Effect of lighting on heart rate performance of Eel (*Anguilla bicolor*)

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Abstract. Eels (*Anguilla bicolor*) are catadromous fish with a complex life cycle, in which the elver stage represents a critical transitional phase from marine to freshwater environments. Environmental factors such as light significantly influence eel physiology, migratory behavior, and metabolic activity. This study evaluated the effects of different light spectra on the cardiac performance of elver-stage eels using a non-invasive electrocardiogram (ECG) technique. The experiment was conducted at the Fish Behavior Laboratory, Faculty of Fisheries and Marine Sciences, IPB University, from January to May 2024. Three lighting treatments were applied: blue light (~450 nm), full-spectrum white light, and a control condition without additional lighting. A Completely Randomized Design (CRD) was employed with three replicates per treatment. Results indicated that white light significantly increased heart rate (69.6 ± 0.92 bpm) compared to blue light (46.6 ± 0.90 bpm) and control conditions (48.6–51.2 bpm) ($P < 0.05$), suggesting a heightened stress response under white light exposure. In contrast, blue light maintained more stable cardiac activity, indicating reduced physiological stress. These findings are relevant for the optimization of eel fishing techniques, conservation, and fish welfare management.

1 Introduction

Eels (*Anguilla* spp.) are catadromous species that reproduce in the ocean, with their larvae and juveniles migrating into coastal and freshwater habitats to grow before returning to the sea for spawning. A critical transition in this life cycle is the elver stage, when juveniles move from marine to freshwater environments and undergo major physiological adjustments, particularly in osmoregulation, morphology, and behavior, that enable freshwater residency and upstream migration [1]. Conditions at river mouths, including light intensity, temperature, and substrate type, strongly influence entry timing, migration success, and spatial distribution of arriving elvers [2, 3].

Light is a key environmental cue for fish, regulating circadian rhythms, feeding behavior, and metabolic rate. High daytime light can increase activity and therefore oxygen and nutrient demands, placing a greater workload on the heart. Conversely, abrupt or unnatural light regimes typical in captivity can induce stress responses that alter heart rate and blood pressure [4]. Organisms living under strong light fluctuations often show cardiac adaptations that reflect those conditions. Specific wavelengths also matter blue light has been reported to influence retinal signaling and melatonin pathways, improving metabolic efficiency and activity in some fish, whereas broad white light can support growth but may cause stress if it mismatches natural habitat conditions [5-9]. Eels are primarily nocturnal and prefer darker microhabitats, although artificial illumination can alter their activity patterns [10, 11].

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Cardiac performance is a sensitive indicator of physiological response to environmental change. Electrocardiography (ECG) is widely used to measure heart rate and rhythm in fish under varying light and activity conditions [12, 13]. Despite this, studies addressing how light intensity affects cardiac function specifically in elver-stage eels are limited. Consequently, this research explored how varying light intensities influence the cardiac activity of eel elvers, offering information that can support better culture techniques and conservation efforts.

2 Materials and methods

Data collection and observation of eel cardiac performance were carried out at the Fish Behavior Laboratory, Department of Fisheries Resource Utilization, Faculty of Fisheries and Marine Sciences, IPB University, from January to May 2024. The experiment examined how different lighting conditions affect cardiac performance in elver-stage eels (*Anguilla* spp.). Given the species' nocturnal behavioral patterns, data acquisition and physiological observations were predominantly performed during nighttime to ensure ecological relevance and minimize behavioral disturbance.

2.1 Preparation of eel samples

The experimental subjects consisted of ten elver-stage *Anguilla* bicolor, with an average total length of 29.3 ± 1.1 cm and a body weight of less than 200 g. Before the commencement of the experimental trials, the specimens underwent an acclimatization period exceeding 40 days in a controlled rearing tank (dimensions: 194.5 × 101 × 62 cm), with a maintained water depth of 27 cm. The tank was continuously aerated with freshwater to ensure optimal oxygenation. During acclimatization, the eels were fed regularly using a pellet and kept under stable environmental conditions, where the water temperature was maintained around 25°C with a pH between 7 and 8.

