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PLANKTON DYNAMICS AS NATURAL FOOD INDICATORS DURING NILE TILAPIA (*Oreochromis niloticus*) LARVAL REARING IN AQUAPONIC, BIOFLOC, AND AQUABIOPONIC SYSTEMS

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ABSTRACT

Plankton communities are important in Nile tilapia larval rearing because they function as natural food, a pathway for nutrient and energy transfer, and an ecological indicator of changes in the rearing medium. This study evaluated plankton abundance, genus composition, and ecological indices during Nile tilapia (*Oreochromis niloticus*) larval rearing in aquaponic (AP), biofloc (BF), and aquabioponic (AB) systems. A 45-day experiment was conducted using a completely randomized design with three treatments and four replicates. Each experimental unit contained 30 L of water and 30 larvae. Plankton was sampled on days 0, 15, 30, and 45 by filtering 10 L of culture water, concentrating the sample to 50 mL, and observing the concentrated sample using a hemocytometer. Plankton community data were interpreted descriptively, and no statistical significance is claimed for plankton parameters. The three systems developed distinct plankton trajectories. AP showed gradual recovery of plankton abundance and an increase in diversity and evenness by day 45 (H' = 1.79; E = 0.92). BF produced the highest final abundance, driven by *Oscillatoria* on day 45 (104.00×10^3 ind. mL^{-1}; approximately 78% of the community), but showed lower final evenness (E = 0.42) and higher Simpson dominance (C = 0.76). AB showed an early *Chlorella* peak on day 15 (53.25×10^3 ind. mL^{-1}) and later shifted toward a more even community by day 45 (H' = 1.79; E = 0.92). These findings indicate that high plankton abundance does not necessarily represent a balanced natural food community. Based on descriptive plankton community indicators, AP and AB appeared more supportive of balanced plankton communities for tilapia larval rearing, whereas BF required stricter management of organic load, floc volume, pH, and nutrient input to prevent cyanobacterial dominance.

Key words: Aquabioponics, Aquaponics, Biofloc, Cyanobacteria, Nile Tilapia Larvae, Plankton.

INTRODUCTION

The larval phase is a critical stage in Nile tilapia (*Oreochromis niloticus*) production because feeding ability, digestive capacity, and environmental tolerance are still developing. During this stage, microscopic natural food can contribute not only to nutrient intake but also to the stability of the rearing medium. Planktonic organisms may provide protein, lipid, pigments, minerals, and other bioactive compounds either directly to larvae or indirectly through the microbial food web. Recent evidence shows that microalgae and microalgae-enriched live prey can support early feeding and larval performance in Nile tilapia (Ritu *et al.*, 2024), while broader aquaculture reviews emphasize algae as nutrient-rich organisms with roles in feed supplementation and water-quality improvement (Vijayaram *et al.*, 2024). Therefore, plankton dynamics are relevant to fish nutrition because they reflect the potential availability and stability of natural food in larval rearing systems.

The development of water-efficient and low-waste aquaculture systems has encouraged the use of aquaponics, biofloc technology, and their integration. Aquaponics relies on interactions among fish, nitrifying microorganisms, and plants to recycle nutrients, allowing fish-derived nitrogenous waste to be transformed and partly absorbed by plants (Kasozi *et al.*, 2021; Khater *et al.*, 2023). In the present study, *Azolla* sp. was used as the plant component because floating aquatic plants can contribute to nutrient uptake and media stabilization. Recent work has shown that *Azolla* can reduce nitrate and phosphate levels in fish-pond water through nutrient accumulation in plant biomass (Chakraborty *et al.*, 2025). Such nutrient regulation is expected to influence phytoplankton development and natural-food availability in larval rearing media.

Biofloc technology, in contrast, stimulates heterotrophic microbial growth by regulating the carbon-to-nitrogen (C:N) ratio. These microorganisms assimilate inorganic nitrogen into microbial biomass, which may serve as supplementary natural food and a bioremediation component (Khanjani & Sharifinia, 2020; Khanjani *et al.*, 2022). Biofloc performance, however, is highly dependent on the carbon source, C:N ratio, floc volume, pH, dissolved oxygen, and the composition of microbial and plankton communities (Abakari *et al.*, 2021a, 2021b; Mali *et al.*, 2024; Xu *et al.*, 2022). Studies on tilapia show that carbon sources such as tapioca flour can improve water quality and fish performance under biofloc conditions, but the response depends on system management (Rind *et al.*, 2023; Soliman & Abdel-Tawwab, 2022).

