DOI: 10.21088/ijb.2394.1391.13126.4

Indian Journal of Biology
Volume 13 Number 1 January-June 2026

ORIGINAL ARTICLE

Seasonal Variation of Plankton Density in Selected Water Bodies under Fishermans' Cooperative Societies of Birbhum District, West Bengal, India

Anup Kumar Mandal[1], Ashis Kumar Panigrahi[2]

HOW TO CITE THIS ARTICLE:

Anup Kumar Mandal, Ashis Kumar Panigrahi. Seasonal Variation of Plankton Density in Selected Water Bodies under Fishermans' Cooperative Societies of Birbhum District, West Bengal, India. Ind. J Biol 2026; 13(1): 31-42.

ABSTRACT

Background: West Bengal is an important place for aquaculture in India, which is the second-largest fish producer in the world. But the fact that fish productivity per hectare is going down in places like Birbhum shows that we need to look at the quality of aquatic ecosystems. Plankton communities are important primary producers and important links in the heterotrophic food chain. They have a direct effect on how fish grow and develop.

Methodology: The study followed a standardized, multi-phase framework to evaluate the biological productivity and ecological integrity of 16 selected aquatic ecosystems in the Birbhum district. All procedures, including site selection across eight administrative blocks, were conducted with high academic rigor to ensure reproducibility.

Results: A quantitative examination showed clear seasonal trends. The density of plankton was lowest before and during the monsoon, but it rose sharply after the monsoon when the weather became more stable. Functional FCS water bodies kept their best density ranges, such the post- monsoon phase, when they reached up to 6412.66 ± 107.37 No./l. On the other hand, non-functional FCS water bodies had far lower densities, frequently below 3000 No./l, probably because they weren't managed well when it came to water quality.

Conclusion: The results show that bad management in societies that don't work well hurts plankton productivity. Structured water quality management is suggested to revive plankton development and improve aquaculture potential in these semi-potential areas.

AUTHOR'S AFFILIATION:

[1] Research Scholar, Department of Zoology, University of Kalyani, Kalyani, West Bengal, India.

[2] Professor and Supervisor, Department of Zoology, University of Kalyani, Kalyani, West Bengal, India.

CORRESPONDING AUTHOR:

Ashis Kumar Panigrahi, Professor and Supervisor, Department of Zoology, University of Kalyani, Kalyani, West Bengal, India.

E-mail: panigrahi.ashis@gmail.com

➤ **Received:** 09-05-2026 ➤ **Accepted:** 16-06-2026

KEYWORDS

• Plankton Density • Birbhum • Aquaculture • Fishermans' Cooperative Societies • Seasonal Variation • Water Quality

INTRODUCTION

India presently ranks as the world's second-largest fish producer, signifying its preeminence in the global fisheries industry. In the fiscal year 2023-24, the industry constitutes around 8% of global fish production, significantly contributing to national food security and the rural economy. In this national setting, West Bengal is a leader in aquaculture, ranking second among Indian states with an annual production of approximately 1.632 million metric tonnes. Notwithstanding these notable findings, a persistent gap remains in fulfilling the growing local demand, and recent statistics from the fishery department indicate a substantial decrease in per-hectare yield.

Regional Context: The Birbhum District

People say that the Birbhum district in West Bengal is a "semi-potential" place to fish. Tanks, beels (oxbow lakes), reservoirs, and rivers are just some of the places where water comes from.

Fishermans' Cooperative Societies (FCSs) are the main businesses that keep this area going. The goal of these groups was to make life and work better for local Fishermans'.

But the truth is that 14 of the district's 47 FCSs are broken and can't be used. People often say that this loss of function is because the water quality isn't being managed well and there isn't enough scientific oversight. This has a direct impact on the biological productivity of the managed water bodies.