2.2 Methods

Cardiac activity in elver-stage *Anguilla* bicolor was assessed using a non-invasive electrocardiography (ECG) technique. The instrumentation included an oscilloscope (Tektronix TDS2014C), a bio-amplifier (Nihon Kohden AB-632), graphite electrodes for signal detection [10], and auxiliary components such as multimeters, copper cables, connectors, and smartphone cameras for visual documentation. Each observation session lasted 30 minutes, with 24 experimental replicates conducted.

The trials were performed in a glass aquarium (57.5 × 31 × 29 cm) equipped with continuous aeration and an artificial lighting system utilizing a 10-watt RGB LED floodlight. Two lighting treatments were applied: blue light (~450 nm) and full-spectrum white light. Light intensity levels followed the protocol by Riyanto [10], with blue light ranging from 0 to 5.2×10^{-8} W/cm² and white light from 0 to 1.7×10^{-8} W/cm². The lamp was set at a height of 30 cm above the water so that the entire aquarium received evenly distributed light.

Electrocardiographic signals were captured via graphite electrodes placed externally on the fish's body, transmitting electrical activity to the bio-amplifier. The amplified signals were visualized as waveforms on the oscilloscope and recorded using a smartphone camera. All recordings were subsequently stored on a flash drive for post-experimental analysis.

Water quality parameters, including temperature and other relevant physicochemical properties, were monitored throughout the experiment to maintain optimal conditions. Heart rate data were statistically analyzed to determine the effects of lighting treatments on cardiac performance, employing ANOVA with additional post-hoc comparisons performed when necessary. The study used a Complete Random Design (RAL) with four sequential phases: Control 1 (dark), Blue Light, Control 2 (dark), and White Light. Each treatment lasted 30 minutes with three repetitions. A 1-hour rest interval is given to minimize residual effects.

2.3 ECG recording

Electrocardiographic (ECG) recordings were conducted to assess the cardiac activity of elver-stage *Anguilla* bicolor under different lighting conditions. Each eel elver was chosen at random from the acclimation tank and then placed into the experimental aquarium (57.5 × 31 × 29 cm). Within the aquarium, each fish was placed inside a PVC pipe (6 cm diameter, 35 cm length) designed to minimize movement and create a calm environment conductive to accurate physiological monitoring.

Two graphite electrodes were positioned at both ends of the pipe using wooden supports to ensure stability and consistent signal acquisition. These electrodes were connected via copper wires to a signal amplifier (Nihon Kohden AB-632), which amplified the bioelectrical signals generated by the fish's cardiac activity. The amplified signals were displayed on an oscilloscope (Tektronix TDS2014C). To minimize electrical noise and interference, grounding wires were attached to a metal table as a neutral reference point.

Prior to data collection, a heart rate normalization procedure was implemented to ensure that each fish's cardiac rhythm had stabilized to baseline conditions [10]. Each fish was used only once per experimental session to avoid repeated stress exposure. After the observation, the fish was transferred to a separate maintenance tank of identical dimensions to promote recovery and minimize physiological disturbance.

Heart rate waveforms were recorded via video using a smartphone camera and stored on a flash drive for subsequent analysis. Three lighting treatments were applied: blue light (~450 nm), full-spectrum white light, and dark control. Illumination was provided using an RGB LED floodlight, calibrating intensities according to established standards [10].

Every treatment was conducted in triplicate, producing 24 total trials in the experiment. For each trial, heart activity was monitored over a 30-minute recording period. The sequence of treatments within a single trial cycle was as follows: control 1 (dark), blue light, control 2 (dark), and white light. All treatments were applied sequentially to the same individual, with sufficient recovery time between exposures. The 30-minute duration was selected based on prior studies indicating its adequacy for capturing physiological responses to light stimuli. A summary of the experimental layout and its procedural steps is illustrated in Figure 1.

