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Influence of Water Exchange Frequency on Phytoplankton Succession in Inland Fish Culture Ponds

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Abstract: The phytoplankton community is the base of productivity in fish culture ponds, but the community structure keeps changing constantly because of the increase in nutrient concentration, and sometimes such changes may become unfavorable, with a tendency towards the prevalence of cyanobacteria in water bodies, which may affect the health of fish. Water exchange is one of the most common methods for the control of the process, but it is always carried out without any planned frequency. In this study, the influence of four different frequencies of water exchange – non-exchange, once every 14, 7, and 3 days (20% of pond volume)- on phytoplankton succession in twelve earthen carp ponds during 120 days of culture was assessed. Higher exchange reduced ammonia, phosphorus, and chlorophyll-a, improved dissolved oxygen and transparency, and stabilized pH. The total phytoplankton abundance decreased from 18.6×10^6 cells L^{-1} in non-exchange to 5.7×10^6 cells L^{-1} when exchanged at a 3-day interval, and the Shannon index increased from 1.84 to 3.02. Cyanobacteria formed over 50% of all cells after about day 38 in the absence of exchange, after day 62 in the case of two-weekly exchange, and transiently just before day 87 in the case of one-weekly exchange, and not at all in the case of three-day exchange. A cyclic scheme for the relationship between exchange, dilution, environment, community structure and pond management is suggested.

Keywords: Water Exchange Frequency; Phytoplankton Succession; Fish Culture Ponds; Cyanobacterial Blooms; Community Diversity; Pond Water Quality.

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I. Introduction

Inland Fish Culture Ponds and their Plankton Base

Inland pond farming provides a great proportion of the freshwater fish consumed in tropical and subtropical climates. Carp polyculture in earth ponds continues to be an important part of freshwater aquaculture in several nations. In semi-intensive farming systems, the ponds are provided with feed, fertilizers and fish waste, which gradually raise the levels of nitrogen and phosphorus in the water. These nutrients help grow a large population of phytoplankton that produce oxygen by way of photosynthesis, take up inorganic nutrients and transform them into cellular matter, forming the base of a natural food chain that serves as nourishment for zooplanktons and small-sized fishes. However, overgrown phytoplankton populations may create certain ecological problems due to their unbalanced population structure. Overgrown blooms lead to drastic changes in levels of oxygen and pH, decrease in light penetration and production of substances by some cyanobacteria affecting water quality and fish health. Studies of the freshwater fishponds have shown that human activities and pond farming methods may affect the biomass, composition and seasonal dynamics of phytoplankton (Adamovich & Medvinsky, 2023). Therefore, a pond should be considered as a managed ecosystem, where both phytoplankton biomass and composition matter.

Phytoplankton Succession in Managed Ponds

Pond management results in phytoplankton communities that are not stable in their composition during the entire cultivation period. The community structure varies depending on ecological succession, which entails the variation in the number of individuals in each group as well as the dominance of different taxonomic groups. In fertilized ponds, the initial phytoplankton community may consist of fast-growing diatoms and green algae, followed by a shift to larger colony-forming phytoplankton or floating species due to increasing nutrient levels and stability of the water column. Factors like nutrient availability, light, temperature, grazing pressure, and physical disturbances determine the nature and rate of succession. They

have a major influence on the productivity of the ponds and oxygen depletion. It has been found from the studies of aquaculture systems that the succession of phytoplankton community is directly related to water quality (Qiao et al., 2020).

Water Exchange as a Management Practice and the Research Problem

The farmers exchange pond water in order to lower the concentrations of the metabolites, clean up water, solve the problem of oxygen, and avoid excess of phytoplankton blooms. Nevertheless, water exchange strategies are rather different from farm to farm. Some farmers exchange the water in the ponds regularly, some do it occasionally or when they see that the fish is under stress. Excessive water exchange is costly in terms of water and energy; it may cause appearance of suspended materials or pathogens as well as disturbance of phytoplankton community. On the contrary, lack of water exchange might cause accumulation of nutrients and organic material leading to excess algal proliferation. Inland aquaculture farms have limited access to the water supply, while the effluents of intensively managed ponds may contain extra nutrients which may be transferred to the aquatic ecosystem nearby.

Objectives and Hypotheses

The primary aim of this research was to investigate the effect of water exchange frequency on the successional pattern of phytoplankton communities in fish breeding ponds in inland waters.

