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

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

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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 socio-economical 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.

***Cover Letter**

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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

REBUTTAL LETTER FOR

LAND-D-18-00321

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

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 so the editor needs to make sure that someone with statistical ability reviews the paper.

RESPONSE: Thank you for spending time to review our manuscript and for you very positive attitude toward it.

There are several instances of misspelling the spider family name as "Dyctinidae" which needs correcting (lines 45, 505, 506)

RESPONSE: Corrected.

line 47: cited as Hertel 1969 in the text but 1968 in the reference section

RESPONSE: Corrected – the right one was 1968.

line 217: citation is "XXXXXXX" but is probably Hanggi which is not cited in the paper and is also 2016

RESPONSE: Actually, this is not a mistake. From the journal's guidelines (see highlight in colour):

"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."

On the other hand, we now reference the missing reference in the text (Hanggi).

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 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"

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"

RESPONSE: Done.

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

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***Highlights (for review)**

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

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

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 socio-economical 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.

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

1. INTRODUCTION

Environmental modifications driven by urbanization have a significant effect on biodiversity (Güneralp & Seto, 2013; Seto, Gueneralp, & Hutyra, 2012; Vitousek, 1997), driving large changes in species abundances and distributions within the original biological communities (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 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), several species of spiders are able to dwell in cities, representing an important component of the urban wildlife (McIntyre, 2000; Shochat, Stefanov, Whitehouse, & Faeth, 2004; Taucare-Ríos, Brescovit, & Canals, 2013). With the exception of some species of medical importance (e.g. Isbister et al., 2005; Sams et al., 2001; Vetter & Isbister, 2008), urban 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 alterations to buildings facades — see discussion in Nentwig (2015).

In Europe, one of the most noticeable species causing aesthetic nuisance to buildings is *Brigittea civica* (Lucas) (Araneae: Dictynidae) (Figure 1A) (Samu, Jozsa, & Csànyi, 2004). This is a small cribellate spider (body length 2.3–3.5 mm; Nentwig, Blick, Gloor, Hänggi, & Kropf, 2018) of South European origin (Hertel, 1968), which spins a circular, tangled cribellate cobweb on flat surfaces (Billaudelle, 1957; Krumpálová, 2001). Although being relatively small in size (ca. 5 cm in diameter), cobwebs of *B. civica* may occur at very high density on wall facades and can persist for long periods of time (Figure 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. 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 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).

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 effectiveness of potential cleaning activities. To the best of our knowledge, the only study referring to habitat selection by *B. civica* was conducted by Samu et al. (2004) in urban environments in Hungary. The authors demonstrated quantitatively how web density is significantly higher in facades with a southern exposure and sheltered to external weathering (especially rain), whereas they found no clear pattern in the selection of different surface-types.

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.

We conducted a one-year field study to identify the environmental factors driving the proliferation of *B. civica* webs in the arcades of the historical down-town district of Turin (NW-Italy) (Figure 1E). Observations made by the authors during a preliminary site inspection, and similar recorded observations published by Samu et al. (2004), lead to an initial prediction that i) the density of webs is significantly higher in the vicinity of artificial lighting systems and in other areas with high illuminance. Moreover, given that webs of *B. civica* may last for long time on the surfaces, we further hypothesize that ii) webs are present through the year, but there should be variation in their density connected with the phenology of the species. In particular, increases in the density of webs may be expected right after the breeding period for this species, approximately from April to June (Kostanjšek & Celestina, 2008; Nentwig et al., 2018; Wiehle, 1953).

2. MATERIAL & METHODS

2.1 Study area

This study was conducted in the municipality of Turin (Torino), NW-Italy (45° 04' N, 7° 42' 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 developed under the Duchy of Savoy (1416–1860). The down-town district of Turin has 18 kilometres of historical Baroque arcades (*"portici"),* mostly interconnected with each other, 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 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 improve the aesthetic value of the historical district, the competent authorities promoted 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.

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).

