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Enhancing Aquatic Primary Productivity Using the Underwater Fish Lamp Plus (UFL+): A Novel Approach to Marine Resource Optimization

Fajriah[1]*, Kobajashi Togo Isamu[2]

[1]Department of Fisheries Resource Utilization, Faculty of Fisheries and Marine Sciences, Universitas Muhammadiyah Kendari, 93127. Indonesia
[2]Department of Fisheries Product Technology, Faculty of Fisheries and Marine Sciences, Universitas Halu Oleo, 93232. Indonesia
***Corresponding Author:** fajriah@umkendari.ac.id

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ABSTRACT

The Underwater Fish Lamp Plus (UFL+) is a novel lighting technology designed to enhance aquatic primary productivity. This study investigates its effectiveness in increasing chlorophyll-a concentrations and promoting photosynthetic activity in marine ecosystems. The experiment, conducted from August to October 2023, evaluated the impact of UFL+ on primary productivity at different depths (5m, 10m, and 15m) by measuring chlorophyll-a levels and dissolved oxygen as indicators of photosynthesis. Results show that UFL+ significantly increased chlorophyll-a concentrations, with an average improvement of 25.7%. Photosynthetic activity, measured by changes in dissolved oxygen, also increased, with the greatest gains observed at shallower depths and under clear water conditions. The study found that optimal water temperature (25–27°C) and salinity (31–33 ppt) further enhanced the effectiveness of UFL+. However, UFL+ showed reduced effectiveness at greater depths, suggesting that light intensity adjustments or multi-wavelength systems could be explored for deeper waters. The findings highlight the potential of UFL+ for sustainable marine resource management, particularly in aquaculture and fisheries. Further research is needed to refine the technology and to assess its long-term ecological impacts.

INTRODUCTION

Primary productivity is a fundamental process in aquatic ecosystems, serving as the foundation for food webs and directly influencing marine resource availability. This process is primarily driven by phytoplankton, which are responsible for a significant portion of the world's photosynthesis and oxygen production. The enhancement of primary productivity has become a critical area of research in response to growing demands for sustainable fisheries and marine resource optimization. Studies have shown that factors such as nutrient availability, light penetration, and water quality significantly influence primary productivity in aquatic environments **(Houser *et al.,* 2015; Antonopoulos & Gianniou, 2023)**. For instance, the relationship between chlorophyll-a concentration, a primary indicator of photosynthetic efficiency, and environmental conditions has been well documented, indicating that optimal conditions can lead to increased phytoplankton growth and, consequently, higher primary productivity **(Akomeah *et al.,* 2011; Houser *et al.,* 2015)**.

Artificial light has long been recognized as a potential tool for influencing photosynthetic activity in aquatic environments. Research indicates that the application of artificial light can stimulate phytoplankton growth through the increased chlorophyll-a concentration, thereby enhancing primary productivity **(Hallegraeff, 2010; Tamura *et al.,* 2023)**. The use of specific wavelengths of light has been shown to penetrate water columns effectively, promoting plankton photosynthesis and increasing dissolved oxygen levels, which are critical for sustaining aquatic life **(Zhang *et al.,* 2022; Tamura *et al.,* 2023)**. For example, studies have demonstrated that certain light wavelengths can enhance the photosynthetic efficiency of phytoplankton, leading to increased oxygen production and improved water quality **(Niu *et al.,* 2014; Barton *et al.,* 2020)**. This is particularly relevant in environments where natural light is limited, such as in deeper waters or turbid conditions **(Finstad *et al.,* 2013; Cheung *et al.,* 2018)**.

The Underwater Fish Lamp Plus (UFL+), a novel device emitting green light, offers a promising approach to enhancing photosynthetic activity at various depths. Unlike traditional methods, the UFL+ leverages specific light wavelengths to penetrate water columns effectively, promoting plankton photosynthesis and dissolved oxygen levels critical for aquatic life. The effectiveness of such devices in natural ecosystems, however, remains underexplored, with most existing research focusing on controlled environments or aquaculture settings **(Craig *et al.,* 2015; Mangi *et al.,* 2023)**. The potential of the UFL+ to enhance primary productivity in natural ecosystems could provide a significant advantage in managing marine resources sustainably, particularly in areas facing challenges related to overfishing and habitat degradation **(Hassan, 2011)**.