Specific aims included:

1. Comparing water quality parameters between various water exchange frequencies.
2. Measuring the abundance, composition, and diversity of phytoplankton in different water exchange frequency.
3. Analyzing the temporal trends in phytoplankton succession during the culture period.
4. Establishing the environmental parameters that correlate with changes in phytoplankton community structure.

Three hypotheses served as the foundation for this research:

- H1: Water exchange frequency affects the nutrient levels and phytoplankton biomass.
- H2: Water exchange frequency affects phytoplankton diversity and reduces the proportion of cyanobacteria.
- H3: The development of cyanobacterial domination is more gradual in high water exchange frequency.

Significance and Scope

This research is important in three aspects. Firstly, the water exchange frequency is viewed as a controllable parameter that needs managing rather than a response to issues associated with the ponds. This will help assess the impact of the factor on ecology in a systematic way. Secondly, the research examines phytoplankton dynamics during the entire life-cycle of the culture and not just at one point in time, which makes the succession process evident. Thirdly, the research establishes the connection between phytoplankton community dynamics and water quality parameters, making it possible to use the results for regular pond monitoring and management. The research scope is limited to freshwater carp earthen ponds operated in semi-intensive regime.

II. Literature Review

Water Exchange Practices and Nutrient Dynamics in Pond Aquaculture

Water exchange is an essential component of the maintenance of physical, chemical and biological parameters of ponds used for inland fish farming. It affects nutrient levels, organic matter concentration, phytoplankton population and water retention period. In the process of water exchange, a certain proportion

of pond water is withdrawn and replaced by fresh water. This leads to reduction of nutrient concentration, suspended organic matter and phytoplankton cells. The amount and regularity of water exchanges affect the degree of removal of these materials from the pond. Inflow and outflow of water can also affect sediment turnover, water currents and mixing processes. Finally, inflowing water may serve as a carrier of phytoplankton species and other plankton and thus influence the biological composition of the pond. Studies of zero water exchange systems in freshwater fish farming have stressed the importance of nutrient inputs, retention and internal balance of nutrients for pond water condition (Zhang et al., 2022). The effect of water exchange depends on the quality of inflow water, stocking rate, feeding, nutrient loading and frequency of exchanges.

Phytoplankton Diversity, Ecological Preferences and Community Succession

The phytoplankton communities found in inland fish ponds contain different taxonomical groups such as diatoms (Bacillariophyta), green algae (Chlorophyta), cyanobacteria and euglenoids. The response of these groups to environmental conditions like nutrient concentration, temperature, light, water movement, and organic enrichment differs among them. For instance, the diatoms usually flourish in the presence of adequate silica and water movement, while the green algae flourish due to nitrogen and phosphorus balance. The cyanobacteria often dominate when the water is warm, nutrient-enriched, stable, and low on nitrogen relative to phosphorus. Euglenoids are mostly found in organically rich environments. Therefore, any alteration in environmental factors may result in the variation of phytoplankton abundance and dominance. Studies carried out on fresh water water bodies in Eastern India have proven that environmental changes play an important role in the formation of phytoplankton communities (Garai et al., 2025).

Ecological Mechanisms Governing Phytoplankton Succession

The succession process of phytoplankton populations is affected by resource competition, environmental disturbance, and interactions in the aquatic food web. Resource competition determines the dominance of certain phytoplankton groups depending on specific nutrients available, mainly nitrogen, phosphorus, and silica. Changes in the frequency of water exchange affect nutrient levels and ratios, thus affecting the competitive abilities of each group. Furthermore, the intermediate disturbance hypothesis explains changes in the diversity of phytoplankton populations ecologically. In cases of more stable conditions, competitive dominance leads to low species diversity. On the other hand, high disturbance eliminates sensitive species while moderate disturbance allows coexistence because it prevents dominance of limited numbers of taxa. Finally, phytoplankton biomass is affected by nutrient levels and grazing activity of zooplankton and filter feeders. Investigations of zooplankton communities in freshwater aquaculture ponds have shown that environmental factors and ecological assembly processes play an important role in plankton community composition (Mao et al., 2025). Therefore, water exchange affects phytoplankton succession not only through cell removal but also through nutrient levels and food-web interactions.

