



HAL
open science

Similarity between natural and artificial lights: weighting by the vision of three species of Heterocera

Marie-Pia Marchant, Pascal Dupuis, Georges Zissis, Luc Legal

► To cite this version:

Marie-Pia Marchant, Pascal Dupuis, Georges Zissis, Luc Legal. Similarity between natural and artificial lights: weighting by the vision of three species of Heterocera. IEEE Sustainable Smart Lighting World Conference (LS:24), IEEE Smart Cities Technical Community & Technical University of Eindhoven, Nov 2024, Eindhoven, Netherlands. hal-04874247

HAL Id: hal-04874247

<https://hal.science/hal-04874247v1>

Submitted on 8 Jan 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

Similarity between natural and artificial lights: weighting by the vision of three species of Heterocera

Marie-Pia Marchant*, Pascal Dupuis*, *Senior Member, IEEE*, Sarah Jeangeorges*, Georges Zissis*, *Fellow, IEEE*, Luc Legal†

*LAPLACE, Université de Toulouse, CNRS, INPT, UPS, Toulouse, France

†Centre de recherche sur la Biodiversité et l'Environnement (CRBE), UPS, Toulouse, France

Abstract—Light pollution, a growing ecological concern, significantly impacts moths, which are crucial for pollination and biodiversity. This study compares artificial and natural light using the Daylight Similarity Index (DSI) and Moonlight Similarity Index (MSI). Spectral data from LED lamps and natural sources were weighted by the visual responses of three moth species.

Maximum similarity was found at Correlated Color Temperature (CCT) between 3 000–4 000 K, which could be perceived as the most similar to natural light by insects. The findings suggest visual perception mechanisms are related to family rather than lifestyle, recommending further research with UV-inclusive light and other light characteristics.

Index Terms—LED Lighting; ALAN; Heterocera; Tortricidae; Moth; Light pollution; Artificial light; Natural light; Visual response; Spectra

I. INTRODUCTION

Initially an astronomical concern, light pollution has become ubiquitous and increasingly impacts biodiversity, particularly insects [1], [2]. Moths (Heterocera), crucial pollinators and preys in trophic networks, are often underestimated in inventories and policy decisions [3]. In France, only 0.13 % of Heterocera species ($n > 4500$) are protected compared to 3.8 % of butterflies ($n = 263$) [4], [5].

Light pollution affects these species via phototaxis, disorientation, glare, and object recognition failures, leading to increased mortality and reproduction issues [6]. It may also help some predators to locate them more easily, but others are lucifugous and find themselves in hunting areas drained of their prey by artificial light at night (ALAN). As those moths are part of their food web, reducing their availability will impact these predators population size and, by rebound, reduce the pressure on other insects like mosquitoes.

Furthermore, moths play a crucial role in pollination, particularly for nocturnal flowering plants. By visiting flowers at night, they ensure the reproduction of species overlooked by diurnal pollinators, supporting plant diversity and ecosystem stability.

White LEDs exacerbates these effects due to insects' sensitivity to blue-rich light [7]. Furthermore, the blue spectrum tends to interact with urban pollution by Stokes shift and create a halo over cities with a broader spectrum than blue only. Urban lighting is replaced by LEDs, a more efficient technology than the High Pressure Sodium used before.

They are becoming mandatory for all kinds of artificial lighting, becoming a global concern for biodiversity because it worsens light pollution.

The "Commission Internationale de l'Éclairage", International Commission of Illumination (CIE) has devoted a committee, TC4-61, to "Artificial Lighting and its Impact on the Natural Environment". This raises some questions: can Human-centric metrics like photopic flux and CCT be used as proxies to infer the influence of light sources on insects ? How effective are recommendations made on the basis of the Human diurnal visual system ?

The higher blue light sensitivity of insects should correlate with a greater attraction towards higher CCT spectra.

This article, part of a thesis, quantifies light pollution's impact on insects, focusing on how some moth species differentiate between artificial and natural light. The findings presented here, taking into account the insect visual response, indicate that the similarity between artificial and natural lights presents a maximum with increasing CCT, then tends to decrease above a threshold of 4 000 K.

II. METHODS

We collected a total of 205 spectra from LED lamps [8], [9]. Additionally, we included spectra of natural light sources such as D65 (6500 K) and a full moon spectrum (4500 K) [10].

Visual responses of insects were also incorporated, obtained by electroretinography, particularly those of three species: *Cydia pomonella*, active mainly during twilight; *Grapholita molesta*, flying in the middle of the night; and *Lobesia botrana*, almost strictly crepuscular [11]. There are illustrated in Fig. 1.