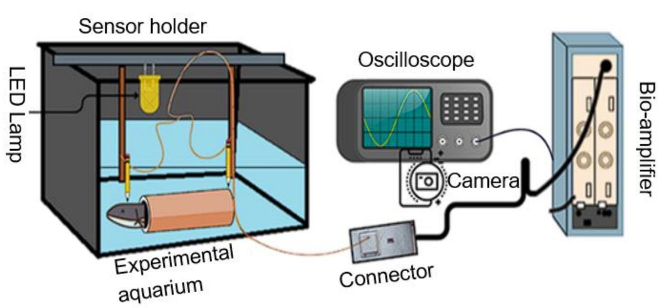

Fig. 1. Experimental setup diagram.

2.4 Data analysis

Eel heart rate data was analyzed using SAS software with the Duncan test to compare the averages between lighting treatments. The study used a complete random design (RAL) with one factor, namely light colors: blue, white, and dark as controls. The analysis was conducted to evaluate how each lighting treatment affects the physiological state of the fish. The statistical model used in this study is presented as follows:

$$Yij = \mu i + \tau i + \varepsilon ij \text{ atau } Yij = \mu i + \varepsilon ij \tag{1}$$

i	:	Treatment
j	:	Deuteronomy
Yij	:	Observations on the first treatment of the j repeat
μ	:	General average
The	:	Effects of the i-treatment
€ij	:	Error of the first treatment experiment of the j test

3 Results and discussion

3.1 Results

Previous studies indicate that this lighting type has a direct influence on the cardiac rhythm of eel elvers. Under blue light, their heartbeat tends to decrease, which can be seen from the number of peak ECG waves. Figure 2 illustrates how the light treatments shaped the elvers' cardiac response.

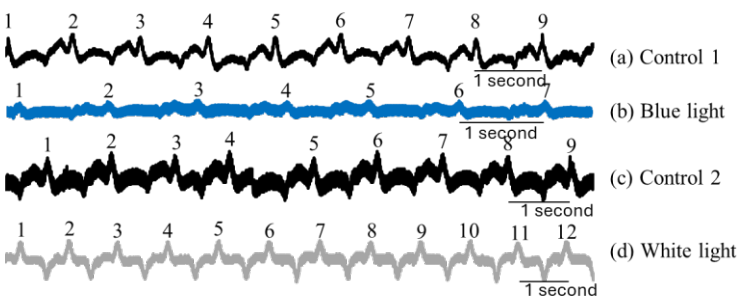

Fig. 2. Eel heart rate profile (30 cm): (a) control 1, (b) blue light, (c) control 2, (d) white light.

Overall, white light seems to have the greatest effect in increasing the heart rate of eels**,** which can be seen from the consistency of high heart rate points in various total lengths of fish. This suggests that no matter the length of the fish, white light causes a consistent increase in heart rate across the sample. This effect stands out when compared to blue light and control conditions, where the heart rate tends to be more stable and less affected by lighting. The fish's heart rate in control 1 was recorded to range from 32 to 62 beats per minute (bpm) with an average ±SE of 48.6±0.61 bpm. In the blue light treatment, the heart rate reached 40 to 54 bpm (46.6±0.90 bpm), and in the 2-heart rate control, it was recorded at 40 to 62 bpm (51.2±0.60 bpm). However, in the white light treatment, the heart rate increased significantly to 66 to 74 bpm (69.6±0.92 bpm), which showed a significant effect of white light on the increase in heart rate. The variation in eel heart rates under control 1, blue light, control 2, and white light across different length categories is shown in Figure 3.