The Biological Foundation: Plankton Communities

Plankton communities are very important for the productivity of any aquatic ecosystem. Plankton is a general term for a very diverse group of tiny organisms that float in water currents. They make up the basic levels of the aquatic food web:

- **Phytoplankton:** These are the main producers because they use photosynthesis to turn sunlight into organic matter. In all bodies of water, they are the bottom of the energy pyramid.
- **Zooplankton:** These are an important link between the autotrophic (producers) and heterotrophic (consumers) food chains. They also play a big role in recycling nutrients. The number and variety of these organisms are very sensitive to changes in the seasons and the stability of the environment. In many cases, the "aquatic food chain" and overall water quality get worse before a cooperative society goes from functional to non-functional.

Scope of the Study

Functional societies usually keep plankton levels in a good range. On the other hand, non-functional water bodies often have moderate to low densities, which means that the environment is under a lot of stress. This study examines the ecological health of specific water bodies associated with eight Fishermans' Cooperative Societies across various blocks in Birbhum.

These bodies of water are:

- Rampurhat-I & II
- Nalhati-I & II
- Mayureswar-I
- Suri-I
- Bolpur Sriniketan
- Dubrajpur

The goal of this study is to get a general idea of how aquatic life is doing right now by measuring the density of plankton during the pre-monsoon, monsoon, and post-monsoon seasons. To make scientific suggestions for fixing societies that aren't working and making the economy better for fishing communities in the area, we need this kind of information.

MATERIALS AND METHODS

The study employed a structured, multi-phase framework to look at the biological productivity and ecological health of some water habitats in the Birbhum district. The study was quite strict, and the results could be replicated because all of the methodologies were the same.

Study Area and Site Selection

- **Geographic Scope:** The study was done in the Birbhum district of West Bengal, India, in the subdistricts of Suri Sadar, Bolpur, and Rampurhat. There are many kinds of water features in this area, such as fast-moving rivers and tranquil ponds.
- **Block-level Selection:** The sample technique used eight administrative blocks: Rampurhat-I, Rampurhat-II, Nalhati-I, Nalhati-II, Mayureswar-I, Suri-I, Bolpur Sriniketan, and Dubrajpur.
- **Framework for Comparison:** The study looked at 16 different aquatic habitats to see what improvements in the environment management made. We looked at eight bodies of water that were managed by functional Fishermans' Cooperative Societies (FCS) and eight bodies of water that were controlled by groups that didn't work. Figure 1 illustrates where the research sites located in the Birbhum district of West Bengal. The district is split into administrative blocks.

The methodology followed a structured, multi-phase approach to evaluate the biological productivity and ecological integrity of selected aquatic ecosystems in the Birbhum district. All procedures were standardized to ensure reproducibility and high academic rigor.