Figure 1: Pictures of the three species of interest. From left to right : *Cydia pomonella*, *Grapholita molesta*, *Lobesia botrana*. Pictures by Lionel Taurand et Philippe Mothiron.

All belong to the Tortricidae family (Lepidoptera – butterflies), sharing a very close genome. The human visual response

was also used. Spectra and visual responses were normalized with respect to their maximal value and are displayed in Fig. 2 for the action spectra, Fig. 3 for the lamps, while natural sources spectra are in Fig. 4.

We computed the Daylight Similarity Index (DSI) and the Moonlight Similarity Index (MSI) between artificial and natural light sources. These indices compare the spectral curves of the lamps - $SPD_n(\lambda)$ - with those of D65 - $SPD_{D65}(\lambda)$ - and the lunar spectrum - $SPD_{Moon}(\lambda)$ - respectively. Initially, we compared the spectral curves of artificial lights directly with those of natural lights. Subsequently, this comparison was conducted by weighting the spectra according to the visual response - $A(\lambda)$ - of *C. pomonella*, *G. molesta*, *L. botrana*, and finally by the visual response of *H. sapiens* - $V(\lambda)$. Lamps were sorted by Correlated Color Temperature (CCT). The action spectra are illustrated in Fig. 2: the lamp spectra in Fig. 3; and the natural sources in Fig. 4.

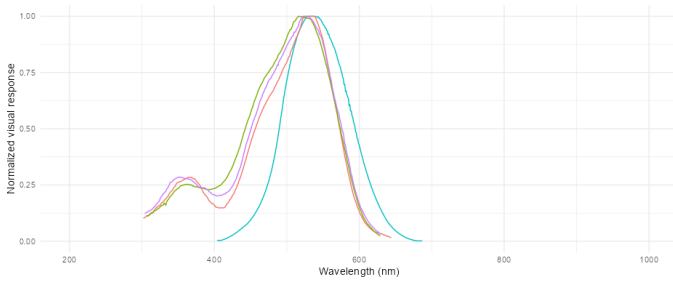


Figure 2: Three moth species and human visual responses, data from [11]. Green: *C. pomonella*; orange: *G. molesta*; purple: *L. botrana*; blue: *Homo sapiens* $V(\lambda)$.

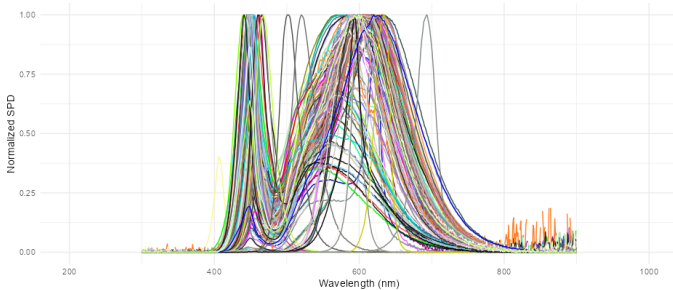


Figure 3: Normalized Spectra of the LED lights used in this study, $n = 205$.

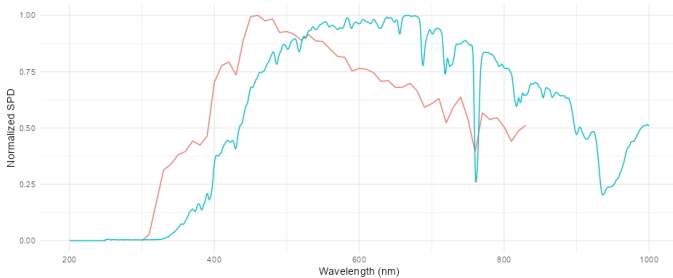


Figure 4: Normalized natural light spectra. Red: CIE D65 standard; blue: full moon spectra with data from [10].

The similarities indexes are defined as follows:

$$DSI = \frac{\int_0^{\infty} SPD_n(\lambda) A(\lambda) d\lambda}{\int_0^{\infty} SPD_{D65}(\lambda) A(\lambda) d\lambda}$$

$$MSI = \frac{\int_0^{\infty} SPD_n(\lambda) A(\lambda) d\lambda}{\int_0^{\infty} SPD_{Moon}(\lambda) A(\lambda) d\lambda}$$

Both a raw index (without spectral weighting) and a specific index (weighted by the action spectrum) were computed. The former is species agnostic; the later tries to define a photometry linked to a species.