The integration of aquaponic and biofloc principles, often described as FLOCponics or aquabioponics, combines microbial biomass production with plant nutrient uptake. In this article, aquabioponic refers operationally to a larval rearing system that includes Nile tilapia larvae, heterotrophic microbial flocs, and *Azolla* sp. in the same rearing unit. Integrated systems may simultaneously provide microbial biomass as internal natural food and plant-mediated nutrient removal, but they may also generate nonlinear plankton responses because phytoplankton, bacteria, plants, zooplankton, and fish larvae compete for and transform nutrients in the same medium (Hwang *et al.*, 2023; Pinho *et al.*, 2021).

Plankton communities in aquaculture ponds respond directly to nutrient loading, feeding practices, temperature, pH, and hydrodynamic conditions. Recent studies indicate that phytoplankton abundance and community composition can be more sensitive to aquaculture management than diversity indices alone (Rao *et al.*, 2025). Cyanobacterial dominance may increase under high nutrient availability, available phosphorus, alkaline pH, and uncontrolled organic loading (Backovic & Tokodi, 2024;

Jin *et al.*, 2024). In larval rearing, this is important because cyanobacterial dominance may reduce the balance of natural food organisms, alter oxygen and pH dynamics, and potentially increase the risk of undesirable metabolites.

Research on biofloc and aquaponic systems for tilapia has largely emphasized growth, feed efficiency, water quality, microbial dynamics, and plant production (Fan *et al.*, 2025; Helal *et al.*, 2024; Yu *et al.*, 2023a, 2023b). Direct comparisons of plankton community dynamics during Nile tilapia larval rearing in aquaponic, biofloc, and aquabioponic systems remain limited. We hypothesized that the integrated aquabioponic system would support a more balanced plankton community than biofloc alone because microbial flocs and *Azolla* sp. may jointly regulate nutrient availability. This study aimed to evaluate plankton abundance, dominant genera, and diversity, evenness, and dominance indices in three tilapia larval rearing systems, and to infer their implications for natural-food management in hatchery media.

METHODS

Experimental Period and Location

The study was conducted for 45 days, from 13 January to 26 February 2026, at the Fish Production and Reproduction Laboratory, Aquaculture Study Program, Faculty of Agriculture, University of Mataram, Indonesia. Nile tilapia larvae were obtained from PT Central Proteina Prima Embung Pas, Lingsar District, West Lombok Regency, West Nusa Tenggara, Indonesia. The experiment was performed under controlled laboratory hatchery conditions using freshwater rearing units.

Experimental Design and Treatments

The experiment used a completely randomized design consisting of three culture-system treatments and four replicates, resulting in 12 experimental units. Each unit consisted of a 45 L plastic container filled with 30 L of working water volume. The initial stocking density was 30 larvae per unit, equivalent to 1 larva L^{-1}. The treatments were aquaponic (AP), biofloc (BF), and aquabioponic (AB) systems. The experimental units were treated as independent replicates, and plankton data were summarized by system and sampling day as descriptive community indicators.

Table 1. Treatment structure used in the Nile tilapia larval rearing experiment.

Code	System	Main components	Key nutrient-management feature
AP	Aquaponic	Nile tilapia larvae + *Azolla* sp.	Plant-based nutrient uptake; 50 g *Azolla* sp. per unit
BF	Biofloc	Nile tilapia larvae + heterotrophic microbial flocs	Tapioca flour as carbon source; target C:N = 10
AB	Aquabioponic	Nile tilapia larvae + *Azolla* sp. + heterotrophic microbial flocs	Combined *Azolla* sp. and floc component; target C:N = 5

Note: AP = aquaponic; BF = biofloc; AB = aquabioponic. The carbon source and C:N targets were applied only to treatments containing the biofloc component.

