

TECHNICAL NOTE OPEN ACCESS

# How Much Does Light Pollution Alter Vector Disease Transmission at Scale?

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## ABSTRACT

Artificial light at night (ALAN) is increasingly recognised as a global change driver due to its widespread use and ecological impacts. ALAN influences mosquitoes under laboratory conditions, altering the biting propensity of diurnal *Aedes* mosquitoes while suppressing that of nocturnal *Anopheles* species complexes, the primary malaria vectors in Africa. This study models ALAN's effects on mosquito vectorial capacity using the R package AnophelesModel, incorporating lab and field data on mosquito biting behaviour and light sources. Findings suggest ALAN may influence malaria transmission dynamics, underscoring the need for further investigation at household and larger ecological scales. However, small reductions in biting propensity alone mean ALAN has a smaller impact compared to other interventions.

## 1 | Introduction

It is now apparent that artificial light at night (ALAN) must be considered a global change driver (Davies and Smyth 2018) because of its spatial extent (Kyba et al. 2023), the severity of its impacts across the biological hierarchy (Sanders et al. 2021) and its increasing use (Giavi et al. 2020; Sánchez de Miguel et al. 2021).

At least in the laboratory, artificial light at night directly alters aspects of mosquito biology. This is because artificial light can increase the biting propensity of diurnal genera like *Aedes* mosquitoes (Rund et al. 2020). In contrast, ALAN may suppress the biting propensity of nocturnal feeders like *Anopheles* mosquitoes (Sheppard et al. 2017; van Zyl et al. 2024), which is the primary vector for malaria globally. Even dim ALAN causes female *Culex pipiens f. molestus* mosquitoes to avert diapause and become reproductively active earlier, suggesting that mosquitoes in light-polluted areas may be more actively biting for longer (Fyie et al. 2021). Exposure to artificial nighttime lighting alters the infectivity of the mature stage of *Plasmodium falciparum* gametocytes in the mosquito vector *Anopheles stephensi* (Llargo

et al. 2023). In both urban and rural populations of *Aedes albopictus*, ALAN can reduce photoperiodically induced diapause (Westby and Medley 2020), while it increases viral competence in West Nile virus (Kernbach et al. 2019). Mosquitoes exhibit a wide range of behaviours, physiological processes and biochemical activities that follow a 24-h daily rhythm. Monitoring their locomotor activity is a powerful tool for assessing the internal circadian clock and is closely linked to behaviours such as flight, swarming and host-seeking. These 24-h rhythms result from the integration of internal circadian signals with external cues from the light–dark cycle. Notably, around 20% of the mosquito transcriptome is regulated in a rhythmic 24-h pattern. Furthermore, light-based cues significantly influence their circadian biting rhythms, which has important implications for the transmission of diseases (Duffield 2024). Taken together, this implies that a more comprehensive understanding of how mosquitoes perceive light, respond to light, and whether attracted or repelled, would allow for more efficient vector sampling as well as potentially limiting the risk posed by domestic lighting to vector disease transmission (Coetzee et al. 2022, 2023; Fabian et al. 2024; Wilson et al. 2021).

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While the potential for disruptions to mosquito biology is now demonstrated in the laboratory, how such alterations play out at household and larger scales, and what that means for reductions in vectorial capacity, remains to be demonstrated and tested. Here, to test how artificial light use may alter malaria transfer, we incorporate published lab data on mosquito biting propensity (van Zyl et al. 2024), with unpublished data on actual artificial light use from exemplar study sites in South Africa, Uganda and Mozambique (van Zyl 2025), into a state transition model depicting the mosquito life cycle (Golumbeanu et al. 2023). We predict that, in general, artificial light use will reduce biting propensity, and that the reduction in biting propensity will significantly reduce the transfer of malaria.

## 2 | Materials and Methods

### 2.1 | Parameterisation—Biological Data

Firstly, we obtained biting propensity data in a laboratory setting (van Zyl et al. 2024). In short, the study investigated whether exposure to commonly used household lighting, namely compact fluorescent lights (CFLs), light-emitting diodes (LEDs) and incandescent bulbs, affected the feeding behaviour of *Anopheles funestus* mosquitoes. Mated, unfed female mosquitoes were subjected to a 30-min pulse of one of the three light types at the onset of darkness, each within separate experimental containers. Following this exposure, a blood-feeding assay was conducted. Compared to the control group, all three light treatments led to a decreased proportion of females taking a blood meal. For full methods, see van Zyl et al. (2024). Further details on the experimental protocol can be found in the [Supporting Information](#).