III. RESULTS

The maximum similarity between natural and artificial light (in grey in Fig. 5) is observed for lamps with a CCT between 3 500 K and 4 000 K for both the MSI and the DSI. This trend is consistent across all visual responses analyzed: Human vision (blue), *Cydia pomonella* (green), *Grapholita molesta* (orange), and *Lobesia botrana* (purple). This peak is then followed by a decrease in similarity with increasing CCT.

For the Heterocera species, the p-value across the three species is not significant within each CCT category (DSI: p-min = 0.01 for one category, but others > 0.15 (Fig. 5b) ; MSI: p-min = 0.17 (Fig. 5a). It means they have comparable results. The two crepuscular species show a slight shift towards the human visual response, indicating a trend towards diurnal vision, though this is not significant.

Certain CCT categories do not show significant differences; however, they are either adjacent or symmetrical with respect to the point of maximum similarity.

IV. DISCUSSIONS

A. Interpretation of results

As the correlated color temperature (CCT) increases, the similarity between artificial light spectra the natural light increases, also when it is weighted by the action spectrum of moths (Fig. 5). This suggests that at higher CCT values, insects may be more likely to perceive artificial light as similar to natural light.

However, this trend is not linear; there is a peak at 3 500–4 000 K, beyond which the similarity decreases (Fig. 5). This pattern is consistent regardless of whether the MSI or DSI indices were calculated with or without weighting by the visual responses of the moths or human. Indeed, the spectra become increasingly dissimilar at CCT values above 4 000 K, which could suggest that when the CCT is too high, the resulting spectrum is less perceptible to moths. Consequently, this may lead to a reduced positive phototaxis.

Something to notice is the absence of significant differences in the results between the *C. pomonella*, *G. molesta* and *L. botrana*, although they exhibit different activity periods - dusk, night-time, or in between (Fig. 5). This indicate a vision mechanism related to family rather than lifestyle, in accordance to the conclusions of Martin *et al.* (2023) [11]. However, the two crepuscular species showed a slight shift towards a diurnal vision pattern, albeit not significantly. If this trend is confirmed across multiple species, this would mean that generalizing

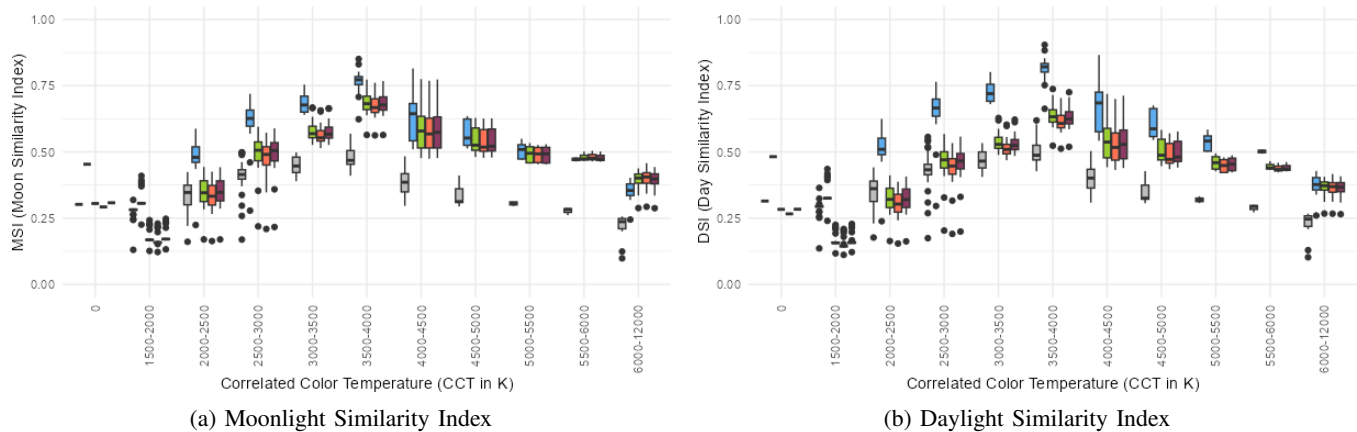


Figure 5: Results computed over $n = 193$ lamps. MSI (a) and DSI (b) are first computed with only the spectra of the natural and artificial light (grey). The indices are then weighted by the visual responses of the three moths (green for *C.pomonella*, orange for *G.molesta* and purple for *L.botrana*), and also by the human visual response (blue). Artificial lights are categorized by correlated color temperature (CCT) with a step of 500 K.

modelization of attractive light characteristics to all moths, and then why not to all nocturnal species, would be much easier than expected. Indeed, it would be possible to work on a single species representing its family. For Heterocera, this is not insignificant, because, in France, there are more than 4750 species of moths for only about twenty families.