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 *Brigittea civica* webs (photo #1) and the intensity of artificial lighting illuminating the wall surface of the plot (photo #2). Full details on the calculation of these variables are given in the section "*Photographic analysis*". At each survey, we further measured the substrate 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 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 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 water on web abundance and insect prey availability — e.g. as observed in other web weaver spiders (Akamatsu, Toda, & Okino 2004, Gillespie, 1987; Kleinteich, 2010).

2.3 Photographic analysis

We carried out the photographic analysis in National Instruments™ LabVIEW environment (Elliott, Vijayakumar, Zink, & Hansen, 2007). In order to obtain a value representing the web coverage of each plot, we acquired a photo of the plot (photo #1) in raw mode with a Nikon D810 camera equipped with a Nikon sb910 flash; the image was then converted to 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. 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 within the plot. After the preliminary trial, we set the B/W conversion threshold at 49000 (where 0 is black and 65535 is white), which proved to be the best trade-off value to 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 used this fixed threshold for converting all images into B/W, and we summed up the number of black pixels via an automated function.

Despite the evaluation of the light intensity that reaches a surface is normally performed directly using a photoradiometer, in our case this resulted highly impractical due to the height of the arcades and the number of plots. Starting from the assumption that the intensity of the light reflected by a surface is correlated with the intensity of the lighting source, we used an evaluation method based on the acquisition of the reflected light with a camera. By choosing surfaces having more or less the same colour and the same surface 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, images with low values of R, G and B channels correspond to low values of light intensity 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) focusing on a web-free surface (Figure 2). Photo #2 was taken in raw mode with a Nikon 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 values (range 0 – 65535). We used the modal value — i.e., the most recurrent value in the image — as an indirect measure of the artificial light intensity that illuminated the photographed surface. We repeated the same operation for each of the RGB channels in order to explore possible relationships between the web coverage and different colours of light.

2.4 Regression analysis

We studied the relation between environmental factors and *Brigittea civica* web coverage by performing a regression-type analysis (Zuur & Ieno, 2016) in R (R core team, 2017). We expressed the dependent variable as the counts of black pixels (i.e. pixel covered with webs) within photo #1 — hereinafter "web coverage" (WEB). We selected the following covariates (explanatory variables) as potential drivers of the web coverage in the sampled plots: distance from the river (Dst; continuous variable), substrate temperature (T°; continuous variable), sampling session (Sampling; categorical variable of three levels), artificial light intensity (ILL; continuous variable calculated from photo #2), Red, Green and Blue light components (R, G, B, respectively; continuous variables calculated from photo #2), distance from the nearest historical lamppost (Dst_lamp; continuous variable) and 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 among webs), we further included a variable reflecting the intercrossed distance of each plot from the others (InterDst; continuous variables). To generate this variable, we calculated the distance matrix of each sampling plot using the spatial coordinates of the 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, Ieno, 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, Ieno, 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 fitted a Poisson generalised linear model (GLM), including all non-collinear covariates of 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 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 considered (Zuur et al., 2010). We fitted the negative binomial GLM in the *MASS* R package (Venables & Ripley, 2002). Over-dispersion in the negative binomial GLM was minimal (DS=1.62), so we chose this error distribution in all subsequent analysis.

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 only significant variables. We conducted model selection using the *MuMIn* R package (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.

2.5 GIS analysis

For each sampling plot, we predicted the value of web coverage using the most appropriate model structure supported by the observations derived from the model selection. In order to provide a graphical representation of the investigated phenomenon in 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 layer of the arcades on the raster topographical map of the study area, and we interpolated the projected values for each sampling plot relative to each sampling session. For the interpolation, we used an Inverse Distance Weighted function (IDW) using a sample of 12 plots (power 2) to estimate cell values and obtain the renderings of the model prediction.

3. RESULTS

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 log-transformation to artificial light intensity to achieve homogenization of its distribution (Zuur et al., 2009), and removed one outlier from the dataset.