Cyanobacterial Dominance and Water Quality Indicators in Fish Culture Ponds

The enrichment of nutrients is one of the key factors affecting the composition of phytoplanktons in fish cultivation ponds. Unconsumed food, excrement from fishes and decomposed organic matter contribute to the amount of nitrogen and phosphorous in the water column and sediments. Over-enrichment of nutrients can result in excessive growth of phytoplanktons and the probability of dominance of cyanobacteria. The combination of warm water, high pH, good lighting conditions and stable water column can favor the development of cyanobacteria. Some cyanobacteria have buoyancy-controlling structures that enable them to float near the water surface and compete for light efficiently. This dominance can create unfavorable conditions in the pond due to excessive shading, oxygen variation and production of cyanotoxins. Seasonal variation of temperature and other environmental factors has been found to cause cyanobacterial dominance in aquaculture fishponds (Bassey et al., 2025).

There are several parameters that could be measured to determine these changes in ecology. Secchi depth gives an estimate of the degree of water transparency, the amount of chlorophyll-a reflects the biomass of phytoplankton, and the concentration of dissolved oxygen reflects the changes in the oxygen status of the pond. The taxonomic composition, the abundance of cyanobacteria, and the phytoplankton diversity indices give additional information about the structure and condition of the pond. Studies investigating the effect of pond depth and the pond aeration process revealed that the physical condition of the ponds can affect phytoplankton communities (Sheng et al., 2023). Moreover, research involving polyculture filtration feeders investigated the regulation of the cyanobacterial blooms and the resulting changes in the water quality and microbial communities in fishponds (Tang et al., 2021). The seasonal nitrogen-phosphorus balance gives additional insights into the ecological conditions affecting the phytoplankton development in fishponds (Kajgrová et al., 2024). These parameters altogether provide a holistic measure of pond water quality and phytoplankton dynamics. Research on phytoplankton succession in freshwater lakes revealed the importance of environmental factors for community changes (Yin et al., 2024).

Research Gaps and the Need for Frequency-Based Water Exchange Assessment

Despite the known usefulness of water exchange in pond management, the role of water exchange on the dynamics of succession of the phytoplankton community is poorly studied under varying conditions of inland aquaculture. Current practices of pond management do not pay due attention to the frequency of water exchanges in terms of the impact on the structure and seasonal dynamics of phytoplankton communities. Indeed, phytoplankton is estimated mostly by means of biomass parameters without paying enough attention to the taxonomic diversity of the phytoplankton, its dominant groups and abundance of cyanobacteria. At the same time, there is a need for further research into the interrelationship between water residence time, nutrients' availability, properties of water sources and biological interactions. Comparative studies should be conducted on the impact of various water exchange frequencies under similar stocking densities, feeding schedules and pond management practices. The recurrent observations of phytoplankton composition, chlorophyll-a, transparency, oxygen content and nutrients concentrations would allow establishing the relationship between the water exchange frequency and the process of ecological succession.

III. Research Methodology

Study Site and Experimental Design

The experiment was conducted in twelve rectangular earthen ponds having a surface area of 400 m^2 and an operating depth of 1.5 meters located at an inland fresh water aquaculture experimental facility. These ponds were drained, dried in the sun for two weeks, limed at 250 kg ha^{-1} and then filled using water from a common reservoir supplied by groundwater and canal water. Fertilization was done once in each pond before stocking to create uniform conditions in all ponds in terms of nutrients and plankton. Each pond was provided with separate inlet and outlet arrangements to avoid any exchange of water among ponds. Paddle wheel aerator was operated only in case of emergency aeration if the dissolved oxygen concentration in water at dawn is less than 2.5 mg L^{-1}. The experimental design was completely randomized design with four treatments and three replications. The exchange was achieved by releasing water through the lower outlet and refilling slowly via a fine mesh to minimize the entry of planktons and other debris. The study was carried out for 120 days during the warm period when the phytoplanktons experience faster growth thus making nutrient management more significant. A constant water balance in each pond was maintained. Weekly, water losses due to evaporation and seepage were monitored via the staff gauges and replenished with fresh water such that depth is kept within 5cm of the desired level. The amount of water during each exchange process was determined from the size of the ponds and quantified using the flowmeter at the refilling line.

Fish Stocking and Feeding

The fingerlings of rohu (Labeo rohita), catla (Catla catla) and mrigal (Cirrhinus mrigala) with an average initial weight of 12 g were stocked at the rate of 10,000 fish ha-1 in a 4:3:3 ratio. The fishes were offered a commercial pellet feed having a 28% crude protein at 3% body weight per day in two feeds, which were adjusted fortnightly based on weighing of the samples. The stocking density and feeding were maintained the same in all treatments so that any variation in planktons can be attributed only to the exchange interval. Fish handling was restricted to fortnightly weighing of a few fishes, and daily monitoring of dawn oxygen level was done to apply aeration whenever needed.