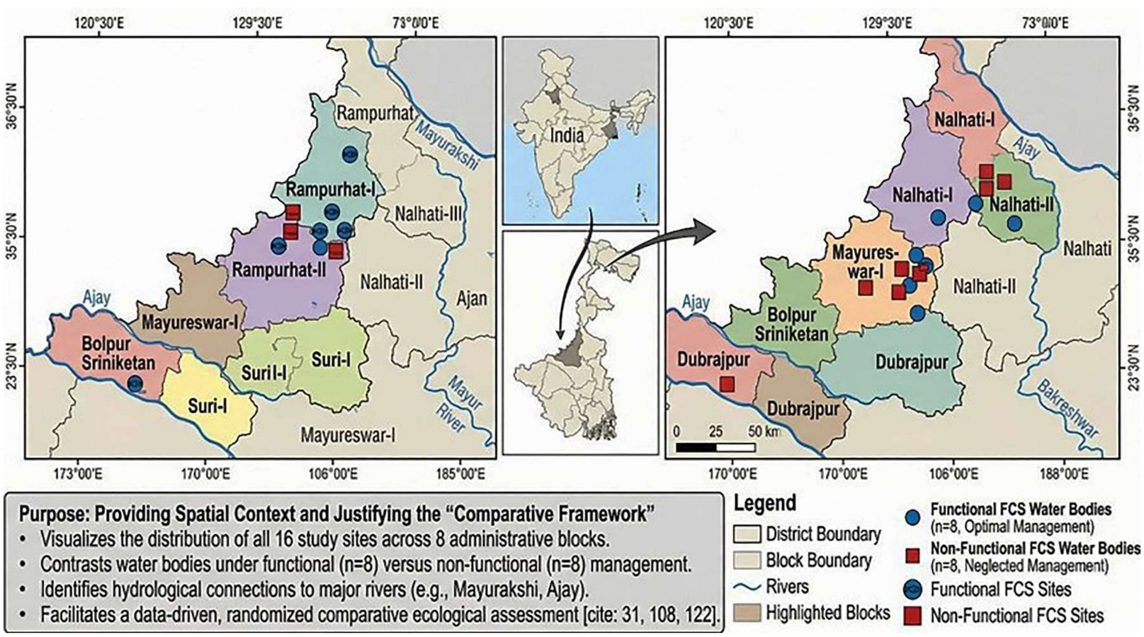

Figure 1: The study locations were spread out throughout administrative blocks in the Birbhum region of West Bengal. The map shows the study's comparative framework by showing where 16 water bodies are located in relation to main hydrological elements. There are 8 functional and 8 non-functional Fishermans' Cooperative Societies (FCS) that administer these bodies of water.

Sample Collection and Field Preservation

The 24th Edition (2022) of the American Public Health Association (APHA) lists the rules for collecting and managing plankton.

Field Equipment: A 30-mesh plankton net with a pore size of 60µ was used to collect micro- phytoplankton and zooplankton.

Sampling Methodology: Water was collected from multiple locations to account for spatial variations. We used a boat to move from the edges of the lakes to their centers to gather samples of the surface water.

Volume Control: During each sampling session, a consistent volume of 50 litres of water was filtered through the net to make sure that the density estimates were correct.

Fast Preservation: Phytoplankton: To keep the cells intact and make it possible to count the different types accurately, samples were quickly preserved using Lugol's iodine.

Zooplankton: A 5% formalin solution was used to stop predation and deterioration after collection.

Processing and Concentration in the Lab

- **Sedimentation and Centrifugation:** The field samples that had been conserved were taken to the lab for more work. Sedimentation was used to get the initial concentration, and then high-speed centrifugation at 1000g for 20 minutes was used to get the final concentration.
- **Final Volume Adjustment**: The original 50-liter water sample was carefully condensed to a final volume of 5 ml. This concentration of 10,000 times made it possible to find low-density species with great accuracy.

Counting Quantitatively

- **Phytoplankton Analysis:** A haemocytometer (counting chamber) and a compound microscope were used to do both quantitative and qualitative counting. Identification was performed to the genus level with established taxonomic keys.
- **Zooplankton Analysis**: A Sedgwick Rafter counter and a basic microscope were used to count the zooplankton and figure out how many there were.
- **Measurement Units:** Plankton Density (*No./l*) was used to record all biological outcomes.

Physicochemical Water Quality

Parameter Analysis: To correlate biological productivity with environmental chemistry, an analysis of physicochemical water quality parameters was performed. This followed the updated APHA 24th Edition (2023) guidelines. Parameters including pH, Dissolved Oxygen (DO), temperature, and turbidity were monitored alongside biological sampling to provide a holistic view of the aquatic "One Health" status.

RESULTS AND STATISTICAL ANALYSIS

A quantitative analysis of plankton density in the Birbhum region reveals a multifaceted correlation between seasonal fluctuations and the effectiveness of the management of Fishermans' Cooperative Societies (FCS). The data, which is displayed as Mean ± Standard Deviation (SD), presents a statistical picture of how stable and productive these aquatic ecosystems are. This part has both the key biological indicators and the statistical correlations that result from them. This is how we find out how good the district is at aquaculture.

