appropriate.

Model	df	AICc	Δ ΑΙCc	wi
y~log(ILL)*Dst_halo + log(ILL)*Dst_lamp + Sampling +	10	2362.37	3.41	0.08
InterDst				
y~log(ILL)*Dst_halo +Dst_lamp + Sampling + InterDst	9	2360.35	1.40	0.21
y~log(ILL)*Dst_halo + Dst_lamp + Sampling	8	2359.72	0.77	0.28
y~log(ILL)*Dst_halo + Sampling	7	2358.95	0.00	0.42

- $Df = degrees of freedom; AICc = Corrected Akaike information criterion for finite sample size; <math>\Delta AICc = (AICc + 654 + 654)$ of themodel)—(AICc of the best model); wi = Akaike weight (*sensu* Burnham & Anderson, 2002). See text for abbreviations of the explanatory variables.

Table 2. Estimated regression parameters and p-values according to GLM analysis. See text forabbreviations of the explanatory variables.

Variable	Estimated β	Standard Error	z-value	p-value
Intercept	-7.3130	2.675	-	-
log(ILL)	1.3224	0.254	5.201	<0.001
Dst_lamp	1.3912	0.548	2.537	0.011
log(ILL) x Dst_lamp	-0.1528	0.052	-2.291	0.003
Sampling (level: December)	-0.1816	0.137	-1.324	0.185
Sampling (level: July)	1.3761	0.138	9.979	<0.001

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667 **FIGURE CAPTIONS**

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669 A) Figure 1. Brigittea civica (Lucas) (Araneae: Dictynidae) (photo credits: 670 Dr. Hans-Juergen Thorns). B) Sampling plot on an arcade ceiling with a reduced density of cobwebs of B. 671 civica. C) Sampling plot on an arcade ceiling with a significant contamination of cobwebs of B. civica. D) 672 Sampling plot on an arcade ceiling entirely covered by cobwebs of B. civica. E) The historical arcades of 673 Turin in the area close to Palazzo Carignano. Arrows point at area covered by webs of B. civica (Photo 674 credits: Nicola Paccagnella — www.nicola.photos).

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676 **Figure 2.** Schematic summary of the monitoring protocol.

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Figure 3. Maps of the studied arcades showing interpolated surfaces of the predicted coverage of webs in winter (**a**), spring (**b**) and summer (**c**) according to GLM results. Size of each sampling plot is proportional to the observed web coverage.

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Figure 4. Predicted relationship between the coverage of webs of *Brigittea civica* and the intensity of artificial light (log-transformed) in interaction with the distance from the incandescent historical lamppost across the three sampling sessions. To generate the predictions, two arbitrary values of distance from the incandescent lamppost were used, namely zero (filled line) and six (dashed line) meters. Shaded grey surfaces are 95% confidence intervals.

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Dst = distance

T° = surface temperature











Graphical Abstract



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2

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