Water Quality Sampling and Analysis

Samples of water were collected on a weekly basis between the hours of 07:00 and 08:00 from three locations in each pond at 30 cm depth. Temperature, pH and dissolved oxygen were recorded in situ using a calibrated multiparameter probe, while transparency was obtained with a Secchi disk. Total ammonia nitrogen, nitrate nitrogen and soluble reactive phosphorus were quantified using colorimetric procedures in the laboratory. Chlorophyll-a was determined using filtration of a certain amount of water through glass-fibre filters, subsequent extraction of the filter in 90% acetone solution and finally measuring absorbance with a spectrophotometer. It was important to sample source water before each exchange to make sure that the concentrations of nutrients and chlorophyll were well below those in the ponds.

Phytoplankton Sampling, Identification and Community Indices

Phytoplanktons were sampled at intervals of 15 days by filtering 50 L of integrated pond water through a 25 μm plankton net into 50 mL and preserving the concentrates in 4% Lugol's iodine solution. Phytoplanktons were counted in a Sedgewick Rafter counting chamber using compound microscopy where colonies and filaments were converted into number of cells from their representative units. The genera of phytoplanktons were identified by using taxonomic keys for freshwater algae. Phytoplankton density was presented in cells/litre while the percentage of Cyanobacteria, Chlorophyta, Bacillariophyta and others were computed per date. Shannon–Wiener diversity index, Pielou's evenness index and number of genera recorded were used to quantify phytoplankton diversity. Succession was determined by the order of dominant groups and by the number of days when cyanobacteria dominated 50% or more of the total phytoplankton population.

The identification process adhered to a set protocol where two trained personnel would examine each sample under a magnification of 400× and note down genera using morphological keys, and unknown forms were photographed and compared to reference samples. Single cell forms and colonies/filament forms were counted separately and expressed as cells per litre. Samples of concentrate were preserved on each day such that unknown samples could be identified again at the end of the experiment. The following steps were employed in order to ensure the validity of the comparison. The locations of the ponds were selected by randomization in order to eliminate any bias regarding location, shadow, and proximity to the reservoir. All experiments were conducted by the same sampling crew and at the same hour of the day, and all equipment was rinsed with source water in between ponds in order to reduce contamination of the plankton.

Statistical Analysis and Study Architecture

Pond was the experimental unit through the culture period in the study. The data were subjected to normality and homogeneity of variance tests and were subsequently transformed where necessary. The significance of treatment effects was analyzed using one-way analysis of variance, followed by Tukey's post hoc test at the 5% level, while temporal trends were analyzed using repeated-measures analysis of variance. Correlation of environmental variables with community indices and the relationship between environmental gradient and the genus composition were done using Pearson correlation and canonical correspondence analysis, respectively. The results are presented as mean ± standard deviation. The instruments used were calibrated prior to each cycle, laboratory analyses were conducted in duplicate, and 10% of plankton slide counts were independently rechecked.

The architecture of the experiment is shown in figure 1 in a cycle rather than a straight line due to the fact that scheduling of exchange in reality is continuously changed as conditions in the ponds vary. The exchange regime (Step 1) determines the frequency of dilution and flushing (Step 2) and thus the conditions of light, pH, and oxygen (Step 3) available for phytoplankton. This creates a certain structure of the phytoplankton communities (Step 4) and its succession dynamics (Step 5). This determines the results of the management and the state of the pond (Step 6).