B. Comparison with previous work

In a previous analysis within the same team, the use of a similarity coefficient had also allowed to conclude to the presence of a maximum of similarity, after which the CCT would be too strong for the insect to which the visual response belonged to be able to see and interact with this artificial light. By comparing the spectra of artificial lights with the spectra of insect visual responses, the maximum of similarity had been reached for 6 000 K.

The difference in the peak values for the similarity coefficient and the MSI & DSI could be explained by several reasons:

- With fewer high CCT lamps in our calculations, the observed peak in MSI & DSI could be shifted to lower values simply due to the distribution of the available spectra. The lamp spectra database in this previous work was less complete, but therefore different from the one used. This must be a point of vigilance, to be analyzed and resolved. ;
- The similarity coefficient is a direct comparison between the action spectrum of the insect and the spectrum of the lamp. However, for the MSI & DSI indices, the action spectra (or visual responses) are used for weighting, they act as a filter;
- The species used to calculate these different indices are not the same. For the similarity coefficient, the visual responses of many insects were tested; nocturnal and/or crepuscular insects like *Paysandia archon* (Castniidae, Heterocera), *Atalophlebia sp.* (Leptophlebiidae, Ephemeroptera), *Aleochara bilineata* (Staphylinidae, Coleoptera), or *Delia antiqua* (Anthomyiidae, Diptera).

But diurnal species were also considered as they were easily found in the bibliography: *Apis mellifera carnica* (Apidae, Hymenoptera), *Bombus dahlbomii* (Apidae, Hymenoptera), and *Aedes aegypti* (Culicidae, Diptera).

Since the results were all around 6 000–6 500 K for all insects for the similarity coefficient, we expected to find a similar result with DSI and MSI as well. It would be worth testing the species each with the indices tested on the others.

C. Light Emitting Diode (LED)

From the 205 LEDs lamps of our database, 196 were used for the calculation of MSI and DSI. The main rejection reason was because the considered lights were monochromatic with no associated CCT, for instance green or amber.

Only LED lights were used, underlying the practical purpose intended for the conclusions of this study and the thesis associated. In fact, artificial lights are increasingly being replaced by LEDs. Nevertheless, taking into account High Pressure Sodium (HPS) and mercury vapor bulb lights in our study is important. On the one hand, HPS is the artificial light that was widely used before being replaced by LED and it attracts moths less [12]; on the other hand, entomological surveys and inventories of moths were often performed using mercury vapor lights, which proved to be quite attractive for them.

D. Correlated Color Temperature

One might think that using CCT causes a loss of information. This assertion is true because CCT can gather several lights that do not have the same composition and spectral power. However, this is not the case in this study as CCT is a tool for sorting lamps, the spectral information is absolutely not lost.

Another important point is that this measure is based on the sensitivities of the cones of the human retina, which determine our color vision. It therefore does not seem relevant to use it for insects. However, this tool is very useful because it

seems to reflect a biological reaction of insects facing light, via the characteristic peak in the blue of the LED spectrum, and the amount of blue in the spectral composition. Finally, as seen at the beginning of the discussion, CCT plays a role in the similarity between light sources, which is an interesting indicator.

In addition, the criterion of color temperature is often associated with the spectrum of a lamp, or at least easily calculable. It must also be taken into account that it is a sales and legislative standard, which allows us to have an impact on it and to easily communicate good practices using this index.

E. Other characteristics of light

Taking into account other light characteristics is one of the next steps in this work and is of capital importance. Indeed, the intensity, the degree of polarization and the flicker of a lamp have impacts on insects [13] [14] [15].

Lamp radiometric flux in W should also be included in the spectra information to make it possible to test if it may possibly change the perception of insects.

In addition, it was demonstrated that a lot of species are able to perceive light polarization. In natural conditions, this occurs in two cases: the blue light from the sky is polarized by Raman scattering; and the reflection on surfaces like water, but also glasses. Insects use those phenomena to navigate, such as honeybees, but also to detect water surfaces and lay eggs. It is the case of the mayflies (Ephemeroptera) which reach the adult form only to reproduce. Females spot the polarized light from water and can leave a new generation of eggs, some of which will become aquatic larvae, then flying adults. The problem for these species is to differentiate polarized light from water or from smooth asphalt. Confusion is common, and females die of exhaustion without having been able to lay eggs in a suitable location [15].

Finally, some insect species can perceive light fluctuations that are imperceptible to the human eye. They can perceive lamp flickers at higher frequencies than the human eye, *i.e.* more than 50–60 Hz [14].