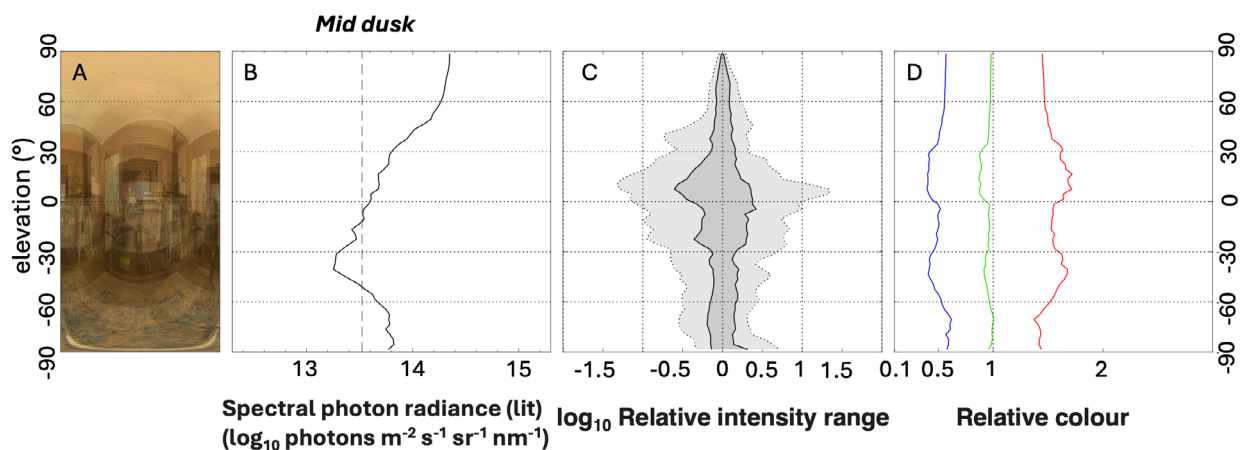
### 2.2 | Parameterisation—Artificial Light Data

To obtain data on artificial light use at the household scale at different exemplar study sites across Africa, we obtained data from van Zyl (2025) (full details in [Supporting Information](#)).

In short, the study employed the recently developed Environmental Light Field (ELF) method to characterise the artificial light environment within households in rural settlements across South Africa, Uganda and Mozambique. The ELF method, recently introduced by Nilsson and Smolka (2021), employs a calibrated digital camera sensor to quantify the radiance perceived by an observer at a specific point within an environment. The spectral sensitivity ranges of the red (600–700 nm), green (500–600 nm) and blue (400–500 nm) channels of standard RGB camera sensors closely align with those of animal visual systems, thereby rendering them well suited for capturing light conditions in a manner analogous to animal vision (Nilsson and Smolka 2021).

ELF can be used to take photographs from various positions in an environment, and is then used to construct three graphs (Figure 1) that describe the light environment. As light sources are mostly found above the horizontal plane, light can be expected to vary with elevation angle. Therefore, the change in spectral photon radiance (or absolute light intensity) in relation to the elevation angle, as shown in Figure 1B, is determined. Light within an elevation angle is variable and comprises an array of radiances. The median radiance is used in Figure 1B as this is less likely to be highly affected by single bright light sources, and a range of radiances is then calculated for each elevation gradient, as shown in Figure 1C. This range is important as it is related to visual contrasts within the environment and influences the visual perception of the light environment. Figure 1D describes the spectral composition of the light environment at the different elevation angles by showing the relative contributions of the red, green and blue spectral channels.

We note that the ELF system does not measure UV light, which is a key component of insect vision, but that most household lighting does not contain much UV, and our focus here is rather on light intensity. Given the potential influence of artificial lighting on exposure to vector-borne diseases such as malaria, understanding these light environments is critical for assessing associated health risks.



**FIGURE 1** | Environmental light field (ELF) chart of an environment, showing the vertical light gradients of the light environment. To characterise this environment images were taken from four different positions. (A) Average image of the environment consisting of the images taken from all positions. The graphs show elevation angle versus (B) intensity (absolute log scale), (C) the intensity range (relative log scale), (D) the contribution of the red, green and blue spectral channels (relative log scale) to the spectral composition of the light environment.