Culture Media Preparation

The rearing containers were washed, filled with 30 L of freshwater, sterilized using 30 ppm chlorine, and neutralized using sodium thiosulfate before use. The culture media were then prepared according to the treatment requirements. BF and AB treatments received tapioca flour as an external carbon source to stimulate heterotrophic floc formation. AP and AB treatments received 50 g of Azolla sp. per unit as the plant component and biofilter. The use of Azolla sp. was intended to support nutrient uptake and reduce the accumulation of dissolved nutrients derived from feed residues and larval metabolic waste.

Larval Acclimation and Feeding Management

Nile tilapia larvae with an initial length of approximately 1 cm were acclimated for 3-4 days before stocking. Prior to stocking, the larvae were fasted for 24 h to standardize the initial feeding condition and reduce organic input at the beginning of the rearing period. Commercial powdered feed was provided three times daily at 08:00, 13:00, and 17:00 using an at-satiation method. Operationally, feed was provided gradually until the feeding response declined and visible feed accumulation in the water was avoided. The daily C:N ratio was targeted at 10 in BF and 5 in AB, reflecting different nutrient-regulation strategies between the biofloc-only and integrated biofloc-plant systems.

Plankton Sampling and Observation

Plankton sampling was conducted on days 0, 15, 30, and 45. A total of 10 L of culture water from each experimental unit was filtered using a plankton net, and the filtered sample was concentrated to 50 mL. The concentrated samples were preserved using Lugol solution and observed with a hemocytometer under a microscope. Plankton abundance was expressed as $\times 10^3$ individuals mL^{-1} of concentrated filtrate to maintain consistency with the hemocytometer-based observation approach. This unit should be interpreted as an abundance index of the concentrated sample rather than as a direct estimate per mL of original rearing water.

Plankton was identified to the genus level. The main genera recorded and discussed in this study were *Chlorella*, *Nitzschia* sp., and *Oscillatoria*. Because genus-level composition was used to evaluate ecological balance and potential natural-food availability, both abundance and relative contribution of dominant genera were considered in the interpretation.

Community Parameters and Supporting Water Quality

The primary parameters were plankton abundance, relative genus composition, Shannon-Wiener diversity index (H'), Pielou evenness index (E), and Simpson dominance index (C). The ecological indices were calculated as follows: $H' = -\Sigma p_i \ln p_i$, $E = H'/\ln S$, and $C = \Sigma p_i^2$, where pi is the relative abundance of the i-th genus and S is the number of genera recorded in the sample. Supporting water-quality parameters included dissolved oxygen (DO), pH, temperature, ammonia, nitrate, nitrite, and floc volume. These parameters were used to support ecological interpretation, particularly the relationship between nutrient conditions, floc development, and cyanobacterial dominance.

Data Analysis

Plankton abundance, genus composition, and ecological indices were analyzed descriptively by treatment and sampling day. No ANOVA or post hoc comparison was applied to plankton community parameters because the objective was to characterize temporal community trajectories rather than to test statistical differences among culture systems. Therefore, the terms higher, lower, increasing, decreasing, more even, and more dominant refer to observed descriptive patterns and not to inferential statistical significance. Water-quality data were also summarized descriptively to support interpretation of plankton community changes.

RESULTS

Plankton Abundance Dynamics

Plankton abundance showed different temporal patterns among the three rearing systems (Figure 1). In AP, the initial community was dominated by *Chlorella* at 14.00 $\times 10^3$ ind. mL^{-1} and *Nitzschia* sp. at 10.00 $\times 10^3$ ind. mL^{-1}. *Chlorella* decreased to 2.70 $\times 10^3$ ind. mL^{-1} on day 15, then increased to 4.60 $\times 10^3$ ind. mL^{-1} on day 30 and 5.70 $\times 10^3$ ind. mL^{-1} on day 45. This pattern indicates that AP did not produce an extreme abundance surge but supported gradual recovery of the dominant plankton component toward the end of rearing.