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 interaction between the artificial light intensity and the distance from the historical 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 Figure 4. We also detected a pattern of seasonal variation in the density of webs on the arcades, with significantly higher predicted values in summer with respect to spring (reference category). Coverage in winter was not significantly different from the reference category (Figure 4). Estimated regression parameters and *p* values are reported in Table 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).

4. DISCUSSION

The two strongest predictors of the web coverage of *Brigittea civica* in the historical arcades of Turin were the intensity of artificial light and the distance from the nearest historical (incandescent) lamppost. Moreover, we found a variation in the web coverage with respect to the sampling session (Figure 3). It is well demonstrated that artificial illuminance plays an important ecological role in urban settings (e.g., Gaston & Bennie, 2014; Gaston, Bennie, Davies, & Hopkins 2013; Sanders & Gaston, 2018) and other 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, 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 lights.*" Our work provides statistical support to this observation, as we demonstrated that the web coverage of the plots was significantly higher in the plots where artificial light was more intense.

It was observed that spiders thriving in urban habitats may benefit from increased trophic resources in cities (Lowe, Wilder, & Hochuli, 2016; Trubl, Gburek, Miles, & Johnson, 2012; Voss et al., 2007). Based upon this premise, the relationship between web coverage and artificial light that we observed, could be explained as a function of the 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 phenomenon (Davies, Bennie, & Gaston, 2012; Eisenbeis, 2006; Frank, 2006; Shimoda & Honda, 2013). It has been shown that *B. civica* is able to feed upon a wide range of small flying insects — including dipterans, but also flying ants, small lepidopterans and aphids. 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 coverage of webs. In particular, spider webs were more abundant in the vicinity of incandescent historical lampposts (Figure 3) rather than halogen lamps. We assume that the light emitted by lampposts has its greater effects on attracting spiders due to its higher 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 UV radiation (Shimoda & Honda, 2013). At the same time, different light spectra have different attraction potential to nocturnal arthropods (e.g. Longcore et al., 2015), with incandescent lights often attracting most nocturnal insects (Justice & Justice, 2016). This would convincingly explain the interaction we observed between light intensity and the distance from the incandescent light sources.

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

4.1 Management implications

It has been argued that there is not an easy solution to the contamination of urban wall 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 we are aware, the only method so far implemented to deal with this issue is the mechanical removal of the spider webs from the wall surfaces. Whilst the mechanical removal is certainly effective, such methodology is rather costly, time consuming and 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.

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 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-town districts of heritage cities towards halogen or light emitting diode (LED) lights may provide a near-permanent solution to this problem, or it may at least contribute to mitigate the contamination. According to our results, arcades and building facades should become a less attractive habitats for spiders, thereby reducing the aesthetic nuisance caused by 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 that webs became more visible due to air pollution — see argumentation in Samu et al. (2004). Pedestrian areas have been introduced in most of the historical down-town 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, 2013). Accordingly, an increase of pedestrian areas associated to a reduction of the local air pollution in down-town districts will, in turn, limit the aesthetic impact associated with *B. civica* webs.

4.2 Significance statement

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 that, despite being of southern European origin, this species has been spreading northward during the last few years. Currently, *B. civica* reaches central Siberia and central Asia (Buchar & Růžička, 2002; Zamani & Mozaffarian, 2017). Recent evidence indicate that the species is much more common than was previously known; for instance, in Central Europe it is likely that its presence has been underestimated (data from Czech Republic; Novotný et al., 2017; see also discussions in Hänggi & Straub, 2016). Moreover, the spider was recently found in North America (World Spider Catalog, 2018) and South Africa (Foord, 2014), which poses additional concerns in light of the potential economic importance of the potential aesthetic damage caused by this species.

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 this one would be useful when considering other species which are known to have potentially negative aesthetic impacts, or that may even cause potential structural damages. For instance, the photography-based methodology herein described can be 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 los Ríos et al., 2009 Gaylarde & Morton, 1999; Lisci, Monte, & Pacini, 2003).