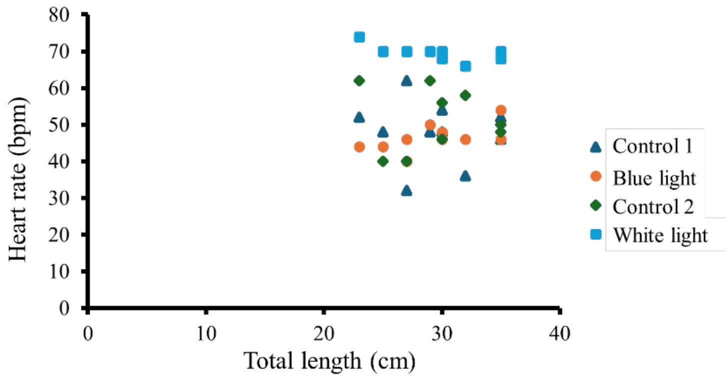

Fig. 3. Comparison of heart rate of eel at different length and light color.

Statistically, the white light treatment produced the highest mean heart rate and showed a significant difference ($P<0.05$) compared to the blue light treatment and control. Control 2 and control 1 showed intermediate values, while blue light produced the lowest heart rate (Table 1). These results indicate that blue light favors a stable physiological condition for eel fish than white light.

Table 1. Average heart rate of eels under different treatments.

Treatment	Heart rate (beats/minute) ± SE	Sample size (n)
Control 1	48.6 ± 0.61a	10
Blue Light	46.6 ± 0.90a	10
Control 2	51.2 ± 0.60a	10
White Light	69.6 ± 0.92b	10

The box plot graph shows the eel heart rate at four treatments: blue light (CB), white light (CP), initial control (K1), and control after blue treatment (K2). White light produces the highest median heart rate (~70 bpm) with low variation and one outlier. Blue light has the lowest median (~45 bpm) with a stable data distribution. Controls 1 and 2 showed a median of about 50 bpm, but K2 had the widest data distribution and few outliers, indicating high variability (Figure 4). Overall, white light was the most powerful in influencing the increase in heart rate, while blue light showed the most stable effect.

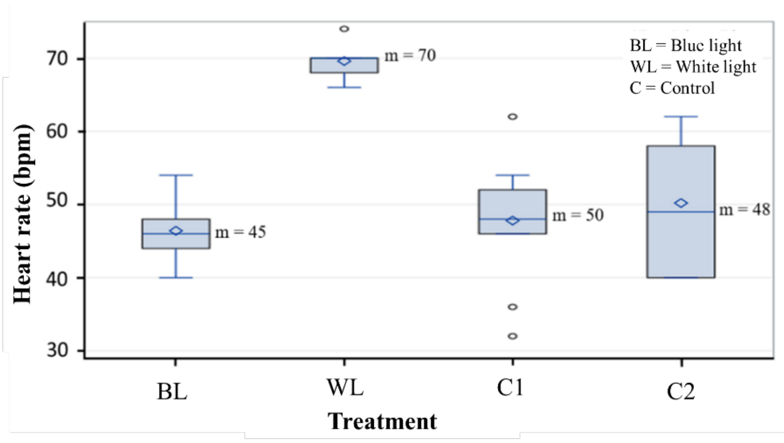

Fig. 4. Box plot the relationship between light treatment and heart rate.

Previous research has explored how fish heartbeats react to light, using different species and experimental conditions. The variations in heart rate observed under various light intensities are summarized in Table 2.

Table 2. Fish heartbeat in different light in some studies

Species	**English Name**	**Fish size**	**Light**	**Heart rate (bits/minute)**	**Reference**
Danio rerio	Zebra fish	Embryo to adult	14-hour light/10-hour dark (LD) cycle	150-180 bpm in light conditions, 120-140 bpm in dark conditions	Previous studies
		Embryo to adult	Glide LD (Light-Dark)	150-180 bpm in light conditions, down to 120-140 bpm in dark conditions	Previous studies
Oryzias latipes	Medaka	Embryo to adult	12-hour day/12-hour dark cycle (LD)	120-150 bpm in light conditions, 100-130 bpm in dark conditions	Previous studies
Cyprinus carpio	Common carp	Adult	LD (Light-Dark) and dark constant (DD) cycles	110-130 bpm in light conditions, 90-110 bpm in dark conditions	Previous studies
Anguilla bicolor	Indonesian shortfin eel	29.3±3.97 cm	Blue Light	46.2±3.52 bpm	This research
			White Light	69.6±1.92 bpm	