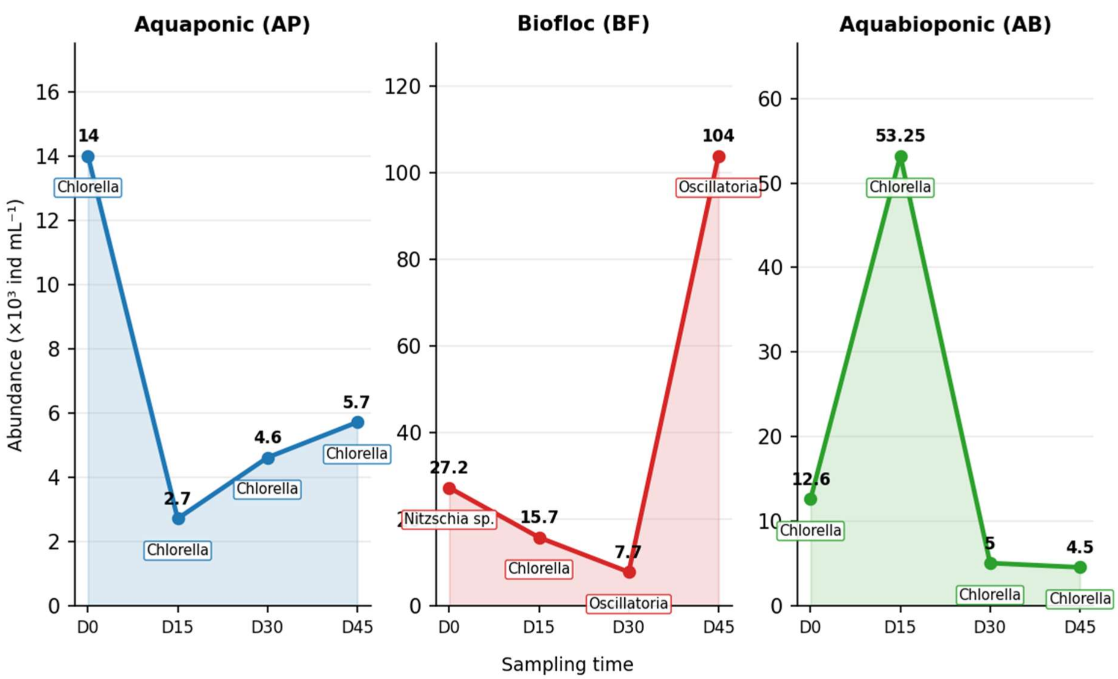

Figure 1. Temporal trajectories of dominant plankton genera in aquaponic (AP), biofloc (BF), and aquabioponic (AB) systems. Values are descriptive treatment summaries and are expressed as $\times 10^3$ ind. mL^{-1} of concentrated filtrate. D0, D15, D30, and D45 indicate sampling days 0, 15, 30, and 45; no inferential statistical comparison is implied.

BF showed the strongest fluctuation. On day 0, the community was dominated by *Nitzschia* sp. at 27.20 ×10³ ind. mL⁻¹. On day 15, dominance shifted to *Chlorella* at 15.70 ×10³ ind. mL⁻¹, whereas on day 30 *Oscillatoria* became the dominant genus at 7.70 ×10³ ind. mL⁻¹. On day 45, *Oscillatoria* increased sharply to 104.00 ×10³ ind. mL⁻¹. Because the plankton parameters were interpreted descriptively, this increase is presented as an ecological tendency rather than as a statistically tested treatment effect.

In AB, the abundance peak occurred earlier, on day 15, when *Chlorella* reached 53.25 ×10³ ind. mL⁻¹. Thereafter, *Chlorella* decreased to 5.00 ×10³ ind. mL⁻¹ on day 30 and 4.50 ×10³ ind. mL⁻¹ on day 45. This pattern suggests an early green-microalgae productivity phase followed by a decline in dominance and a more distributed genus composition by the end of the experiment.

Genus Composition and Ecological Indices

Genus composition indicated that AP and AB moved toward a more even plankton community by day 45, whereas BF shifted toward *Oscillatoria* dominance (Figure 2). In AP, the proportion of *Chlorella* decreased from 57% on day 0 to approximately 27% on day 45. In AB, *Chlorella* increased sharply to 81% on day 15 but decreased by day 45 as the contribution of other genera increased. In contrast, *Oscillatoria* in BF increased to approximately 78% of the community on day 45.

