2023 Spring
Experimental Analysis of Light Pollution Impacts on Glow-worm and Moths Using Machine Learning and XAI

Anonymous ACL-IJCNLP submission

Abstract

There is a well-known issue with light pollution, which has negative effects on the well-being of humans, animals, and plants. One of the major consequences of this is the attraction of nocturnal insects to artificial light sources, which can be fatal to them. Glow worms and moths are two of the nocturnal insects that show a maladaptive response to artificial light. To evaluate the effects of light pollution on insects, we did an experimental analysis of the data of glow worms and moths using different machine learning and deep learning algorithm. we have also included Explainable AI to explain and interpret the models' predictions.

1 Introduction

A type of light source that is produced by humans and utilized for a number of reasons is known as artificial light. Contrary to natural light sources like the sun, artificial lights can be turned on and off at will, and their brightness and color temperature can be changed to accommodate a variety of requirements and tastes. Typical kinds of artificial lighting include halogen lamps, LEDs, fluorescent tubes, and incandescent bulbs. Artificial lights play a significant role in modern society by allowing us to work and live peacefully at all hours of the day and night. They are widely used in homes, workplaces, public spaces, and industrial settings to provide illumination for various tasks and activities.

Despite being a benefit to modern civilization, artificial light is a growing environmental issue. Light pollution, which has negative effects on the ecosystem, has been caused by the proliferation of streetlights, business buildings, and residential properties that are illuminated at all hours of the day and night. Numerous species and ecosystems are affected by light pollution, which alters the cycles of life and poses a serious danger to biodiversity. Animal existence is disrupted by light pollution, which is one of its most serious effects. The sudden appearance of artificial light can have a disruptive effect on the behavior of many species because they are adapted to survive and flourish in the dark. For instance, it's been observed that marine turtles can become confused by lights along the shoreline, leading them to stray from the ocean and risk getting trapped or hurt. Similar to nocturnal creatures, bright lights attract nocturnal creatures like bats and moths, which can make them disorientated and susceptible to predators.

Environmental harm from manufactured light is referred to as ecological light pollution. Ecological light pollution can have widespread impacts on a variety of species and ecosystems. Animal behavior modifications, changes to the rhythms of life, and effects on human health are some of the most notable effects of ecological light pollution. Animal behavior disruption is one of ecological light pollution's most important impacts. When artificial light is suddenly introduced to a species that has evolved to exist in the dark, it can have a significant effect on how they behave. Artificial light, for instance, can throw off a bird's internal navigation systems and cause it to fly off course. Birds, for instance, are known to migrate based on shifts in light patterns. Similar to nocturnal creatures, bright lights attract nocturnal creatures like bats and moths, which can make them disorientated and more susceptible to predators.

An example of a bioluminescent insect is the glow-worm, which is distinguished by its unique glow. Both the mature females and the larvae of specific species of fireflies and beetles that have the ability to emit light are referred to as "glow-worms." In addition to forests, meadows, and gardens, glow-worms can be found in a variety of habitats. They are most active at night.

The mature female glow worm has no wings and a soft, elongated body that can grow to a maximum length of 20 millimeters. The distinctive glowing abdomen of the female glow-worm, which produces a greenish-yellow light, is what makes it so well-known. In the insect's body, an enzyme called luciferase and a substance called luciferin undergo a chemical process that results in the glow. The female glow-worm uses the light to entice men for mating. It's critical to preserve and safeguard glow-worms' natural environments. Sustainable land management techniques, like agroforestry and conservation plowing, can be used to accomplish this. Additionally, the use of non-toxic pest management techniques like biological control and integrated pest management can aid in shielding populations of glow-worms from the negative impacts of pesticides.

Nighttime illumination is frequently cited as a driving cause behind dramatic moth population decreases in heavily lighted areas. It is necessary to determine if artificial light merely causes higher mortality or also has genotoxicity consequences. A study has discovered that moths spend less time consuming and searching for food in artificial night lights than they do in the dark. As a result, we want to use our model to determine how much night light affects moth foraging and habitat.

2 Literature Review

This research (Elgert et al., 2020) emphasizes how nocturnal animal behavior is being impacted by the rise of artificial nighttime lighting worldwide. However, it is not fully known how these behavioral responses affect population survival and individual fitness. The study explores whether female common glow-worms may alter the timing and position of their shining in order to reduce the detrimental effects of artificial light on mate attractiveness. The results show that females delay or abstain from shining instead of moving away from the light, which is ultimately maladaptive since it lowers their capacity to attract mates. According to the study, one reason for glow-worms' global decrease may be that they are unable to adapt to spatial variations in artificial light.The findings therefore validate the idea that animals frequently fail to adjust their behavior to environmental changes caused by humans, emphasizing the significance of taking behavioral responses into account when researching how human activities affect wildlife.