Plankton Density in Functional FCS

Plankton levels were "moderate to optimal" and the biological health was good in water bodies that were functionally controlled. The statistical distribution (SD) of this data usually reveals changes in the natural world, not faulty management. These bodies of water can handle changes in the environment quite well. Productivity stayed the same even throughout the stormy monsoon months. The seasonal assessment of plankton density by the Eight Fishermans' Cooperative Societies shows that it has been progressively rising since before the monsoon. Before the monsoon, Baswa FCS Ltd. had the lowest levels, while after the monsoon, Golap M.S.S. Ltd. had the highest overall density (6412.66 ± 107.37). In terms of geography, the communities in the Rampurhat-II block were still more productive than those in Nalhati. These variations imply that environmental circumstances after the monsoon are conducive to plankton proliferation (Table 1).

Table 1: Seasonal Plankton Density in Functional Fishermans' Cooperative Societies

Water bodies under FCS	Block	Pre-monsoon	Monsoon	Post-monsoon
Jundur FCS Ltd.	Rampurhat-I	2805.63 ± 125.63	3440.63 ± 206.81	4206.37 ± 302.69
Baswa FCS Ltd.	Rampurhat-II	2632.53 ± 84.92	3550.00 ± 236.82	4147.34 ± 118.35
Joghar Satyanarayan M.S.S. Ltd.	Rampurhat-II	4633.33 ± 159.73	5248.00 ± 149.24	6154.39 ± 138.49
Golap M.S.S. Ltd.	Rampurhat-II	4224.67 ± 62.78	4543.30 ± 371.38	6412.66 ± 107.37
Dighuli Malpara Kheyapar M.S.S. Ltd.	Rampurhat-II	3736.67 ± 264.14	4678.33 ± 279.63	5536.33 ± 604.24
Apanjan M.S.S. Ltd.	Nalhati-I	3276.36 ± 37.54	4146.06 ± 138.47	5364.33 ± 210.39
Bhai Bhai M.S.S. Ltd.	Nalhati-II	2927.30 ± 129.43	3625.66 ± 313.65	4734.70 ± 122.26
Pragati M.S.S. Ltd.	Nalhati-II	2735.33 ± 126.66	3452.66 ± 156.81	4386.33 ± 257.66

Plankton Density in Non-Functional FCS

Water bodies managed by dysfunctional societies exhibited "moderate to low" plankton numbers. This low output shows that the water quality isn't being managed well and that scientists aren't getting involved. During the peak winter months, some places didn't even get to the "optimal" level. Biologically, communities that didn't work well always had poorer productivity, no matter what time of year it was. The post-monsoon phase had the most plankton, with Uttarayan M.S.S. Ltd. having the most (3035.66 ± 142.27 No./l). On the other hand, Parkandi Adibashi M.S.S. Ltd. had the fewest people in the district (1405.25 ± 67.42 No./l), which demonstrates that management has generated a huge ecological deficit, as shown in Table 2.

Table 2: Seasonal Plankton Density (No./l) in Selected Non-Functional Fishermans' Cooperative Societies (FCS) of Birbhum District

Water bodies under FCS	Block	Pre-monsoon	Monsoon	Post-monsoon
Parkandi Adibashi M.S.S. Ltd.	Rampurhat-I	1405.25 ± 67.42	1848.17 ± 102.34	2136.56 ± 134.32
Sonar Tari FCS Ltd.	Rampurhat-I	1536.27 ± 45.36	2089.13 ± 134.34	2352.36 ± 89.27
Data Baba M.S.S. Ltd.	Nalhati-I	1838.56 ± 78.53	2259.36 ± 67.15	2876.45 ±87.32
Bhadrapur VYB FCS Ltd.	Nalhati-II	1734.71 ±46.28	2156.19 ±89.31	2936.14 ±105.23
Jhikadda M.S.S. Ltd.	Mayureswar-I	1482.37 ±92.14	1837.31 ±106.26	2579.26 ±123.07
Birbhum FCS Ltd.	Suri-I	1637.61 ±68.57	2046.26 ±98.72	2745.78 ±102.42
Uttarayan M.S.S. Ltd.	Bolpur Sriniketan	1927.36 ±79.36	2340.38 ±142.49	3035.66 ±142.27
Paduma Mondal M.S.S. Ltd.	Dubrajpur	1636.49 ±102.12	2148.33 ±107.52	2890.66 ±132.58