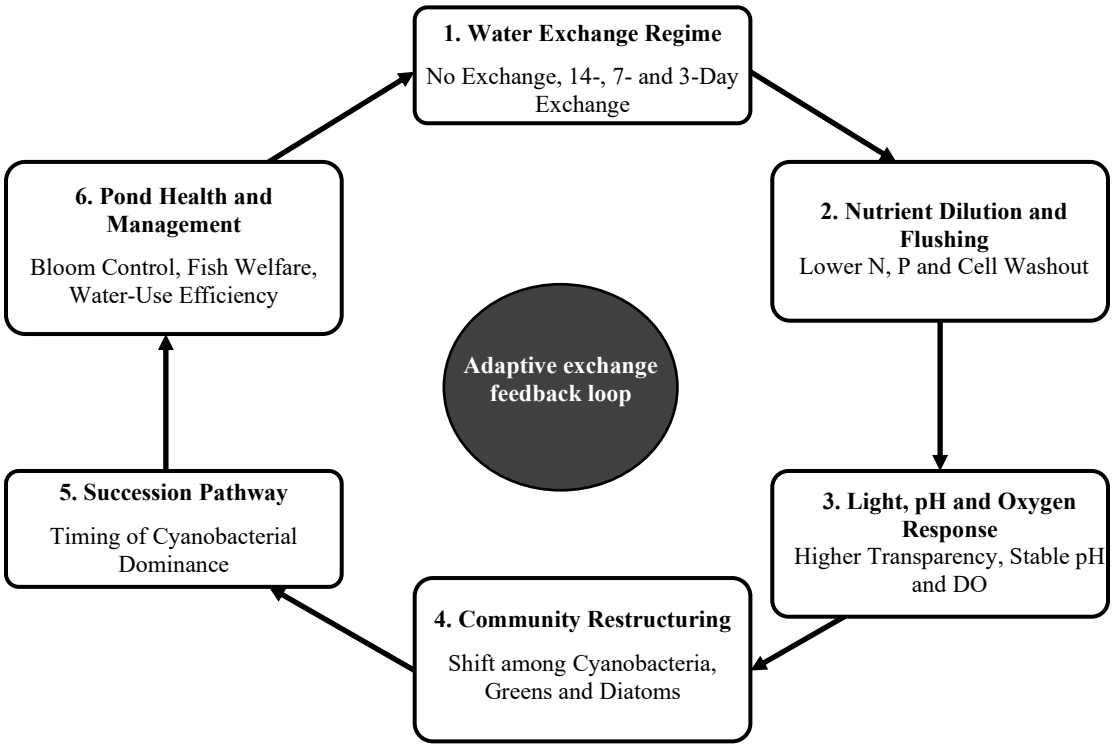


Figure 1: Cyclic Architecture Framework for the Influence of Water Exchange Frequency on Phytoplankton Succession

IV. Results

Water Quality Responses

There was no significant difference in water temperature among treatment groups ($p = 0.62$), and the temperatures stayed between 27 and 31 °C during all measurements. All other measured variables were significantly affected by the exchange frequency (Table 1). The morning DO concentration increased from 3.4 to 5.3 mg L^{-1}, and pH dropped from 8.9 to 7.9, which suggests that there was a lesser extent of photosynthetic alkalinization at locations with less biomass. The concentrations of total ammonia nitrogen and soluble reactive phosphorus decreased by around 73% and 67%, respectively, between WE0 and WE3. The Secchi transparency increased by almost twofold from 22 to 41 cm, and chlorophyll-a concentration was reduced from 148 to 52 µg L^{-1}.

Phytoplankton Density, Composition and Diversity

The total number of phytoplankton genera recorded, which belong to the Cyanobacteria, Chlorophyta, Bacillariophyta, Euglenophyta and Dinophyta, is 41. The total density of phytoplankton was more than three times higher in WE0 compared to WE3 (see table 1). While cyanobacteria (Microcystis and Oscillatoria) predominated in unexchanged ponds, green algae (Chlorella and Scenedesmus) and diatoms (Navicula and Cyclotella) became increasingly abundant with the increase in pond exchange frequency.

Richness, Shannon diversity and evenness values were the lowest in WE0 and the highest in WE3, with Tukey test differentiation of all four pond types regarding density and Shannon index.

Table 1: Water Quality and Phytoplankton Community Variables (Mean ± Sd) Under Different Water Exchange Frequencies

Variable	WE0	WE14	WE7	WE3	p-value
Temperature (°C)	28.9 ± 1.1	28.8 ± 1.0	28.7 ± 1.1	28.5 ± 1.0	0.62
pH	8.9 ± 0.4	8.5 ± 0.3	8.2 ± 0.3	7.9 ± 0.2	< 0.001
Dissolved oxygen (mg L^{-1})	3.4 ± 0.8	4.1 ± 0.6	4.8 ± 0.5	5.3 ± 0.4	< 0.001
Secchi transparency (cm)	22 ± 5	28 ± 6	34 ± 6	41 ± 7	< 0.001
Total ammonia N (mg L^{-1})	1.42 ± 0.31	0.98 ± 0.22	0.61 ± 0.15	0.38 ± 0.10	< 0.001
Soluble reactive P (mg L^{-1})	0.46 ± 0.11	0.33 ± 0.08	0.22 ± 0.06	0.15 ± 0.04	< 0.001
Chlorophyll-a (µg L^{-1})	148 ± 34	112 ± 27	79 ± 19	52 ± 14	< 0.001
Total density (× 10^6 cells L^{-1})	18.6 ± 3.9	12.8 ± 2.9	8.4 ± 2.1	5.7 ± 1.6	< 0.001
Genus richness	21 ± 2	27 ± 3	33 ± 3	36 ± 3	< 0.001
Shannon index (H′)	1.84 ± 0.22	2.31 ± 0.25	2.78 ± 0.27	3.02 ± 0.24	< 0.001
Pielou evenness (J)	0.60 ± 0.06	0.70 ± 0.05	0.79 ± 0.05	0.84 ± 0.04	< 0.01
Cyanobacteria share, mean of dates (%)	60.0	40.4	30.9	22.0	< 0.001
First day cyanobacteria > 50% of cells	~38	~62	~87 (brief)	not reached	—