In this paper(Van den Broeck et al., 2021), everyday individual female glow-worms (Lampyris noctiluca L.) were observed in artificially lit and unlit surroundings over the course of a complete mating season, with the aim to determine whether street lighting (low pressure sodium (LPS; monochromatic orange) affects female mate-attraction success. Additionally, in order to demonstrate that any changes on mating success were induced only by ALAN and not by variations in female quality or attractiveness between locations with more or less light, they exposed field-collected and captive-raised females to various light settings. Females in dark environments tended to quit glowing after one night, signifying that they had mated, but females in lit environments glowed for noticeably longer periods of time, sometimes up to 15 nights. This research[1] supports earlier results and predictions that females exposed to artificial light have lower mate attraction success, which has a detrimental effect on populations.

The researchers (Keinath et al., 2021) conducted a study in the Berlin-Brandenburg region of Germany to examine how artificial light affects the moth species Agrotis exclamationis. They focused on traits such as body length, eye size, and forewing length, and hypothesized that increasing light pollution would lead to a decrease in these traits. The researchers used a ”light pollution map” to categorize artificial light at night (ALAN) levels at different sites and years. They analyzed moths collected over the past 137 years and found that while there were no differences in traits across different locations, there were changes over time that were dependent on sex and trait. They observed a trend of decreasing eye size in female moths in areas with higher levels of light pollution, indicating that the morphological traits of these moths are being impacted by artificial light.

A model by collecting glow worms (Bird and Parker, 2014) came to an interpretation that Artificial lights effects the ability of male glow worms to locate female glow worms (Bird and Parker, 2014). According to their study, for females, a student T test showed that the LED illumination on the canes had no impact on how long the female bioluminescence lasted. However, there was a tendency for females to stop glowing when around

Table 1: Dataset-‘Data Moth Foragin’ Attributes

Attribute Name	Attribute Explanation
Day	Date of the experiment
Block	Refers to the block design
Treatment	Lamp type (Green, White or Red) or no lamp (Dark)
Species	Four moth species
Sex	Male versus female;
unique.id	Unique id of every individual, measured over approximately 8 hours
Obs	Observation of foraging by moths every six minutes, where 1 = foraging and 0 = not foraging
Size	Size classes of moths, where 1 = large (forewing length $<$ 15mm) and 0 = small (forewing length $\geq 15mm$)

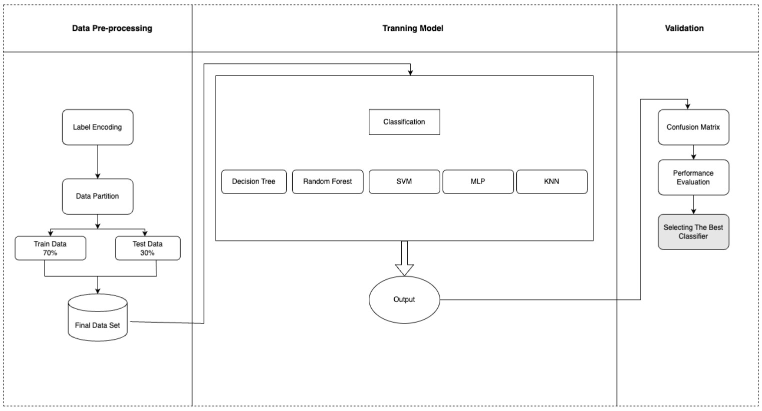

Figure 1: Dataflow Diagram

fake females. However, the ability of males to locate the artificial females was greatly hampered by very low levels of light pollution. At 0.3 or 0.18 lux, no males were drawn to the imitation females, whereas 33 males were drawn to each of the two matched controls. For these data, a custom model with a 95% confidence limit was created in order to better illustrate how light pollution affects males.

In another study (Kivelä et al., 2023) on 2022, Linnea et al. experimented over 624 individual glow worms. A total of 57% of the traps during the experiment were effective in capturing at least one male, with 170 instances of one or more males being captured and 129 instances of no males being caught. Therefore, other than the fact that the difference between the blue and white light treatments was no longer significant, the findings of the binary analysis were consistent with those obtained from the analysis using the number of males. According to their laboratory experiment, despite attempts to mitigate this, the artificial light intensity may have had an impact on the success of the illuminated traps in attracting males. This is because the artificial light intensity varied between treatments due to the color filters used, which had an impact on the light output. It was not possible to include the intensity of each light hue as a factor in the statistical analyses because it was only measured once and not individually for each observation. However, there is no discernible correlation between artificial light intensity and male catch size independent of artificial light color when comparing the quantities of males caught in each treatment and their corresponding light intensities. Lastly they came to a conclusion that, the artificial light intensity alone cannot account for the variations in male attraction effectiveness between treatments; light color also must be a factor.