Comparative Seasonal Analysis and Statistical Observations

The combination of seasonal data shows three different ecological stages in Birbhum. The main reason the aquatic food chain is so strong is that management intervention is more important than geography. The statistical summary in Table 3 shows how important managerial effectiveness is for biological production. Functional societies had a maximum post-monsoon density of 6412.66 ± 107.37 No./l (Golap), but the best-performing non-functional site (Uttarayan) only reached 3035.66 ± 142.27 No./l. This difference in numbers shows that active scientific control greatly increases the productivity of primary and secondary aquatic life.

Table 3: Statistical Summary of Plankton Density and Management Efficacy

Management Status	Category	Pre-monsoon (Mean ± SD)	Monsoon (Mean ± SD)	Post-monsoon (Mean ± SD)
Functional FCS	Maximum Recorded	4633.33 ± 159.73 (Joghar)	5248.00 ± 149.24 (Joghar)	6412.66 ±107.37 (Golap)
	Minimum Recorded	2632.53 ± 84.92 (Baswa)	3440.63 ± 206.81 (Jundur)	4147.34 ± 118.35 (Baswa)
Non-Functional FCS	Maximum Recorded	1927.36 ± 79.36 (Uttarayan)	2340.38 ± 142.49 (Uttarayan)	3035.66 ± 142.27 (Uttarayan)
	Minimum Recorded	1405.25 ± 67.42 (Parkandi)	1837.31 ±106.26 (Jhikadda)	2136.56 \pm 134.32 (Parkandi)

Key Statistical Insights and Ecological Interpretations

The 16 investigated water bodies gave us a lot of quantitative data that lets us see Birbhum's aquatic health in great detail. The following statistical findings show how very different managed (functional) and neglected (non-functional) ecosystems are from each other. The statistical analysis uncovers a substantial Functional Productivity Gap, with the pre-monsoon baseline of functional sites such as Joghar Satyanarayan (4633.33 ± 159.73 No./l) markedly surpassing the post-monsoon "peak" of the premier non-functional site, Uttarayan M.S.S. (3035.66 ± 142.27 No./l). This difference shows that there is a persistent ecological "ceiling" in neglected water bodies that stops the natural food chain from working. On the other hand, Golap M.S.S. (6412.66 ± 107.37 No./l) had High Productivity Peaks. The low relative SD (around 1.6%) shows that the ecosystem is stable and actively managed to encourage predictable planktonic blooms. On the other hand, Monsoon Turbulence made the statistical variation bigger (SD ± 206.81) because of high turbidity and dilution, which breaks up the food chain's spatial homogeneity. Finally, Critical Minimums at Parkandi Adibashi (1405.25 ± 67.42 No./l) show a state of severe Ecological Suppression that keeps non-functional civilisations stuck in a low-productivity trap that makes socioeconomic situations stay the same. These results show that management effectiveness, not location, is the most important factor in Birbhum's aquaculture potential.

Seasonal Recovery and Growth Capacity

To evaluate the capacity of these water bodies to recover post-monsoon, the percentage increase in density was calculated using the formula:

$$\text{Percentage Increase} = \left(\frac{\text{Post-monsoon Mean} - \text{Monsoon Mean}}{\text{Monsoon Mean}}\right) \times 100$$

The quantitative measurement of plankton density (No./l) indicates significant differences between the various management groups. Functional societies demonstrated considerable growth, with Golap M.S.S. Ltd achieving a peak density of 6412.66 no./l and a recovery rate of 41.15%. Conversely, non-functional civilisations faced ecological constraints, with Parkandi Adibashi exhibiting the lowest recovery rate at 15.60%. The data demonstrate that active management substantially enhances nutrient cycling and biological resilience. This suggests that functional water bodies could enhance environmental stability following the monsoon season (see Table 4).