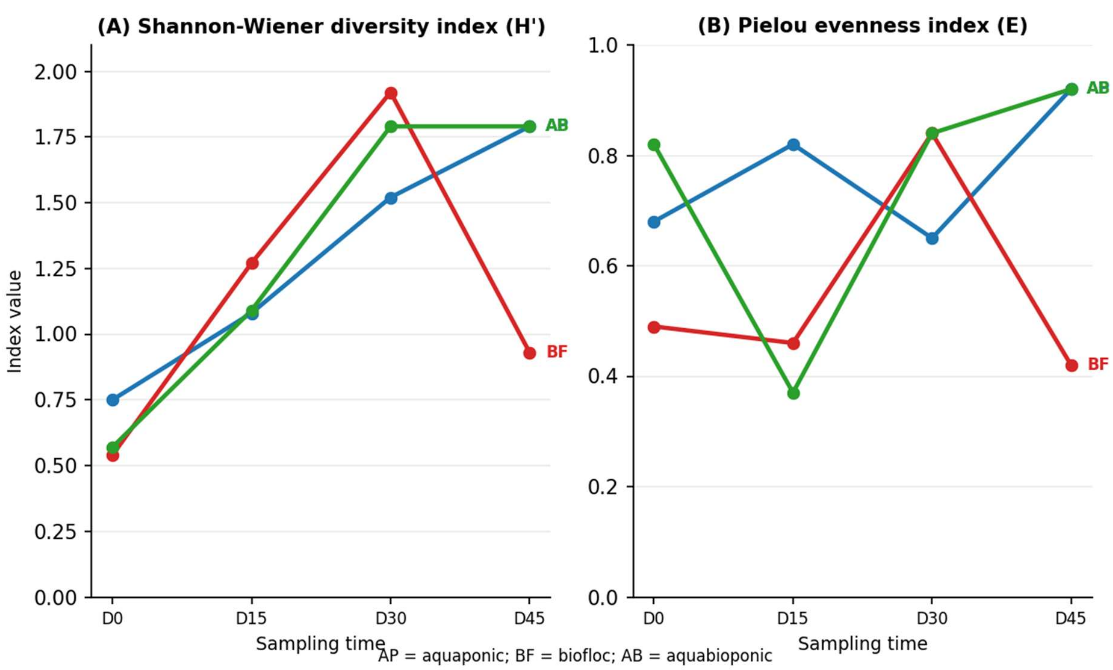

Figure 2. Changes in Shannon-Wiener diversity index (H’) and Pielou evenness index (E) of plankton during Nile tilapia larval rearing in AP, BF, and AB systems. Values are descriptive treatment summaries; no inferential statistical comparison is implied.

The ecological indices supported these patterns. H' in AP increased from 0.75 on day 0 to 1.79 on day 45, while AB increased from 0.57 to 1.79 over the same period. In BF, H' increased from 0.54 on day 0 to 1.92 on day 30 but decreased to 0.93 on day 45. Final E values were 0.92 in AP and AB, indicating a more even distribution of individuals among recorded genera, whereas BF decreased to 0.42. The Simpson dominance value in BF increased to 0.76 on day 45, consistent with the strong dominance of *Oscillatoria*. These values are descriptive indicators of community structure (Table 2).

The ecological index patterns in Figure 2 show that AP and AB maintained higher final evenness than BF, while the sharp decline in BF evenness on day 45 supports the interpretation of late cyanobacterial dominance.

Table 2. Descriptive summary of plankton community dynamics during 45 days of Nile tilapia larval rearing.

System	Dominant abundance trajectory	Final dominant pattern	Final H'	Final E	Interpretation based on plankton indicators
AP	Day-15 decline followed by gradual recovery to day 45	*Chlorella* remained present but declined to approximately 27%	1.79	0.92	More even final community without an extreme abundance surge
BF	Sharp increase at day 45	*Oscillatoria* reached approximately 78%; abundance 104.00 $\times 10^3$ ind. mL^{-1}	0.93	0.42	High final abundance but strong dominance and lower evenness
AB	Early *Chlorella* peak at day 15 followed by dispersion	*Chlorella* decreased and other genera contributed more by day 45	1.79	0.92	More even final community after an early productivity peak

Note: Values are descriptive treatment summaries. H' = Shannon-Wiener diversity index; E = Pielou evenness index.