V. CONCLUSION

The similarity between artificial light and natural light, perceived by moths, reaches a maximum for color temperatures between 3,500 and 4,000 K. Beyond this threshold, the similarity decreases, suggesting that too high CCT values could make artificial light less perceptible to insects. Experiments are planned to validate the results.

The results also reveal that the visual response of the studied species is more influenced by their family affiliation than by their lifestyle. These results open the way to a more general modeling of the light characteristics impacting nocturnal species, and underline the importance of continuing research on the impact of different light sources on insects, in particular by including broader light spectra, including UV, and other light characteristics.

CCT (Correlated Color Temperature) is a key parameter to characterize artificial light, influencing the behaviors of nocturnal insects. In the context of this paper, it allows to evaluate

how different color temperatures affect the attractiveness of light for moths and other light-sensitive species, even if CCT is a measure related to human vision.

The long-term goal is to be able to model artificial lights that have the least impact on insects, depending on the species present. However, it is obvious that the struggle against light pollution begins with the extinction of as many artificial lights as possible.

ACKNOWLEDGEMENTS

The authors acknowledge partial support for this work from the French Agence Nationale de la Recherche (ANR) project LUNNE (ANR-22-CE22-0004-05) and the French Agence de la Transition écologique (ADEME) project LightBlob.

REFERENCES

- [1] K. W. Riegel, "Light pollution," *Science*, vol. 179, pp. 1285–1291, 3 1973.
- [2] G. Eisenbeis, C. Rich, and T. Longcore, "Artificial night lighting and insects: attraction of insects to streetlamps in a rural setting in Germany," *Ecological consequences of artificial night lighting*, vol. 2, pp. 191–198, 2006.
- [3] R. E. Walton, C. D. Sayer, H. Bennion, and J. C. Axmacher, "Nocturnal pollinators strongly contribute to pollen transport of wild flowers in an agricultural landscape," *Biology Letters*, vol. 16, p. 20190877, 5 2020.
- [4] "Arrêté du 23 avril 2007 fixant les listes des insectes protégés sur l'ensemble du territoire et les modalités de leur protection," <https://www.legifrance.gouv.fr/loda/id/JORFTEXT000000465500>, Accessed: Nov 28, 2024.
- [5] "Free and open access to biodiversity data," <https://www.gbif.org/>, Accessed: Nov 28, 2024.
- [6] A. C. S. Owens and S. M. Lewis, "The impact of artificial light at night on nocturnal insects: A review and synthesis," *Ecology and Evolution*, vol. 8, pp. 11 337–11 358, 11 2018.
- [7] J. L. Deichmann, C. A. Gatty, J. M. A. Navarro, A. Alonso, R. Linares-Palomino, and T. Longcore, "Reducing the blue spectrum of artificial light at night minimises insect attraction in a tropical lowland forest," *Insect Conservation and Diversity*, vol. 14, pp. 247–259, 3 2021.
- [8] "LSPPD," <https://lspdd.org/database>, Accessed: Nov 28, 2024.
- [9] C. E. Tapia Ayuga, A. Sanchez de Miguel, and J. Calvo, "LICA-UCM lamps spectral database 1.6," https://guaix.fis.ucm.es/lamps_spectra, 2015. Accessed: Nov 28, 2024.
- [10] M. van der Steen, "Spectrum of moon light," <https://olino.org/blog/us/articles/2015/10/05/spectrum-of-moon-light/>, 2015. Accessed: Nov 28, 2024.
- [11] A. Martín-Gabarrella, C. Gemeno, and G. Belušič, "Spectral sensitivity of retinal photoreceptors of tortricid moths is not tuned to diel activity period," *Journal of Experimental Biology*, vol. 226, 8 2023.
- [12] S. Pawson and M. Bader, "LED lighting increases the ecological impact of light pollution irrespective of color temperature," vol. 24, pp. 1561–1568.
- [13] A. Hakami, K. A. Khan, H. A. Ghramh, Z. Ahmad, and A. A. A. Al-Zayd, "Impact of artificial light intensity on nocturnal insect diversity in urban and rural areas of the asir province, Saudi Arabia," *PLoS ONE*, vol. 15, 12 2020.
- [14] R. Inger, J. Bennie, T. W. Davies, and K. J. Gaston, "Potential biological and ecological effects of flickering artificial light," *PLoS ONE*, vol. 9, p. e98631, 5 2014.
- [15] G. Horváth, G. Kriska, P. Malik, and B. Robertson, "Polarized light pollution: a new kind of ecological photopollution," *Frontiers in Ecology and the Environment*, vol. 7, p. 317, 2009.