Journal of Fish Health
Volume 6, Issue 3, August 2026
https://doi.org/10.29303/jfh.v6i3.11802

Potential of Local Microalgae from Lembar Bay Waters for Climate Change Mitigation: Insights from Photosynthetic Assimilation Index

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Received:
July 31th, 2026
Accepted:
August 17th, 2026
Published:
August 31th, 2026

Keywords:
Microalgae, Chlorophyll-a, Net Primary Productivity, Assimilation Index

ABSTRACT

Climate change mitigation requires innovative approaches to reduce atmospheric carbon dioxide (CO_2) through efficient and sustainable carbon fixation. Microalgae are promising biological agents because of their photosynthetic capacity to assimilate inorganic carbon into biomass. This study aimed to assess the potential of local microalgae communities in Lembar Bay waters, West Lombok, as carbon assimilation agents based on the relationship between chlorophyll-a, net primary productivity (NPP), and assimilation index. The study was conducted from March to May 2026 at five sampling stations, with three sampling periods at 30-day intervals. Phytoplankton samples were collected using a plankton net and identified microscopically, while chlorophyll-a was analyzed spectrophotometrically. NPP was determined using the light-and-dark bottle method based on changes in dissolved oxygen during a six-hour incubation period. The relationships among environmental parameters, chlorophyll-a, and NPP were analyzed using Spearman correlation. The results showed a relatively strong positive correlation between chlorophyll-a and NPP ($r = 0.727$), indicating that higher phytoplankton biomass was associated with greater photosynthetic productivity. Chlorophyll-a showed weak correlations with nitrate ($r = −0.045$) and phosphate ($r = −0.107$). The assimilation index varied among stations, ranging from 6.13 to 11.51 (mg C mg Chl-a^{-1} hour^{-1}), with the highest value at Station 4 and the lowest at Station 5. These findings indicate that local microalgae in Lembar Bay have potential for biological carbon assimilation and may support climate change mitigation. However, further species-specific cultivation and controlled photobioreactor experiments are required to validate their CO_2 fixation capacity and long-term carbon sequestration potential.

INTRODUCTION

Increasingly evident climate change, driven by rising concentrations of greenhouse gases—particularly carbon dioxide (CO_2)—has emerged as a global challenge in the 21st century. Anthropogenic activities such as fossil fuel combustion, deforestation, and intensive agricultural practices have drastically increased the accumulation of atmospheric CO_2, contributing to global warming and resulting in disrupted climate patterns, rising sea levels, and ecosystem disturbances (Arif *et al*., 2018). Effective and actionable mitigation efforts are urgently needed to ensure global environmental, social, and economic sustainability. In this context, climate change mitigation requires the large-scale implementation of carbon capture and storage (Kazlou *et al*., 2024).

One carbon sequestration approach attracting the attention of researcher is the utilization of microalgae. Microalgae are photosynthetic organisms that inhabit aquatic environments (Diniariwisan & Muahiddah, 2024) and are capable of converting CO_2 into biomass through photosynthesis with greater efficiency than terrestrial plants. The use of microalgae for CO_2 capture helps mitigate global warming (Ighalo *et al*., 2022). Their key advantages lie in rapid growth rates, adaptability to diverse environmental conditions, and high photosynthetic productivity. Consequently, microalgae have the potential to sequester large amounts of CO_2 in a relatively short time, making them excellent candidates for scalable and sustainable carbon sequestration (Anshori *et al*., 2024). In addition to superior photosynthetic efficiency, microalgae also offer advantages regarding land requirements. Unlike terrestrial crops, which require vast areas and compete with land use for food production or human settlements, microalgae can be cultivated in closed systems—such as photobioreactors—or open ponds on limited land. Microalgae have also demonstrated effectiveness in wastewater management by removing pollutants (Riesoglu & Aydin, 2023).

Another aspect that makes microalgae highly relevant to carbon mitigation is their ability to integrate with industrial waste (Kurniawan *et al*., 2017). Several studies indicate that microalgae can thrive in nutrient-rich media derived from industrial or agricultural wastewater while simultaneously absorbing CO_2 emitted from factory stacks. Such integration contributes not only to carbon emission reduction but also to more efficient waste treatment and added value for the resulting biomass (Mulyanto & Handayani, 2015).