Supporting Water Quality

Supporting water-quality parameters showed different media characteristics among systems. DO ranged from 4.1 to 7.2 mg L^{-1}, temperature ranged from 27 to 34 °C, nitrite ranged from 0 to 0.25 mg L^{-1}, and floc volume ranged from 0 to 34 mL L^{-1} (Table 3). BF and AB tended to have more alkaline pH than AP, and the highest ammonia concentration was recorded in BF. These water-quality summaries were used to support ecological interpretation and not to infer statistically significant treatment differences. The relatively high pH range and high floc volume in BF should be interpreted cautiously because they may influence the proportion of unionized ammonia and may favor cyanobacterial proliferation under organic-rich conditions.

Table 3. Range of supporting water-quality parameters during the rearing period.

Parameter	AP	BF	AB
DO (mg L^{-1})	4.8-6.9	4.1-7.1	4.6-7.2
pH	7.44-8.97	8.22-9.25	8.09-9.28
Temperature (°C)	27-33	27-34	27-33
Ammonia (mg L^{-1})	0-0.6	0-1.0	0-0.25
Nitrate (mg L^{-1})	8.75-50	0.5-100	15.5-50
Nitrite (mg L^{-1})	0-0.25	0-0.1	0-0.1
Floc volume (mL L^{-1})	0-3	8-34	1-6

Note: AP = aquaponic; BF = biofloc; AB = aquabioponic. Values are descriptive ranges used as supporting information for ecological interpretation.

DISCUSSION

The three rearing systems produced distinct plankton community trajectories, indicating that nutrient regulation mechanisms influenced not only plankton abundance but also the structure of the potential natural-food community. In AP, the decline in *Chlorella* abundance on day 15 may indicate early adjustment among larvae, plants, microorganisms, and plankton after stocking. The subsequent increase in diversity and evenness until day 45 suggests that the AP medium became less controlled by a single dominant genus. This response is consistent with aquaponic principles, where nitrogenous waste from fish is transformed by microorganisms and partly absorbed by plants, reducing excessive nutrient accumulation (Kasozi *et al.*, 2021; Khater *et al.*, 2023).

From a fish-nutrition perspective, the presence of green microalgae such as *Chlorella* is relevant because microalgae can contribute to natural-food availability, improve the green-water environment, and provide nutrients or bioactive compounds to larvae either directly or indirectly through the food web. Reports on *Chlorella vulgaris* supplementation in biofloc systems show that this microalga can contribute to Nile tilapia rearing performance (Araujo *et al.*, 2019), while broader reviews support the role of algae as nutrient-rich resources in aquaculture (Vijayaram *et al.*, 2024). However, in the present study the key indicator was not only the presence of *Chlorella* but also the reduction of excessive dominance in AP and AB by day 45, suggesting a more balanced plankton community.

BF produced the highest final plankton abundance but the weakest final evenness. The sharp increase in *Oscillatoria* on day 45 coincided with the BF system having relatively alkaline pH and the highest floc-volume range compared with the other systems. Although the water-quality data are summarized as ranges and not as day-specific statistical comparisons, this pattern suggests that suspended organic matter accumulation, changing nutrient ratios, and alkaline conditions may have favored cyanobacterial dominance. This interpretation is consistent with reports that cyanobacteria in aquaculture can increase under eutrophic or nutrient-rich conditions and may alter phytoplankton community structure (Backovic & Tokodi, 2024; Jin *et al.*, 2024).