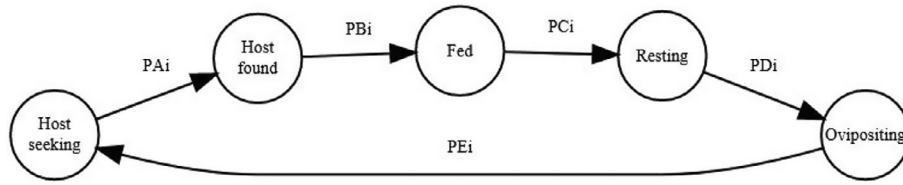


FIGURE 2 | General model workflow.

### 2.3 | Model Overview

The AnophelesModel package facilitates the parameterisation of a mosquito feeding cycle model by incorporating data on mosquito bionomics, biting patterns, human activity, and intervention effects. Extracted from field studies, the package includes various types of data. It integrates real-world entomological data on feeding, host seeking, resting and oviposition rates to refine models for evaluating intervention impacts based on actual species and location-specific characteristics. The model assesses the species-specific effects of vector control interventions on vectorial capacity, allowing comparison across mosquito species and the generation of parameterisations for entomological and vector control components in more intricate models of malaria transmission dynamics. Full methods can be found here <https://swisstph.github.io/AnophelesModel/articles/AnophelesModel.html> and preprint (Golumbeanu et al. 2023).

Built upon a state transition model from (Chitnis et al. 2008), the AnophelesModel package employs three difference equations to describe the dynamics of not infected, infected and infective mosquitoes in a population biting hosts. The transitions within the feeding cycle are represented by probabilities, including host seeking, host found, feeding, resting, ovipositing and egg development. By estimating the probable reduction of biting propensity, here as a consequence of measured reductions due to artificial light, one can alter the  $P_{Bi}$  parameter, or the probability ( $P$ ) that a mosquito bites ( $B$ ) a host of type  $I$ , after encountering a host of type  $i$ .  $0 < P_{Bi} < 1$  (Chitnis et al. 2008). The model depicts how a range of lights at different intensities may reduce biting propensity. We here thus alter  $P_{Bi}$  to reflect the consequence of measured reductions in biting propensity due to artificial light. The model thus can estimate how a range of lights at different intensities may reduce biting vectorial capacity.

These probabilities, depicted as arrows in Figure 2, are influenced by mosquito ecology, human behaviour, and interventions. The documentation outlines various use cases with examples, starting with a general analysis workflow. It covers the package database, data objects and provides detailed examples of using package functions. Users can learn how to parameterise the embedded entomological model, assess the impact of vector control interventions across mosquito species and locations and format inputs for downstream analyses with the OpenMalaria individual-based model of malaria transmission dynamics (Smith et al. 2006). The outputs generated allow for a direct comparison not only with existing interventions of the model but also with incorporating new intervention effects.

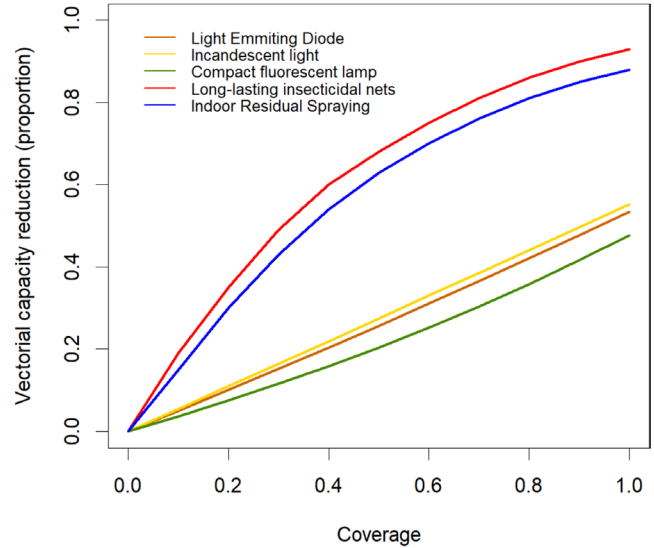


FIGURE 3 | Modelled reduction in vectorial capacity of three kinds of artificial lights used in households, compared to existing interventions, using real-world data in the AnophelesModel package (Golumbeanu et al. 2023), for *Anopheles funestus*.