4 Discussion

Light characteristics in aquatic environments are particular and play a critical role in shaping fish behavior and physiology. Fish generally exhibits two types of phototactic responses: positive phototaxis, where individuals are attracted to light sources, and negative phototaxis, where they actively avoid them [14]. These responses vary across species and are influenced by phylogenetic lineage, ecological adaptations, and the physical properties of the light particularly its intensity and wavelength.

In *Anguilla* spp., light-induced responses are further categorized into primary responses, involving direct chromatophore reactions independent of visual input, and secondary responses, which are mediated by visual perception and regulated by the nervous system [15]. The present study demonstrated that white light elicited a higher frequency of heart rate peaks in elver-stage eels than blue light, indicating a stronger physiological reaction to white light. This is likely attributable to its broader spectral range and higher intensity, which may be perceived as more intrusive or stimulating.

The elevated heart rate observed under white light conditions suggests increased metabolic demand and a potential stress response. Full-spectrum lighting activates fish' behavioral and physiological stress pathways, including heightened cortisol secretion and accelerated metabolic activity. These effects are particularly pronounced in nocturnal species such as eels, which are evolutionarily adapted to low-light environments. Exposure to bright light may be interpreted as a threat or disturbance, thereby triggering cardiovascular activation.

Conversely, blue light was associated with a more stable and lower heart rate, consistent with findings by Riyanto et al. [10], which reported reduced activity in glass eels under blue illumination. This response likely reflects the spectral sensitivity of eel photoreceptors, which are adapted to deep or turbid waters where blue wavelengths dominate and are less disruptive. Interestingly, behavioral differences between developmental stages were noted: glass eels exhibited avoidance behavior, while elvers responded through physiological modulation, such as changes in heart rate.

From an ecological perspective, these findings reinforce the role of light as a key environmental cue in eel migration. Light influences spatial orientation, habitat selection, and diel vertical migration in anguillid species. Therefore, artificial manipulation of lighting in laboratory or aquaculture settings can significantly affect behavioral and physiological outcomes.

Regarding practical applications, the results offer valuable insights into eel fisheries management. White light may be effective as an attractant in fishing operations; however, it should be used judiciously to avoid inducing chronic stress. In contrast, blue light appears more suitable for conservation and restocking programs, as it promotes a calmer environment conducive to long-term survival and welfare.

5 Conclusions and recommendations

5.1 Conclusion

Exposure to white light significantly elevates heart rate in elver-stage *Anguilla* bicolor compared to blue light and dark control conditions, indicating a heightened physiological stress response. In contrast, blue light was associated with more stable cardiac activity, suggesting its potential to minimize stress and maintain physiological equilibrium.

These results highlight how adjusting light conditions can shape the physiological reactions of eels, especially when they are in vulnerable developmental phases. The differential effects of light spectra provide a foundation for further research to optimize environmental conditions in both experimental and applied settings. Specifically, blue light may offer advantages in conservation and restocking programs by promoting a less stressful environment. In contrast, white light may be strategically utilized in capture operations to enhance efficiency.

5.2 Recommendations

White light may be utilized as a short-term attractant in eel capture operations due to its ability to stimulate physiological responses. However, its prolonged application should be avoided to minimize stress and potential adverse effects on health and welfare. In contrast, blue light is recommended for use in conservation and restocking programs, as it promotes physiological stability and reduces stress, thereby supporting post-release survival and long-term well-being.

Future studies are encouraged to explore how different light intensities, exposure periods, and mixed wavelengths influence eel physiology and behavior at various stages of their development. Such studies will contribute to a more comprehensive understanding of light-based environmental manipulation and its implications for sustainable eel fisheries management and conservation strategies.

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