Biofloc remains valuable for aquaculture because it can improve nitrogen utilization and generate microbial biomass that may act as an internal food resource (Khanjani & Sharifinia, 2020; Khanjani *et al.*, 2022). Nevertheless, the present findings emphasize that biofloc success should not be evaluated only from high plankton abundance or high floc volume. When floc accumulation is excessive and the plankton community shifts toward cyanobacterial dominance, the medium may become less balanced as a natural-food environment. Therefore, biofloc management in larval rearing should include routine monitoring of pH, floc volume, organic load, dissolved oxygen, and carbon-source input, especially during the later rearing phase.

AB showed an early *Chlorella* peak followed by a more even community at the end of rearing. This pattern suggests that combining flocs and *Azolla* sp. may initially enhance green-microalgae productivity but later regulate nutrient availability through plant uptake and microbial processes. The interpretation is consistent with integrated systems such as FLOCponics, which can establish complex nutrient circulation involving fish, plants, bacteria, and suspended microbial aggregates (Hwang *et al.*, 2023; Pinho *et al.*, 2021). However, AB also differs from BF not only because of the plant component but also because the target C:N ratio was lower (5 in AB versus 10 in BF). Therefore, the AB response should be interpreted as the combined outcome of plant presence and different carbon-input strategy.

The final ecological indices support the view that AP and AB were more favorable than BF based on plankton community stability indicators. AP and AB reached final H’ and E values of 1.79 and 0.92, respectively, while BF declined to H’ = 0.93 and E = 0.42 on day 45 due to *Oscillatoria* dominance. Rather than classifying the systems as categorically good or poor, these indices should be interpreted together with genus composition and water quality. A system with high abundance but low evenness may provide less balanced natural-food conditions than a system with moderate abundance but a more distributed community structure.

The practical implication is that plankton management in Nile tilapia hatcheries should target balance rather than simply maximizing plankton density. In AP and AB, nutrient uptake by plants should be monitored so that natural-food availability is not suppressed during the early larval phase. In BF, the main priority is to prevent excessive floc accumulation, high pH, and cyanobacterial dominance during the later phase. Carbon-source input, aeration, sludge/floc control, and feed loading should be adjusted according to system age and plankton response (Mali *et al.*, 2024; Rind *et al.*, 2023; Soliman & Abdel-Tawwab, 2022).

This study has several limitations. First, plankton data were interpreted descriptively and were not used for inferential statistical testing. Second, the nutritional composition of plankton and biofloc, bacterial community structure, and cyanotoxin presence were not measured. Third, the study focused on plankton community indicators and supporting water quality, so direct links with larval survival, growth, feed utilization, and body nutrient composition require further investigation. These limitations do not reduce the ecological relevance of the findings, but they delimit the strength of conclusions that can be drawn for fish nutrition and hatchery performance.

Overall, the results suggest that the most favorable system for Nile tilapia larvae should not be defined solely by the highest plankton abundance. Based on descriptive plankton community indicators, AP and AB provided more balanced final communities, whereas BF produced a late abundance surge dominated by *Oscillatoria*. Therefore, aquaponic and aquabioponic systems appear promising for maintaining balanced natural-food communities in larval rearing media, while biofloc systems require more precise control of organic load, floc volume, pH, and nutrient input to prevent the benefits of internal microbial productivity from shifting toward ecological imbalance.

CONCLUSION

Aquaponic, biofloc, and aquabioponic systems produced different plankton community dynamics during 45 days of Nile tilapia larval rearing. AP showed gradual recovery of plankton abundance and reached a more even community by day 45 (H’ = 1.79; E = 0.92). BF produced the highest final abundance, driven by *Oscillatoria* on day 45 (104.00 $\times 10^3$ ind. mL^{-1}; approximately 78% of the community), but showed lower final evenness (E = 0.42) and higher dominance (C = 0.76). AB showed an early *Chlorella* peak on day 15 (53.25 $\times 10^3$ ind. mL^{-1}) and later shifted toward a more even final community (H’ = 1.79; E = 0.92). Based on descriptive plankton community indicators, AP and AB appeared more supportive of balanced natural-food communities than BF at the end of rearing. Biofloc systems remain promising, but stricter management of carbon sources, floc volume, pH, organic load, and nutrients is required to prevent cyanobacterial dominance. Future research should link plankton dynamics with larval survival, growth performance, feed utilization, and nutritional quality of plankton and biofloc.

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