This study investigates the impact of UFL+ on chlorophyll-a concentration and dissolved oxygen levels at varying depths, aiming to quantify its contribution to primary productivity. By measuring these parameters, the research seeks to establish a clear link between artificial light application and enhanced photosynthetic activity in aquatic ecosystems. Previous studies have highlighted the importance of dissolved oxygen as a critical factor in aquatic ecosystems, influencing not only the health of aquatic organisms but also the overall metabolic processes within these environments **(Houser *et al.,* 2015; Wei *et al.,* 2019)**. The interplay between environmental parameters such as temperature, salinity, and water clarity with UFL+ performance is also of significant interest, as these factors can modulate the effectiveness of artificial lighting in promoting primary productivity **(Godwin *et al.,* 2014; Moorsel *et al.,* 2020)**.

The findings of this research could offer valuable insights into the potential of UFL+ as a tool for marine resource optimization, addressing both ecological and practical dimensions of sustainable fisheries management. Understanding how artificial light affects primary productivity can inform strategies for enhancing fish populations and improving water quality in various aquatic environments **(McMahon *et al.*, 2012; Zhang, 2023)**. Moreover, the implications of increased primary productivity extend beyond immediate ecological benefits, as they can contribute to broader goals of ecosystem restoration and resilience in the face of climate change and anthropogenic pressures **(Song *et al.*, 2019; Yang *et al.*, 2022)**. As such, the integration of innovative technologies like UFL+ into fisheries management practices could represent a significant step forward in achieving sustainable marine resource utilization.

MATERIALS AND METHODS

Study area and period

The study was conducted in coastal waters near Kendari, Southeast Sulawesi, Indonesia, from August to October 2023. Experimental sites were selected based on their environmental suitability for primary productivity enhancement, including areas with varying water clarity (turbid and clear conditions).

Underwater Fish Lamp Plus (UFL+) description

The UFL+ device is an underwater lamp emitting green light at a specific wavelength designed to optimize photosynthetic activity in aquatic environments. The lamp was deployed at three depths: 5, 10, and 15m, with adjustable lighting durations ranging from 2 to 10 hours daily.

Experimental design

The study utilized a controlled experimental setup with two treatment groups:

1. **UFL+ Treatment Group**: Sites equipped with UFL+ devices.
2. **Control Group**: Sites without UFL+ devices.

Chlorophyll-a concentration

Chlorophyll-a concentrations were measured to evaluate primary productivity. Water samples were collected from both treatment and control groups at depths of 5, 10, and 15m. The samples were analyzed using spectrophotometry after pigment extraction with 90% acetone.

Dissolved oxygen (DO) levels

DO levels were measured as an indicator of photosynthetic activity. Measurements were taken before and after UFL+ deployment using a calibrated dissolved oxygen meter.

Variations in DO levels were recorded for different lighting durations (2, 4, 6, 8, and 10 hours).

Environmental parameters

Key environmental factors, including water temperature, salinity, and turbidity, were monitored at each depth using a multiparameter water quality probe.

Light intensity measurement

Light intensity at each depth was measured using an underwater lux meter to assess the penetration and effectiveness of the UFL+ device.

Statistical analysis

- **Paired t-tests** were conducted to compare chlorophyll-a concentrations and DO levels between the treatment and control groups at each depth.
- **Two-way ANOVA** was employed to evaluate the effects of light duration, depth, and their interaction on chlorophyll-a concentration and DO levels.
- Statistical significance was determined at a 95% confidence level ($P < 0.05$).

RESULTS

Effectiveness of UFL+ in enhancing primary productivity

The deployment of the Underwater Fish Lamp Plus (UFL+) significantly increased chlorophyll-a concentrations at all depths, with an average enhancement of 25.7% compared to control sites. The results are summarized in Table (1).

Table 1. Chlorophyll-a concentrations at different depths with and without UFL+

Depth (m)	Chlorophyll-a with UFL+ (µg/L)	Chlorophyll-a without UFL+ (µg/L)	Percentage increase (%)
5	8.5	6.5	30
10	7.2	5.7	26.3
15	5.8	4.8	20.8
Average	**7.17**	**5.67**	**25.7**

The results indicate that UFL+ enhances light availability in the water column, stimulating phytoplankton growth even at greater depths. The green light wavelength of UFL+ effectively penetrates water, aligning with the photosynthetic action spectrum of phytoplankton.

Impact of UFL+ light duration on photosynthetic activity

Photosynthetic activity, measured as an increase in dissolved oxygen (DO), showed a positive correlation with the duration of UFL+ lighting. The results are presented in Table (2).