## 3 | Results and Discussion

The model outputs (Figure 3) show that the use of artificial light only shows modest reductions in vectorial capacity when considering only the biting rate in *Anopheles funestus*, compared to more well-known interventions in real-world systems, like indoor residual spraying (IRS) and Long Lasting Insecticidal Nets (LLINs). The different proportions and curves between traditional techniques, like IRS and LLINs, and that of artificial light, mean that, despite a reduction in biting rates, even under total coverage, there is little overall reduction in feeding. This is because (i) unlike other interventions, ALAN only reduces biting rates and does not kill the mosquitoes and (ii) the use of ALAN may only serve to delay the onset of feeding. This means that changes in biting propensity alone may have a smaller impact than one would hope for, and claims that ALAN itself is a panacea for vector control must be vetted. We note that while the model is built on real data, it is exploratory, and indicative of broad trends, with room for improvement. For instance, it only explores one dimension of a biological impact, the reduction of biting, but new work supports the idea that ALAN can not only influence mosquito biting behaviour but also reduce the parasite success in the mosquito midgut (Llergo et al. 2023). What is more, the impact of ALAN on disease vector transmission varies depending on the specific

vector, geographic variations in both host and disease, and environmental conditions, complicating the generality of research to date, as it does the model.

The key remaining scientific questions to further understand how ALAN may alter vector disease transfer relate to further elucidating the mechanistic influence of artificial light on mosquitoes, how it may interact with other global change drivers at different spatial scales, and how it interacts with other vector control strategies. Only field trials will ultimately demonstrate the impact of light on vector-disease transfer, given the difficulties with scaling the impacts documented in the lab into real-world and complex socio-ecological systems (for a review see Coetzee et al. 2023). Given the projected impacts of other global change drivers on the increase in vector borne disease (i.e., Caminade et al. 2014), how much artificial light may alter vector disease transmission and act as a synergetic or antagonistic additional driver at larger spatial scales remains a pressing question.

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### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

All data are available from the authors upon request.

### References

Caminade, C., S. Kovats, J. Rocklov, et al. 2014. "Impact of Climate Change on Global Malaria Distribution." *Proceedings of the National Academy of Sciences* 111, no. 9: 3286–3291. <https://doi.org/10.1073/pnas.1302089111>.

Chitnis, N., T. Smith, and R. Steketee. 2008. "A Mathematical Model for the Dynamics of Malaria in Mosquitoes Feeding on a Heterogeneous Host Population." *Journal of Biological Dynamics* 2, no. 3: 259–285. <https://doi.org/10.1080/17513750701769857>.

Coetzee, B. W. T., A. M. Burke, L. L. Koekemoer, M. P. Robertson, and I. P. J. Smit. 2023. "Scaling Artificial Light at Night and Disease Vector Interactions Into Socio-Ecological Systems: A Conceptual Appraisal." *Philosophical Transactions of the Royal Society, B: Biological Sciences* 378, no. 1892: 20220371. <https://doi.org/10.1098/rstb.2022.0371>.

Coetzee, B. W. T., K. J. Gaston, L. L. Koekemoer, T. Kruger, M. A. Riddin, and I. P. J. Smit. 2022. "Artificial Light as a Modulator of Mosquito-Borne Disease Risk." *Frontiers in Ecology and Evolution* 9: 768090. <https://doi.org/10.3389/fevo.2021.768090>.

Davies, T. W., and T. Smyth. 2018. "Why Artificial Light at Night Should Be a Focus for Global Change Research in the 21st Century." *Global Change Biology* 24, no. 3: 872–882. <https://doi.org/10.1111/gcb.13927>.

Duffield, G. E. 2024. "Circadian and Daily Rhythms of Disease Vector Mosquitoes." *Current Opinion in Insect Science* 63: 101179. <https://doi.org/10.1016/j.cois.2024.101179>.

Fabian, S. T., Y. Sondhi, P. E. Allen, J. C. Theobald, and H.-T. Lin. 2024. "Why Flying Insects Gather at Artificial Light." *Nature Communications* 15, no. 1: 689. <https://doi.org/10.1038/s41467-024-44785-3>.

Fyie, L. R., M. M. Gardiner, and M. E. Meuti. 2021. "Artificial Light at Night Alters the Seasonal Responses of Biting Mosquitoes." *Journal of Insect Physiology* 129: 104194. <https://doi.org/10.1016/j.jinphys.2021.104194>.

Giavi, S., S. Blösch, G. Schuster, and E. Knop. 2020. "Artificial Light at Night Can Modify Ecosystem Functioning Beyond the Lit Area." *Scientific Reports* 10, no. 1: 11870. <https://doi.org/10.1038/s41598-020-68667-y>.

Golumbeanu, M., O. Briët, C. Champagne, et al. 2023. "AnophelesModel: An R Package to Interface Mosquito Bionomics, Human Exposure and Intervention Effects With Models of Malaria Intervention Impact." *Ecology* 20, no. 9: e1011609. <https://doi.org/10.1101/2023.10.17.562838>.