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TABLES

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 AICc**	**wi**
y~log(ILL)*Dst_halo + log(ILL)*Dst_lamp + Sampling + InterDst	10	2362.37	3.41	0.08
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; ΔAICc = (AICc of themodel)—(AICc of the best model); wi = Akaike weight (*sensu* Burnham & Anderson, 2002). See text for abbreviationsof the explanatory variables.

Table 2. Estimated regression parameters and p-values according to GLM analysis. See text for abbreviations 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

FIGURE CAPTIONS

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

Figure 2. Schematic summary of the monitoring protocol.

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.

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.

ure 1

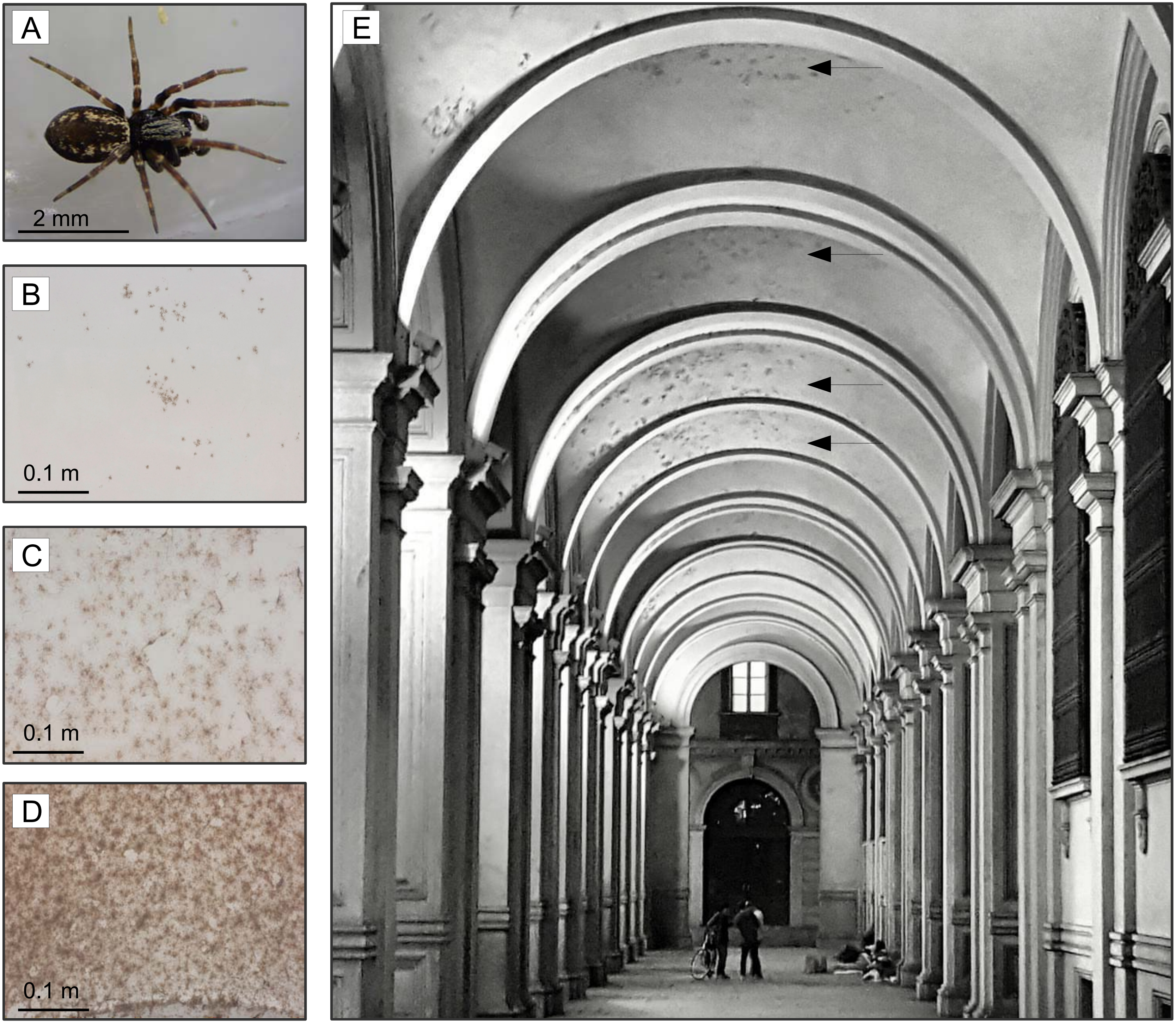


Figure 2

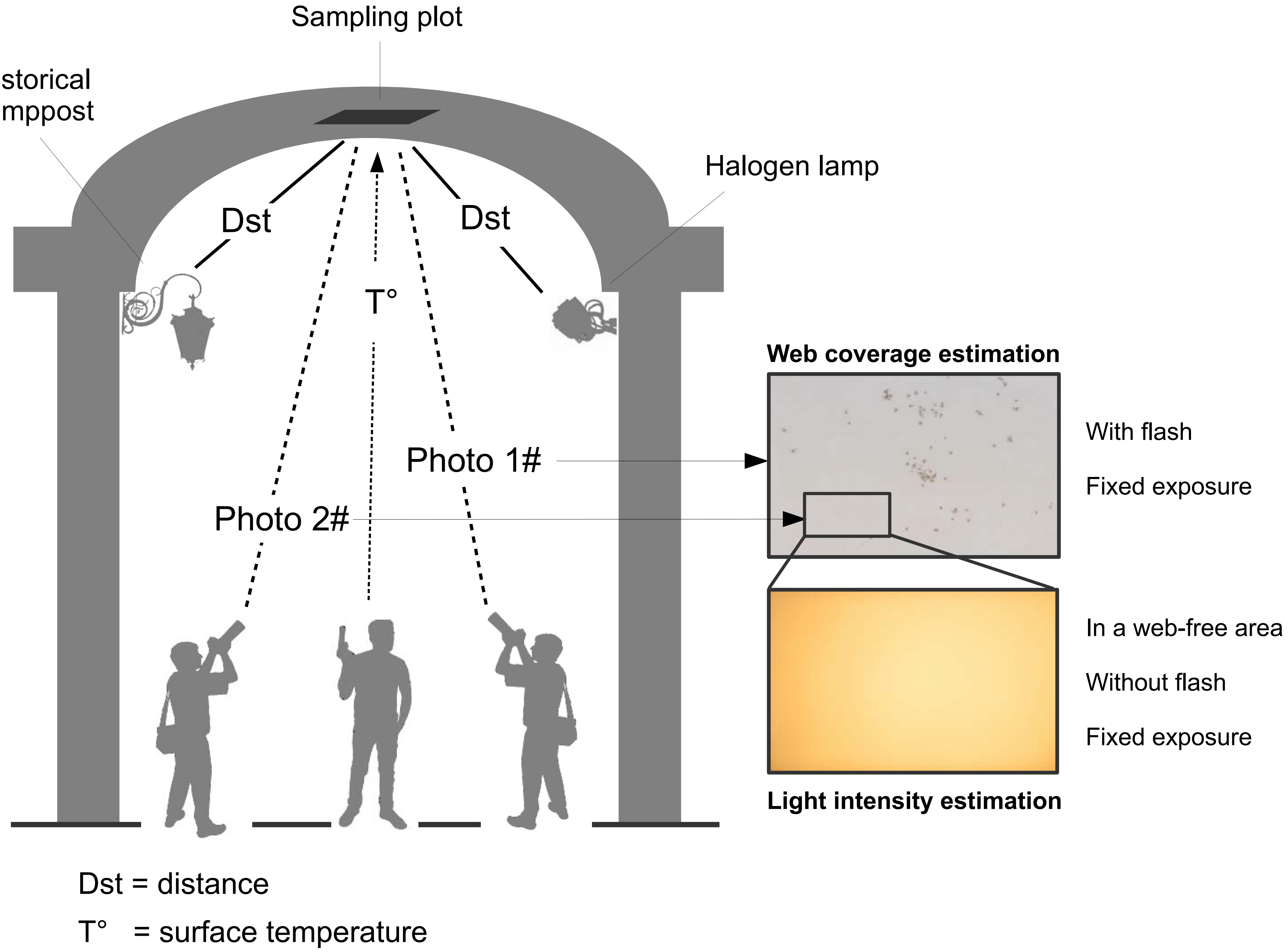

Sampling plot
Historical lamppost
Halogen lamp
Dst
Dst
T°
Photo 1#
Photo 2#
Web coverage estimation
With flash
Fixed exposure
In a web-free area
Without flash
Fixed exposure
Light intensity estimation
Dst = distance
T° = surface temperature