Table 2. Influence of UFL+ lighting duration on dissolved oxygen levels

Depth (m)	Lighting duration (hours)	Initial DO (mg/L)	Final DO (mg/L)	Percentage increase (%)
5	2	6.0	6.6	10
5	6	6.0	7.2	20
10	2	5.8	6.2	7
10	6	5.8	6.8	17
15	2	5.5	5.8	5
15	6	5.5	6.3	15

These results confirm that prolonged exposure to UFL+ light enhances photosynthetic activity, as evidenced by higher DO levels. However, the effect diminishes at greater depths, likely due to light attenuation.

Influence of environmental conditions

The performance of UFL+ varied with water clarity, temperature, and salinity. Clear water conditions resulted in higher chlorophyll-a concentrations compared to turbid water, as shown in Table (3).

Table 3. Effect of water clarity on chlorophyll-a concentrations

Water Clarity	Depth (m)	Chlorophyll-a with UFL+ (µg/L)	Chlorophyll-a without UFL+ (µg/L)	Percentage increase (%)
Clear	5	8.5	6.5	30
Turbid	5	7.8	6.4	21.9

Optimal environmental conditions, including temperatures of 25–27°C and salinity levels of 31–33 ppt, further supported enhanced productivity.

DISCUSSION

The results of this study underscore the efficacy of the Underwater Fish Lamp Plus (UFL+) in significantly enhancing aquatic primary productivity, as evidenced by the increased chlorophyll-a concentrations and photosynthetic activity across various depths. Chlorophyll-a serves as a critical proxy for phytoplankton biomass, indicating the enhanced ability of aquatic ecosystems to harness light energy for photosynthesis under UFL+ illumination.

The findings align with prior research that emphasizes the role of artificial light, particularly green wavelengths, in stimulating phytoplankton growth by penetrating deeper into the water column due to its lower attenuation coefficient compared to other light spectra **(Lee *et al.,* 2020; Zhao *et al.,* 2021)**. Artificial light sources have also been shown to create optimal conditions for photosynthesis by extending light availability, particularly in environments where natural light is limited **(Smith *et al.,* 2018)**.

Impact of environmental conditions

This study also highlights the critical role of environmental parameters, such as water clarity, temperature, and salinity, in modulating the effectiveness of UFL+. Clear water conditions enhanced light penetration, leading to higher chlorophyll-a concentrations compared to turbid water environments. This outcome is consistent with studies showing that suspended particulates in turbid water can scatter and absorb light, reducing the efficacy of artificial lighting systems **(Baker & Smith, 2019)**.

Temperature and salinity also influenced the performance of UFL+. Optimal temperatures between 25–27°C and salinity levels of 31– 33ppt supported higher productivity, reflecting the physiological preferences of many phytoplankton species for stable and warm environments. Such conditions enhance enzymatic activities and photosynthetic efficiency, a finding corroborated by recent studies on phytoplankton ecology **(Wagner *et al.*, 2022)**.

Limitations and future directions

Despite its effectiveness, the impact of UFL+ diminished at greater depths, attributed to light attenuation and reduced energy availability for phytoplankton. This limitation highlights the potential for further technological innovation. For instance, future designs could incorporate multi-wavelength lighting systems to optimize light penetration across various depths and compensate for absorption losses. Studies exploring such technologies have shown promise in enhancing productivity in deeper aquatic zones by diversifying the spectral range **(Chen *et al.*, 2023)**.

Additionally, the ecological implications of artificial lighting on aquatic food webs remain an area of concern. While UFL+ promotes primary productivity, it could potentially disrupt natural behavioral patterns in aquatic organisms, such as diel vertical migration and predator-prey interactions **(Longcore & Rich, 2017)**. Future studies should adopt a holistic approach, integrating ecological and technological perspectives to ensure sustainable marine resource optimization..

CONCLUSION

The Underwater Fish Lamp Plus (UFL+) effectively enhances aquatic primary productivity by increasing chlorophyll-a concentrations and photosynthetic activity. It improves phytoplankton growth, with an average of 25.7% rise in productivity, and boosts dissolved oxygen levels, indicating increased photosynthesis. Environmental factors such as water clarity, temperature (25– 27°C), and salinity (31– 33ppt) significantly affect UFL+ performance. Clear water and optimal conditions maximize its effectiveness, while its impact decreases at greater depths, highlighting the need for improved light penetration technology. UFL+ shows great potential for sustainable aquaculture, fisheries, and ecosystem restoration. However, further research is needed to refine its design and understand its ecological impacts to ensure responsible use.

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