Microalgae biomass generated through carbon sequestration processes has diverse commercial applications due to the bioactive compounds produced—such as proteins, polyunsaturated fatty acids, carotenoids, and vitamins (Camacho *et al*., 2019). It is utilized for biofuels, natural fish feed, nutritional supplements, and raw materials for the pharmaceutical and cosmetic industries (Tang *et al*., 2025). Thus, the microalgae-based carbon sequestration approach not only contributes to climate change mitigation but also offers significant economic value and broad potential for technological innovation (Yadav *et al*., 2025). The potential of local microalgae for carbon sequestration in the waters of Lembar Bay is a matter of great urgency, given that the bay is a dynamic coastal area subject to intense anthropogenic pressures—such as port operations, industry, and human settlements—that contribute to rising carbon emissions and the degradation of water quality. Furthermore, understanding of carbon sequestration dynamics in tropical aquatic ecosystems—particularly in Indonesia—remains relatively limited; therefore, local research is essential to generate effective and sustainable solutions.

Journal of Fish Health, 6(3), 459-468 (2026)
Diniariwisan *et al*. (2026)
https://doi.org/10.29303/jfh.v6i3.11802

METHODS

Place and Time

The study was conducted in the waters of Lembar Bay, a coastal area characterized by anthropogenic activities and oceanographic dynamics that potentially influence microalgal productivity. Water sample analysis and microalgal identification were performed at the Testing Laboratory of the Lombok Marine Aquaculture Center, the Analytical Chemistry Laboratory of the University of Mataram, and the Aquaculture Environment Laboratory of the University of Mataram. The research was carried out from March to May 2026, involving three sampling rounds spaced 30 days apart to obtain temporal data. Samples were collected from 5 distinct locations, selected to ensure representation of the entire study area.

Figure 1. Map of Sampling Site around Lembar Bay, West Lombok

Phytoplankton Sampling

Phytoplankton sampling was conducted using a filtration method with a plankton net. Samples were collected from the research site by taking 25 liters of water from the surface. A 50 ml volume of the water sample was filtered using a plankton net (Diniariwisan & Rahmadani, 2024). The filtered sample was transferred to a film canister and treated with 1–2 drops of Lugol's solution (Diniariwisan & Rahmadani, 2023), after which it was transported to the laboratory for identification via microscopy (Amnur *et al*., 2025). Cell abundance was calculated using a Sedgwick-Rafter cell, applying the formula modified by Anugerah *et al*. (2023):

$$N = \frac{ns \times Va}{Vs \times Vc}$$

Where:

N = Number of cells per liter of water sample
ns = Number of cells in the Sedgwick-Rafter
Va = Water volume in the bottle sample (50 ml)
Vs = Water volume in the Sedgwick Rafter's preparation (1 ml)
Vc = Volume of filtered water sample (25 l)

https://doi.org/10.29303/jfh.v6i3.11802

Chlorophyll-a Sampling

Water sampling for chlorophyll-a analysis was conducted by collecting 1 liter of water at the surface (approximately 0.5–1 meter depth) using a dark sample bottle or one wrapped in aluminum foil and dark plastic to exclude light, followed by storage in a coolbox at approximately 4°C prior to filtration and laboratory analysis (Muslim *et al*., 2024). Chlorophyll-a content was analyzed as an indicator of phytoplankton biomass. Chlorophyll-a pigments were extracted using a 90% acetone solvent, and their absorbance was measured using a spectrophotometer (Nuzapril *et al*., 2019).

Primary Productivity

Seawater samples were collected from the study site and placed into two types of Winkler bottles: light bottles and dark bottles. These bottles were then incubated under conditions matching the sampling site for a period of six hours (18). Dissolved oxygen concentrations were measured at the beginning and end of the incubation using a DO meter. Primary productivity was calculated using the light-and-dark bottle method to obtain data on Net Primary Productivity (NPP), Respiration (R), and Gross Primary Productivity (GPP) (19). Subsequently, these values were converted to carbon-based primary productivity. The formula for calculating carbon-based net primary productivity using the light-dark bottle method are:

$$\mathrm{NPP} = \frac{(\mathrm{O2BT}) - (\mathrm{O2BG})\,\mathrm{x}\;1000\;\mathrm{x}\;0.375}{\mathrm{PQ\;x\;t}}$$

Where:

NPP = Net Primary Productivity (mgC/m^3/hour)
O_2 = Dissolved Oxygen (mg/l)
BT = Light Bottle
BG = Dark Bottle
PQ = Photosynthetic Quotient (1.2)
t = time (hour)

Assimilation Number

The assimilation number (P^B) is a photophysiological parameter in aquatic ecology. It defines the maximum, light-saturated rate of photosynthesis or carbon fixation by phytoplankton, normalized to a unit of biomass—typically expressed per mg or g of chlorophyll-a per hour (Demidov *et al*., 2023).