Figure 3

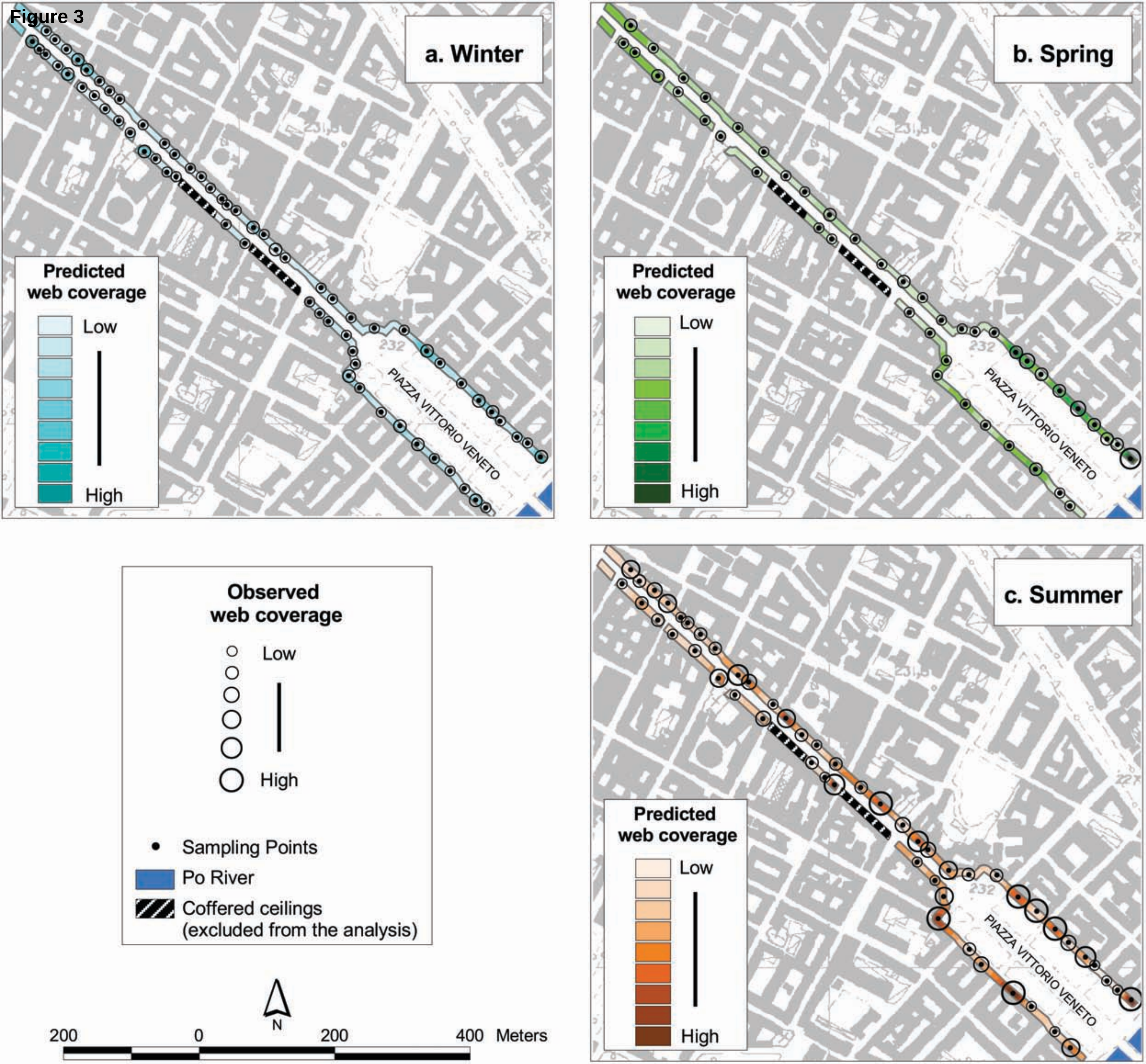
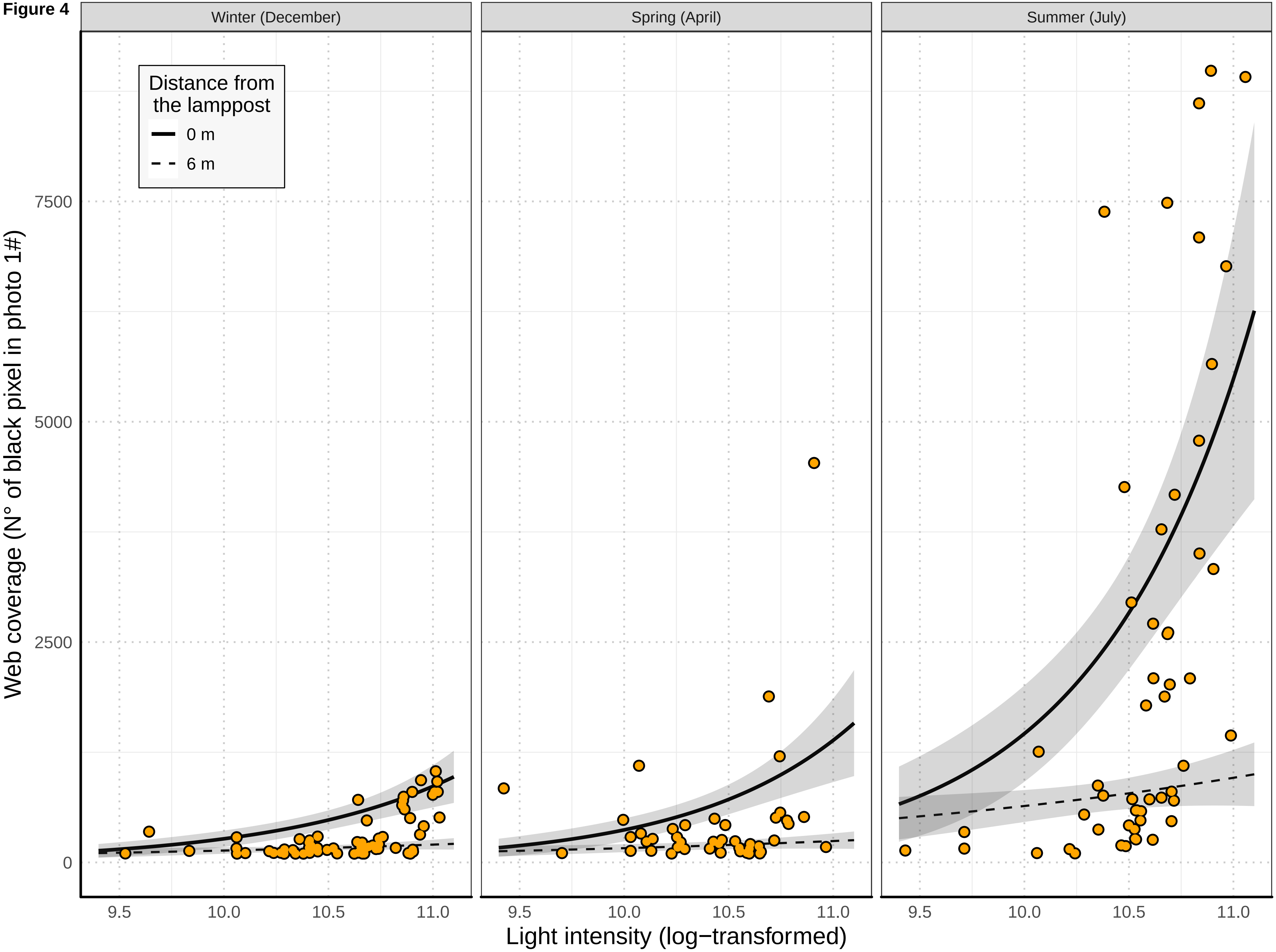
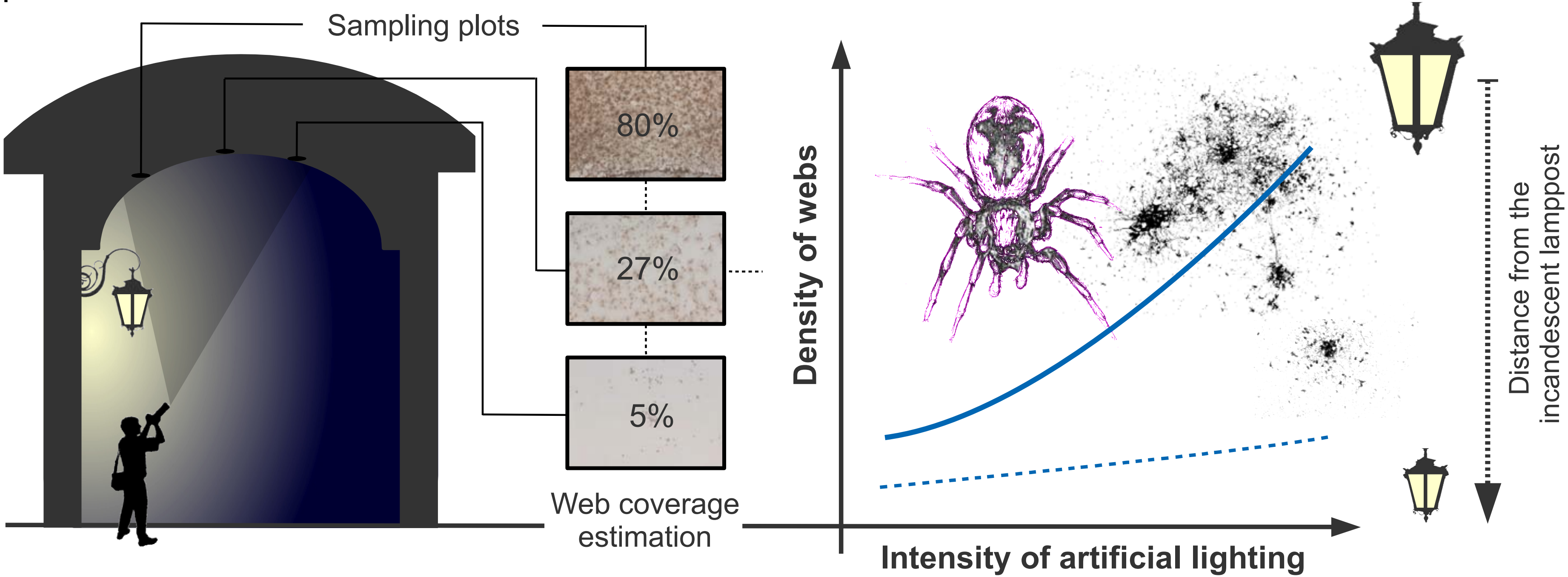

a. Winter
b. Spring
c. Summer
Predicted web coverage
Low
High
PIAZZA VITTORIO VENETO
232
231
227
Observed web coverage
Low
High
Sampling Points
Po River
Coffered ceilings (excluded from the analysis)
N
200
0
200
400
Meters

Figure 4


Winter (December)
Spring (April)
Summer (July)
Distance from the lamppost
0 m
6 m
7500
5000
2500
0
9.5
10.0
10.5
11.0
Web coverage (N° of black pixel in photo 1#)
Light intensity (log−transformed)

Graphical Abstract



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