3 Methodology

3.1 Dataset

The dataset is called ‘Data Moth Foraging’. It includes 6900 annotated data points and 8 characteristics on moth behavior in the presence of artificial night light (Table 1). General information such as day, block, and treatment type, as well as moth species and sex, are included in the files. The datasets contain data like unique.id, foraging observations, and moth size. The portions were designated using the identifier ‘Day’.

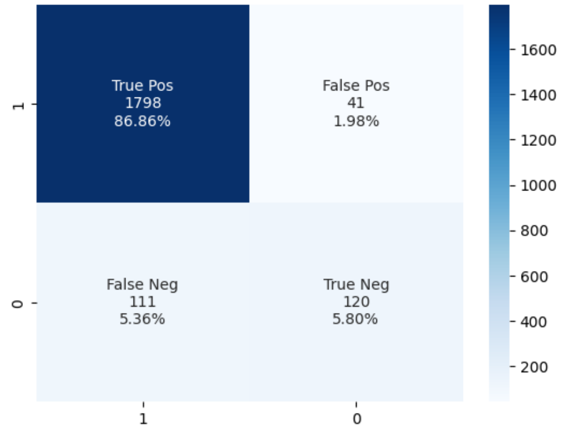

Figure 2: Confusion Matrix of Decision Tree

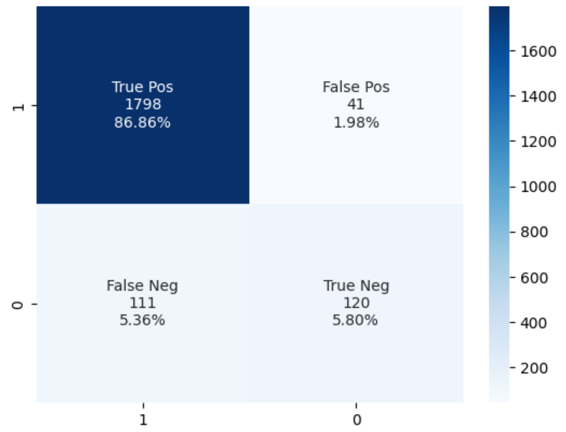

Figure 3: Confusion Matrix of Random Forest

3.2 Proposed Model

From Figure 1 we can see that this section consists of three parts describing the data pre-processing to select the best model for the dataset.

4 Implementation and Result

We examine the dataset to check whether it includes any null values. We utilized label encoding on the dataset to convert the columns from categorical (Boolean and Objective type) to numerical for the classifier and divided the Dataset into Training (70%) and Test (30%) data. Finally, the dataset was ready to be used to train a model.

Classification is a method of separating two or more classes. There are three steps to it. The initial step is to develop a training set containing data with known classes, and the next phase is to select the features relevant to the model. Finally, we will have to test a classifier's accuracy using test sets. In our model, we tested five classifiers to determine the best fit for our dataset.