The proportion of each group followed a similar pattern. On average across the culture period, cyanobacteria represented 60.0%, 40.4%, 30.9% and 22.0% of cells in WE0, WE14, WE7 and WE3, respectively. This trend was partially balanced out by the increase in green algae, whose share increased from around 25% of cells in WE0 to 40% in WE3, and in diatoms, their share increasing from a few percent to around 25% of the total community. Groups Euglenophyta and Dinophyta were a small share of the community, comprising 7-11% of cells and not differing statistically between the treatments. Dominant genera included Microcystis and Oscillatoria in WE0, Scenedesmus and Chlorella in WE7, and Chlorella, Navicula and Cyclotella in WE3.

Temporal Pattern of Succession

All four treatments were similar during the first 30 days when the community was dominated by small green algae and diatoms with low nutrient concentrations (Figure 2). Treatment divergence started after day 30 when more feed was supplied. In WE0, cyanobacteria surpassed 50% of cell abundance at approximately day 38 and were above 80% between days 60 and 90 and then dominated up until the end of the experiment, experiencing only one temporary decrease with an associated sharp reduction in dissolved oxygen. In WE14, the threshold was reached at approximately day 62, but the bloom was uneven and partially recovered following the exchange. In WE7, the threshold was surpassed temporarily at day 87, and then green algae became dominant for the last two weeks. In WE3, cyanobacteria were less than 40% of cells on any sampling date and there was alternating dominance between green algae and diatoms. The repeated-measures analysis showed a significant interaction between treatment and time for density and cyanobacterial share (both $p < 0.001$).

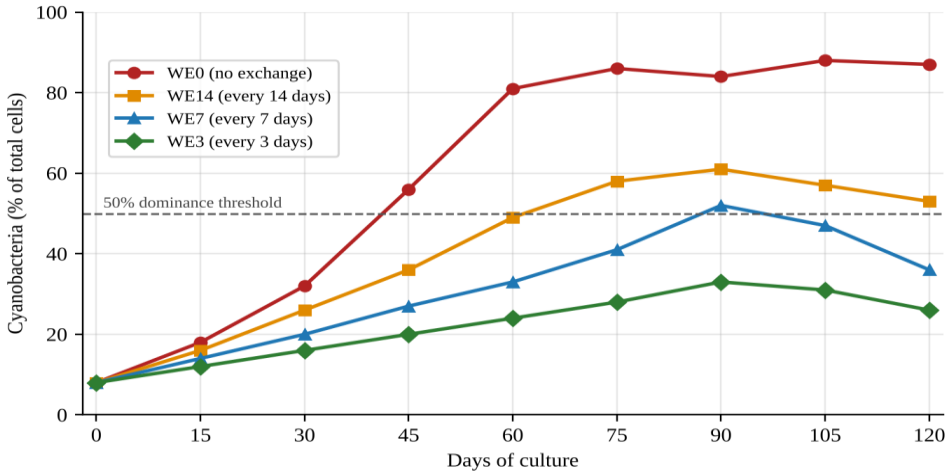


Figure 2: Change in the Percentage of Cyanobacteria in Total Phytoplankton Cells over the Culture Period Under Four Water Exchange Frequencies

Relationships Between Environmental Variables and Community Metrics

There is a strong positive correlation between chlorophyll-a concentration and total ammonia nitrogen ($r = 0.86$) and soluble reactive phosphorus ($r = 0.81$) and a negative correlation between it and Secchi transparency ($r = -0.88$). There is a positive correlation between cyanobacteria proportion and pH ($r = 0.79$) and a negative one between the proportion and dissolved oxygen ($r = -0.74$), while there is a positive correlation between Shannon diversity and transparency ($r = 0.83$) and a negative one between Shannon diversity and ammonia ($r = -0.77$). The first two canonical axes account for 68% of the variation in genus composition, with ammonia, phosphorus and pH showing the direction of the cyanobacteria dominated unexchanged ponds and transparency and dissolved oxygen showing the direction of frequently exchanged ponds.