$$\mathrm{P^B} = \frac{\mathrm{NPP}}{\mathrm{Chlo - a}}$$

Where:

P^B = Assimilation Number (mg C mg Chl-a^{-1} $hour^{-1}$)
NPP = Net Primary Productivity (mgC/L/hour)
Chlo-a = Chlorophill-a (mg/L)

Water Quality

Water quality, which serves as the basis for determining the condition of the water body, encompasses fundamental physicochemical parameters that influence the life of aquatic organisms. Water quality also reflects nutrient content—an indicator of fertility; the relevant water quality parameters measured in this study include temperature, pH, salinity, DO, nitrate, and phosphate. Measurements were taken during each of the three phytoplankton and chlorophyll-a sampling event. The equipment used included a thermometer, pH meter, refractometer, DO meter, and Winkler bottles. Chlorophyll-a, nitrate, and phosphate levels were measured using a spectrophotometer.

Data Analysis

The observational data were analyzed using Spearman correlation matrix. Spearman correlation matrix, a non-parametric statistical measure used to calculate the strength of the relationship between two variables.

RESULTS

Correlation Matrix of Each Parameters

The data from the Spearman correlation matrix for each parameter are presented are presented in Table 1 below.

Table 1. Spearman Correlation Matrix of Each Parameters

Parameter	Temp	pH	Nitrate	Phosphate	Salinity	Chlo-a	NPP
Temp	1.000	-0.319	-0.530	-0.726	0.489	0.210	0.129
pH	-0.319	1.000	0.363	0.091	-0.478	0.340	0.155
Nitrate	-0.530	0.363	1.000	0.246	-0.435	-0.045	-0.140
Phosphate	-0.726	0.091	0.246	1.000	-0.465	-0.107	-0.147
Salinity	0.489	-0.478	-0.435	-0.465	1.000	-0.217	0.179
Chlo-a	0.210	0.340	-0.045	-0.107	-0.217	1.000	0.727
NPP	0.129	0.155	-0.140	-0.147	0.179	0.727	1.000

Correlation of Chlorophyll-a and Net Primary Productivity

The graph showing the correlation between chlorophyll-a values and NPP is presented in Figure 2.

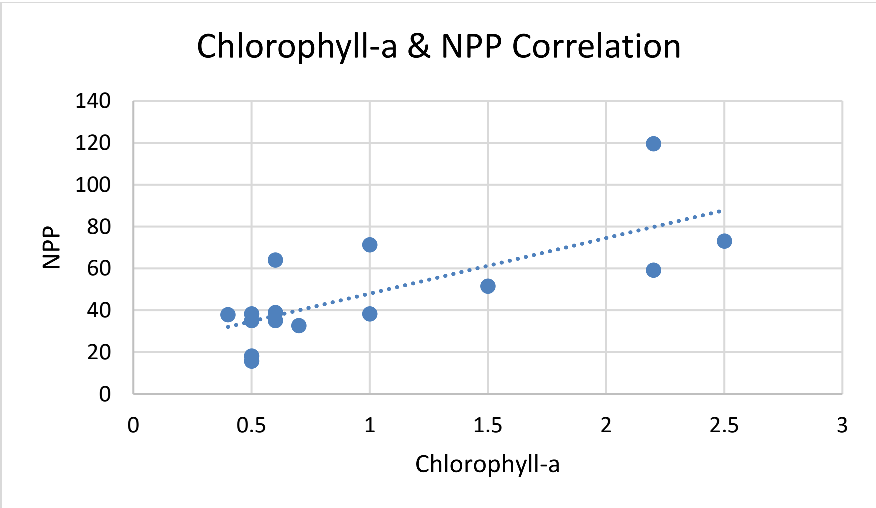

Figure 2. Correlation Graph of Chlorophyll-a and NPP

Assimilation Index

The graph on Figure 3, showing the assimilation index value that indicates the maximum rate of photosynthesis per unit weight of chlorophyll-a per hour.