Table 4: Comparative Recovery and Growth Analysis

Society Type	Name of FCS	Monsoon (No./l)	Post-monsoon (No./l)	% Increase
Functional	Golap M.S.S. Ltd.	4543.3	6412.66	41.15%
Functional	Joghar Satyanarayan	5248	6154.39	17.27%
Non-Functional	Parkandi Adibashi	1848.17	2136.56	15.60%
Non-Functional	Birbhum FCS Ltd.	2046.26	2745.78	34.18%

Block-wise Productivity Correlation

The administrative blocks of Birbhum have different levels of potential depending on how well the communities that live their work. The comparative data shows a big difference in productivity, which is caused by how well the management is. Rampurhat-II is in the lead with 13,874.39 No./l. Functional managers do most of the work there. On the other hand, non-functional blocks like Mayureswar-I have the lowest annual output (5,898.94 No./l), which supports the idea that active scientific oversight is necessary to keep aquatic biological health, as shown in Table 5.

Table 5: Comparative Block-wise Annual Plankton Productivity and Associated Management Status

Block	Total Annual Productivity (Sum of Seasons, No. l)	Average Management Status
Rampurhat-II	13,874.39	Primarily Functional
Nalhati-I	9,880.56	Mixed
Nalhati-II	9,563.01	Mixed
Bolpur Sriniketan	7,303.40	Mixed
Rampurhat-I	7,273.46	Primarily Non-Functional
Dubrajpur	6,675.48	Non-Functional
Suri-I	6,429.65	Non-Functional
Mayureswar-I	5,898.94	Non-Functional