Summary of Treatment Contrasts

Table 1 and Figure 2 combined demonstrate a consistent gradient of change from WE0 to WE3 in all variables associated with nutrient status and community structure. The biggest jump in changes occurred in transition between WE0 and WE14 in chlorophyll-a content and percentage of cyanobacteria, thus proving that any exchanges provide better results than no exchanges at all. Increases in transition between WE14 and WE7 were comparable in all water quality variables, while an increase between WE7 and WE3 was relatively smaller for dissolved oxygen, pH and Shannon diversity, pointing out to the decreasing effect of the exchange at a higher frequency. Replicate ponds varied insignificantly in all variables, and the coefficient of variation for density and Shannon diversity was below 20% and 10%, respectively, thus ensuring that treatment effect was not determined by a single abnormal pond. The exception in following the gradient was temperature, as it was predictable due to the similarity of depth, exposure and climate in all the ponds.

V. Discussion

Water Exchange as a Control on Nutrients and Biomass

The negative correlation between the exchange rate and ammonia, phosphorus, and chlorophyll-a demonstrates the validity of the first hypothesis and is in line with the dilution and flushing processes discussed in the framework. Since each exchange event removed only 20% of the total volume, the influence on the dissolved nutrients resulted from multiple exchanges rather than from a single major water replacement process. Ponds that were being exchanged every three days contained only one-third of the

nutrients found in the ponds without any exchanges despite equal feed input. Thus, part of the nutrients needed for the algal bloom could be removed due to management.

Effects on Community Composition and Diversity

Transition from dominance of cyanobacteria to green algae and diatoms with frequent exchange is consistent with the second hypothesis. Cyanobacteria thrive in stable and nutrient-rich environment at high pH levels where floating colonies can colonize the surface layer. The effect of frequent exchange decreases the concentrations of nutrients, pH level, as well as promotes mixing and loss. Green algae and diatoms with higher growth rates and low tolerance to alkaline and anoxic conditions have comparative advantage in such circumstances. The greater diversity and evenness of communities in WE7 and WE3 indicate that moderate disturbance and reduced nutrients allowed the survival of several genera rather than a few bloom-forming taxa. In the absence of exchange in the ponds, ammonia increased faster than phosphorus was consumed creating favorable conditions for cyanobacteria that could utilize reduced nitrogen in high pH environment.

Interpretation of Succession Dynamics

Thirdly, the third hypothesis has been validated as well. The day when more than 50% of cells of cyanobacteria exceeded was shifted from 38 to 62 to 87 with the frequency of water exchange changing from no water exchange, every 14 days, and to every 7 days; and it could not be reached with water exchange every 3 days. Water exchange, in addition to decreasing biomass, influences the trajectory of the community as well. Frequent water exchange events that have occurred shortly after each water exchange event in WE3 prove the fact that very frequent water exchange leaves the community in the early stage of succession through repeated re-setting of populations.

Links to Grazers, Fish and the Food Web

Even though the zooplankton was not quantified, there will definitely be effects on higher trophic levels. While small green algae and diatoms are easier to digest and provide better nutrients than cyanobacteria forming colonies, they also provide for zooplankton which in turn feeds the fry of carp. Cyanobacteria are known to grow in dense numbers and usually they are poorly grazed, leading to the problem of oxygen depletion in water bodies and the emission of taste-altering compounds. Lower dawn oxygen stress and lower ammonia in regularly renewed ponds would suggest reduced physiological stress on fish and better nutrient uptake and disease tolerance.

Agreement with Ecological Expectations

The findings fit into the ecological principles that were discussed above. An inverse relationship between exchange frequency and nutrient content proves the importance of nutrients' removal in the process of succession re-direction. The delay in the dominance of cyanobacteria is related to resource competition because low levels of ammonia and phosphorus as well as low pH decreased the ability of bloom forming genera to compete. Increased levels of diversity and evenness in the presence of increased exchange frequency without any decrease at the highest exchange rate prove that the level of disturbance caused by 20% exchange each three days does not exceed the threshold of disturbances.