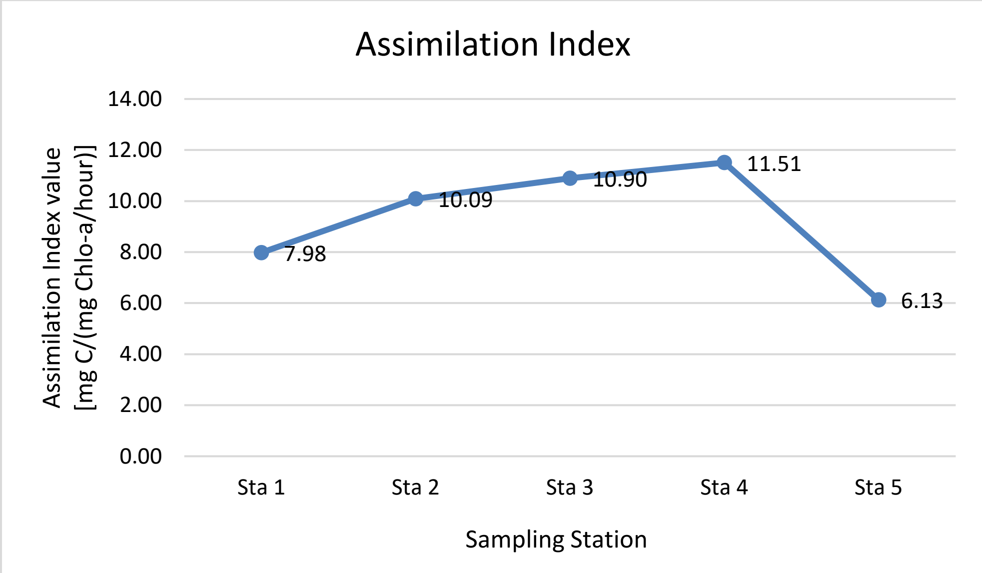

Figure 3. Graph of the Average Assimilation Index for Each Station

DISCUSSION

These relationships indicate that the distribution of nutrients in Lembar Bay is influenced by the interaction of physical and chemical processes rather than by a single environmental parameter. In coastal waters, nutrient availability and phytoplankton productivity are generally controlled by a combination of temperature, water-column mixing, light availability, nutrient supply, and hydrodynamic processes. Chlorophyll-a showed a positive correlation with pH ($r = 0.340$) and, more importantly, a relatively strong positive correlation with NPP ($r = 0.727$). Chlorophyll-a is widely used as an indicator of phytoplankton biomass, whereas NPP represents the rate at which organic carbon is produced through photosynthetic activity. Therefore, the positive correlation observed in this study indicates that areas with greater phytoplankton biomass tended to exhibit higher photosynthetic productivity. A similar relationship between chlorophyll-a and NPP has been reported in the Banda Sea, where changes in chlorophyll-a were closely associated with changes in NPP (Marpaung *et al*., 2022).

The correlation coefficient of 0.727 is particularly relevant to the carbon assimilation potential of Lembar Bay. Phytoplankton assimilate dissolved inorganic carbon during photosynthesis and convert it into organic carbon incorporated into cellular biomass. Consequently, an increase in phytoplankton biomass accompanied by increasing NPP suggests an active biological carbon fixation process. Recent studies have emphasized that microalgae are promising biological systems for CO_2 fixation because carbon is incorporated into biomass while simultaneously supporting the production of potentially valuable biochemical compounds (Xu *et al*., 2023).

However, the relatively weak correlations between chlorophyll-a and nitrate ($r = -0.045$) and phosphate ($r = -0.107$) indicate that nutrient concentrations alone did not strongly control phytoplankton biomass during the sampling period. This finding is ecologically plausible because phytoplankton growth is determined by multiple interacting factors. The availability of nutrients must be considered together with light intensity, temperature, salinity, carbon availability, and physiological condition of the phytoplankton community. A recent review of microalgal cultivation emphasizes that photosynthetic productivity is strongly dependent on the simultaneous optimization of light, temperature, carbon supply, and physiological state (Zhu *et al*., 2023).

The weak relationship between chlorophyll-a and nutrients may also reflect temporal variability in nutrient uptake. Dissolved nitrate and phosphate measured in the water column represent the concentration available at the time of sampling, whereas chlorophyll-a reflects the accumulated response of phytoplankton biomass to environmental conditions. Therefore, low correlation coefficients do not necessarily imply that nitrate and phosphate are unimportant for phytoplankton productivity. Instead, nutrients may have already been assimilated by phytoplankton or may not have been the primary limiting factors during the sampling period.

The assimilation index, expressed as chlorophyll-specific carbon fixation, provides information on the photosynthetic efficiency of phytoplankton independently of their absolute biomass. A high assimilation index means that a unit amount of chlorophyll-a is associated with a relatively high rate of carbon fixation. Demidov *et al*. (2023) described the optimal assimilation number as an important parameter for estimating water-column primary production because it represents the maximum chlorophyll-specific carbon fixation rate of phytoplankton.