Kernbach, M. E., D. J. Newhouse, J. M. Miller, et al. 2019. "Light Pollution Increases West Nile Virus Competence of a Ubiquitous Passerine Reservoir Species." *Proceedings of the Royal Society B: Biological Sciences* 286, no. 1907: 20191051. <https://doi.org/10.1098/rspb.2019.1051>.

Kyba, C. C. M., Y. Ö. Altıntaş, C. E. Walker, and M. Newhouse. 2023. "Citizen Scientists Report Global Rapid Reductions in the Visibility of Stars From 2011 to 2022." *Science* 379, no. 6629: 265–268. <https://doi.org/10.1126/science.abq7781>.

Llargo, J. L., H. Garuti, C. Lopez, J. Sanchez, and D. Calvo. 2023. "Artificial Nighttime Lighting Impacts Plasmodium Falciparum Mature Stage V Gametocytes Infectivity in Anopheles Stephensi." *Malaria Journal* 23, no. 1: 42. <https://doi.org/10.21203/rs.3.rs-3647933/v1>.

Nilsson, D.-E., and J. Smolka. 2021. "Quantifying Biologically Essential Aspects of Environmental Light." *Journal of the Royal Society Interface* 18: 20210184. <https://doi.org/10.1098/rsif.2021.0184>.

Rund, S. S. C., L. F. Labb, O. M. Benefiel, and G. E. Duffield. 2020. "Artificial Light at Night Increases Aedes aegypti Mosquito Biting Behavior With Implications for Arboviral Disease Transmission." *American Journal of Tropical Medicine and Hygiene* 103, no. 6: 2450–2452. <https://doi.org/10.4269/ajtmh.20-0885>.

Sánchez de Miguel, A., J. Bennie, E. Rosenfeld, S. Dzurjak, and K. J. Gaston. 2021. "First Estimation of Global Trends in Nocturnal Power Emissions Reveals Acceleration of Light Pollution." *Remote Sensing* 13, no. 16: 3311. <https://doi.org/10.3390/rs13163311>.

Sanders, D., E. Frago, R. Kehoe, C. Patterson, and K. J. Gaston. 2021. "A Meta-Analysis of Biological Impacts of Artificial Light at Night." *Nature Ecology & Evolution* 5, no. 1: 74–81. <https://doi.org/10.1038/s41559-020-01322-x>.

Sheppard, A. D., S. S. C. Rund, G. F. George, E. Clark, D. J. Aciri, and G. E. Duffield. 2017. "Light Manipulation of Mosquito Behaviour: Acute and Sustained Photic Suppression of Biting Activity in the Anopheles gambiae Malaria Mosquito." *Parasites & Vectors* 10, no. 1: 255. <https://doi.org/10.1186/s13071-017-2196-3>.

Smith, T., G. F. Killeen, N. Maire, et al. 2006. "Mathematical Modeling of the Impact of Malaria Vaccines on the Clinical Epidemiology and Natural History of Plasmodium Falciparum Malaria: Overview." *American Journal of Tropical Medicine and Hygiene* 75, no. 2: 1–10. [https://doi.org/10.4269/ajtmh.2006.75.2\\_suppl.0750001](https://doi.org/10.4269/ajtmh.2006.75.2_suppl.0750001).

van Zyl, L. 2025. "Measuring Artificial Light at Night in the Field, and Its Impact on Mosquito Vector Abundances." MSc Thesis. University of Pretoria.

van Zyl, L., A. M. Burke, L. L. Koekemoer, and B. W. T. Coetzee. 2024. "Only Incandescent Light Significantly Decreases Feeding of Anopheles Funestus s.s. (Diptera: Culicidae) Mosquitoes Under Laboratory Conditions." *Parasitology Research* 123, no. 355: 1–8.

Westby, K. M., and K. A. Medley. 2020. "Cold Nights, City Lights: Artificial Light at Night Reduces Photoperiodically Induced Diapause in Urban and Rural Populations of *Aedes albopictus* (Diptera: Culicidae)." *Journal of Medical Entomology* 57, no. 6: 1694–1699. <https://doi.org/10.1093/jme/tjaa139>.

Wilson, R., A. Wakefield, N. Roberts, and G. Jones. 2021. "Artificial Light and Biting Flies: The Parallel Development of Attractive Light Traps and Unattractive Domestic Lights." *Parasites & Vectors* 14: 28. <https://doi.org/10.1186/s13071-020-04530-3>.

### **Supporting Information**

Additional supporting information can be found online in the Supporting Information section.