Water Use, Management Implications and Reliability

The optimal water quality and community parameters were achieved with an exchange of every three days, but it needed around 40 exchanges during the cycle instead of 17 for WE7 and 8 for WE14, and it will lead to more pumping costs and risks of pathogen and solid particles introduction. Exchange of every 7 days reached most of the improvements in ammonia, oxygen content, transparency and the ratio of cyanobacteria at smaller water consumption and seems to be a better solution for farms facing shortage of water resources. If the release of the water is a problem, then the effluent can be processed in settling or vegetated systems or used as irrigation water. A good way is a base exchange of 20% of the water every 7 days starting from the second month of operation and temporary shortening the period of exchange when

cyanobacteria start to dominate or the dawn oxygen content becomes low on the basis of constant monitoring of transparency, pH and chlorophyll-a.

Practical Reading of the Succession Curves

The lines shown in Figure 2 can be interpreted as an easy tool for making a decision. In all treatments, the first month is the safe period, in which cyanobacteria do not exceed 20% of cells and, thus, any exchange made in this period does not serve biological purposes but ensures the water depth only. It is between days 30 and 60 that the difference between lines appears, and this moment is the moment from which on exchange affects the succession path. In other words, a manager who makes his decision in Favor of exchange when cyanobacteria become dominant, e.g. in WE0 after day 45, deals with a bloom that is hard to stop, while a manager who decides to make a weekly exchange earlier remains in the non-dominance zone for the major part of the cycle.

Scope for Generalization

This study has provided insights into the workings of mechanisms such as nutrient dilution, reducing pH and increasing oxygen concentration. These mechanisms do not relate only to the particular fish species that have been studied; they can work in other semi-intensive pond systems as well. The impact level of the mechanisms will, however, be related to the amount of feeding, depth of the ponds, water quality and climatic conditions. There can be a different reaction to these mechanisms in deeper ponds where thermal stratification takes place, or in ponds where sediment contains high levels of nutrients, even when exchanges take place often.

VI. Conclusion and Future Perspectives

Summary of Major Findings

Frequency of water exchange was an important factor affecting phytoplankton succession in inland aquaculture ponds. Frequent water exchange reduced nutrient content and chlorophyll-a concentration and enhanced dissolved oxygen and transparency levels. It increased phytoplankton diversity and prevented the dominance of cyanobacteria that was common in non-exchanged ponds. Three-day water exchange showed maximum effectiveness while weekly water exchange gave almost all benefits but with lower water consumption.

Contributions of the Study

Exchanges are viewed as a control variable in this study; the complete culture cycle is covered and the changes in the community are related to quantifiable indicators of water quality. The cyclic model presents a straightforward mechanism of scheduling exchange as a continuous process of adaptation. All these features indicate that exchanges can be used to influence phytoplankton communities and make them stable, diversified, and beneficial for fish.

Practical and Environmental Implications

The regular weekly partial exchange represents an effective and inexpensive bloom-prevention technique for farmers which requires no special equipment. In turn, for extension agencies, the findings can be used to establish a guide that relates the frequency of water exchanges to the pond size, stocking levels, and amount of water available. Finally, for authorities who are interested in effluents, the findings show that similar improvements can be achieved with a modest frequency of water exchanges, minimizing water releases. Environmentally speaking, the study reveals that improvements in the condition of ponds do not necessarily have to require massive amounts of water. A modest exchange rate coupled with proper feeding will result in more sustainable outcomes than massive exchanges without paying any attention to other aspects of farming, including feeding efficiency, stocking level, and aeration only where necessary.

Limitations of the Study

There was only one exchange volume involved in the study (20%) thus there were no data to separate the effect of volume from that of frequency. The research was carried out in one pond over one culture period while the input water did not contain high phytoplankton content unlike the farms supplied with nutrient rich water from canals and reservoirs. Genus-level identification cannot distinguish the difference in toxin production or vulnerability to zooplankton grazing. Growth response of zooplankton, bacteria and fish was not investigated.

Future Research Directions

Future work must investigate combinations of exchange volumes and frequencies, examine comparisons among ponds in different seasons and geographical locations, and employ species-specific or molecular approaches to identify risks associated with particular types of cyanobacteria. The inclusion of zooplankton, nutrient balances and fish performance will provide a better insight into the pond reactions to such processes. Furthermore, the installation of dissolved oxygen, pH and chlorophyll sensors will be beneficial for trigger-based exchanges – that is, exchanges based on crossing threshold values rather than regular schedules.

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