The relatively high assimilation index at Station 4 (11.51 mg C mg Chl-a^{-1} hour^{-1}) suggests that the phytoplankton community at this location had comparatively high photosynthetic carbon fixation efficiency. This condition may indicate that the environmental combination at Station 4 was more favorable for photosynthetic activity than at the other stations. Nevertheless, the available data do not allow the specific factor responsible for the high value to be identified conclusively. The correlation matrix only evaluates the relationships among temperature, pH, nitrate, phosphate, salinity, chlorophyll-a, and NPP, and does not directly test the relationship between each environmental variable and the assimilation index. Therefore, attributing the high assimilation index specifically to nutrients, temperature, or salinity would require additional statistical analysis.

In contrast, Station 5 recorded the lowest assimilation index (6.13 mg C mg Chl-a^{-1} hour^{-1}). This result indicates lower carbon fixation per unit of chlorophyll-a compared with the other stations. Importantly, a low assimilation index should not automatically be interpreted as low phytoplankton abundance. Instead, it suggests that the photosynthetic efficiency of the existing phytoplankton biomass was comparatively lower. Environmental stress, suboptimal light conditions, nutrient imbalance, temperature variation, or differences in phytoplankton species composition could contribute to such differences. Previous research has shown that light, temperature, carbon availability, and physiological condition are among the major factors controlling microalgal photosynthetic performance.

The spatial variation in assimilation index is important for identifying potentially promising locations for subsequent isolation and cultivation of indigenous microalgae. Stations with relatively high assimilation values, particularly Stations 3 and 4, may represent suitable locations for screening phytoplankton with high photosynthetic carbon fixation capacity. However, station-level assimilation values should be interpreted as indicators of carbon fixation potential, rather than direct evidence of permanent carbon sequestration.

Implications for Carbon Assimilation and Climate Change Mitigation

The combination of the relatively strong positive correlation between chlorophyll-a and NPP ($r = 0.727$) and the relatively high assimilation index at several stations indicates that phytoplankton in Lembar Bay actively contribute to carbon fixation. The results support the hypothesis that local microalgal communities have potential as biological agents for carbon assimilation. Microalgae have attracted considerable attention as CO_2 mitigation agents because they can rapidly convert inorganic carbon into biomass through photosynthesis.

Reviews published in recent years have consistently identified microalgal CO_2 fixation as a promising pathway for carbon capture and utilization (Ighalo *et al*., 2022).

The potential is not limited to carbon capture itself. The biomass generated through photosynthetic carbon fixation can potentially be converted into biofuels, feed ingredients, biochemicals, pigments, and other value-added products. This carbon capture and biomass valorization pathway is important because the economic feasibility of microalgae-based carbon mitigation depends partly on the ability to utilize the resulting biomass (Sadvakasova *et al*., 2023)

Nevertheless, an important distinction must be made between carbon fixation and long-term carbon sequestration. The NPP and assimilation index measured in this study indicate the rate or efficiency of photosynthetic carbon fixation, but they do not directly demonstrate how much carbon remains stored over an extended period. Fixed carbon can subsequently be transferred through grazing, respiration, decomposition, remineralization, sedimentation, or biomass harvesting. Therefore, the present study should be interpreted as an assessment of the potential for biological carbon assimilation, rather than a complete quantification of permanent carbon sequestration.

Therefore, the natural phytoplankton community in Lembar Bay provides an important ecological starting point for identifying local microalgal strains with high photosynthetic efficiency. The next research stage should focus on isolating dominant or potentially high-performing species from Stations 3 and 4, followed by species identification and controlled cultivation experiments. Parameters such as biomass productivity, chlorophyll-a concentration, photosynthetic efficiency, carbon fixation rate, and CO_2 uptake should then be measured under controlled conditions.

CONCLUSION

The waters of Lembar Bay exhibit potential carbon fixation activity by phytoplankton communities, as indicated by a relatively strong positive relationship between chlorophyll-a and Net Primary Productivity (NPP). The assimilation index values show inter-station variation, indicating differences in photosynthetic efficiency and carbon fixation capacity per unit of chlorophyll-a across locations. These results suggest that local microalgae in the waters of Lembar Bay have potential as carbon assimilation agents to support climate change mitigation, although the assimilation index values cannot be directly interpreted as long-term carbon sequestration.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the Institute for Research and Community Service (Lembaga Penelitian dan Pengabdian kepada Masyarakat/LPPM), University of Mataram, for providing financial support for this research through the Early-career Lecturer Research Scheme under Contract No. 5108/UN18.L1/PP/2026. The authors also gratefully acknowledge the support and assistance provided by all parties who contributed to the implementation of this research.

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