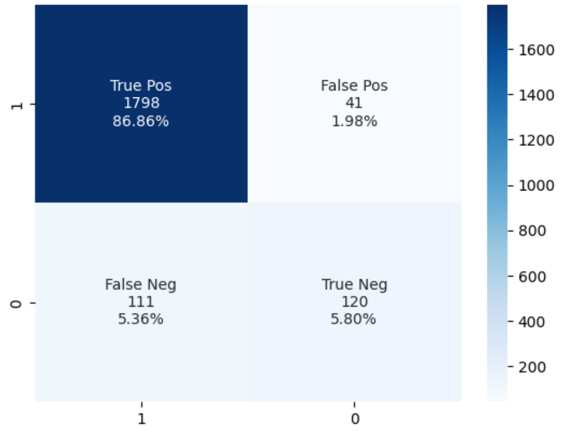

Figure 4: Confusion Matrix of SVM

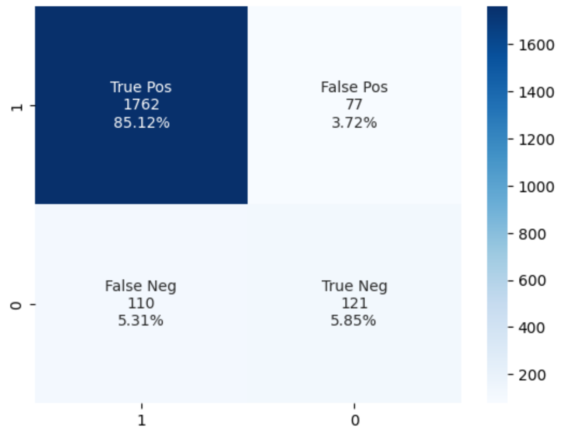

Figure 5: Confusion Matrix of KNN

Validation plays the most crucial role in objectively determining a model's performance and reliability. We applied statistical validation approaches to assess a model's performance. To empirically compare these five models and select the best one, we used Confusion Matrix on the models.

We applied a statistical validation approach, namely Confusion Matrix, to assess a model's performance and compare the five models empirically. Among the five models, the Decision Tree and Random Forest produced more consistent outcomes. After examining the outcomes, we can state that the Decision Tree and Random Forest produce more accurate and reliable results among the models.

We have applied five classifiers to the dataset to distinguish foraging behavior of moths(obs) (Figure - 7). Decision Tree and Random Forest scored the highest score among the five classifiers at 92.657%, whereas Support Vector Machine

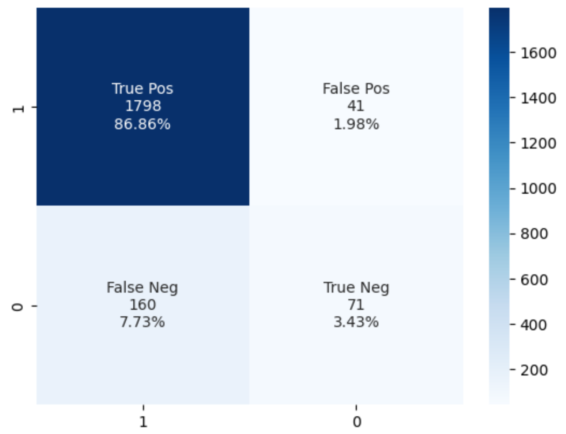

Figure 6: Confusion Matrix of MLP

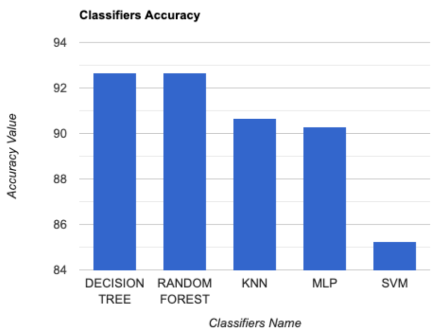

Figure 7: Result

(SVM) scored the lowest, at 85.259%. MLP and KNN falls between Decision Tree, Random Forest and SVM. KNN and MLP have accuracy scores of 90.662% and 90.289%, respectively. Where KNN performance score is better than MLP.

5 Conclusion and Future Work

Light pollution is a well-known problem that has detrimental impacts on the health of people, animals, and plants. The attraction of nocturnal insects to artificial light sources, which can be fatal to them, is one of the main effects of this. Two nocturnal insects that exhibit a maladaptive reaction to artificial light are glow worms and moths. We conducted an experimental analysis of data from glow worms and moths using various machine learning and deep learning algorithms in order to assess the impacts of light pollution on insects. To interpret and describe the predictions made by the models, we have also included Explainable AI.

References

Stephanie Bird and Joel Parker. 2014. Low levels of light pollution may block the ability of male glow-worms (lampyris noctiluca l.) to locate females. *Journal of Insect Conservation*, 18:737–743.

Mira Van den Broeck, Rapha´1 De Cock, Stefan Van Dongen, and Erik Matthysen. 2021. Blinded by the light: Artificial light lowers mate attraction success in female glow-worms (lampyris noctiluca l.). *Insects*, 12(8).

Christina Elgert, Juhani Hopkins, Arja Kaitala, and Ulrika Candolin. 2020. Reproduction under light pollution: maladaptive response to spatial variation in artificial light in a glow-worm. *Proceedings of the Royal Society B*, 287(1931):20200806.

Silvia Keinath, Franz Hölker, Johannes Müller, and Mark-Oliver Rödel. 2021. Impact of light pollution on moth morphology–a 137-year study in germany. *Basic and Applied Ecology*, 56:1–10.

Linnea Kivelä, Christina Elgert, Topi Lehtonen, and Ulrika Candolin. 2023. The color of artificial light affects mate attraction in the common glow-worm. *Science of The Total Environment*, 857:159451.