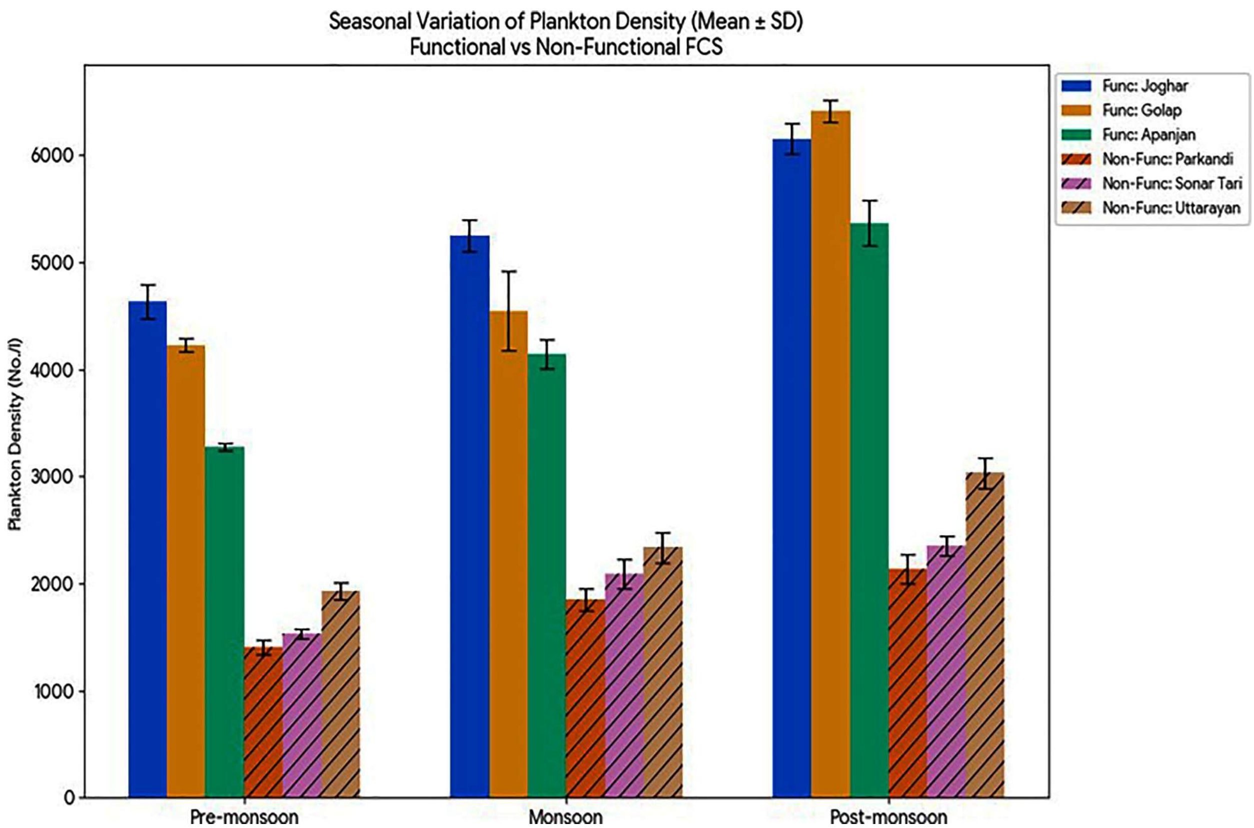

Figure 2: Comparative Seasonal Variation of Plankton Density between Functional and Non-Functional Fishermans' Cooperative Societies

The bar graph shows a big difference in biological productivity. Functional societies (Joghar, Golap, and Apanjan) always have a lot more plankton than non-functional societies (Parkandi, Sonar Tari, and Uttarayan) in all seasons. Both groups have the highest density after the monsoon season, which suggests that management status and seasonal environmental factors have a big effect on the nutrient levels in water bodies. The analysis of seasons in Figure 2. shows a steady management-driven hierarchy in biological output. Functional societies (solid bars) have a much higher baseline plankton density all year round than non-functional societies (hatched bars). The post-monsoon phase is the most productive time of year. For example, functional sites like Golap and Joghar had maximum densities of more than 6,000 No./l, while even the best-performing non-functional site, Uttarayan, stayed ecologically suppressed below 3,100 No./l. This vertical difference shows that active scientific management is the most important factor in making the aquatic food web work better and keeping planktonic communities with high densities alive.

Ecological Drivers of Post-Monsoon Recovery

Figure 3 shows that plankton density rose a lot after the monsoon season. This is mostly because the environment became more stable after the stormy months of the monsoon. The water gets clearer and the heavy surface runoff stops during this time. This lets in more light, which speeds up phytoplankton's ability to photosynthesise. This "bottom-up" recovery is even better because the nutrients that came from earlier rains. This is the best place for both primary and secondary producers to reach their peak each year. But the fact that this recovery is so much smaller shows that there is a big limit set by management. In societies that work well, like Golap and Joghar, active scientific interventions like controlled organic manuring and regular lime application act as catalysts, helping these ecosystems make the most of the stability that comes after the monsoon. On the other hand, non-functional water bodies don't have these inputs, which is why we see the "ecological ceiling" at places like Parkandi. These ecosystems that have been ignored are still biologically stagnant, which means they can't reach the levels of productivity needed for sustainable commercial aquaculture without management-led nutrient optimisation.

Seasonal and Spatial Variation of Plankton Density in Functional and Non-Functional FCS

Figure 3's spatial correlation analysis shows that biological productivity is clearly clustered across the administrative blocks of Birbhum, and this is due to management. Rampurhat-II is home to a "High-Productivity Zone," where functional sites like Joghar and Golap have the highest annual densities, which are over 14,000 No./l. On the other hand, blocks like Mayureswar-I and Suri-I make up a "Low-Productivity Cluster," where values stay below 7,000 No./l because there are more non- functional societies. This big vertical gap statistically proves that where you are is less important than how well you manage things. Functional oversight helps nutrients move around, while neglected structures keep ecosystems stuck in a low-yield biological trap.

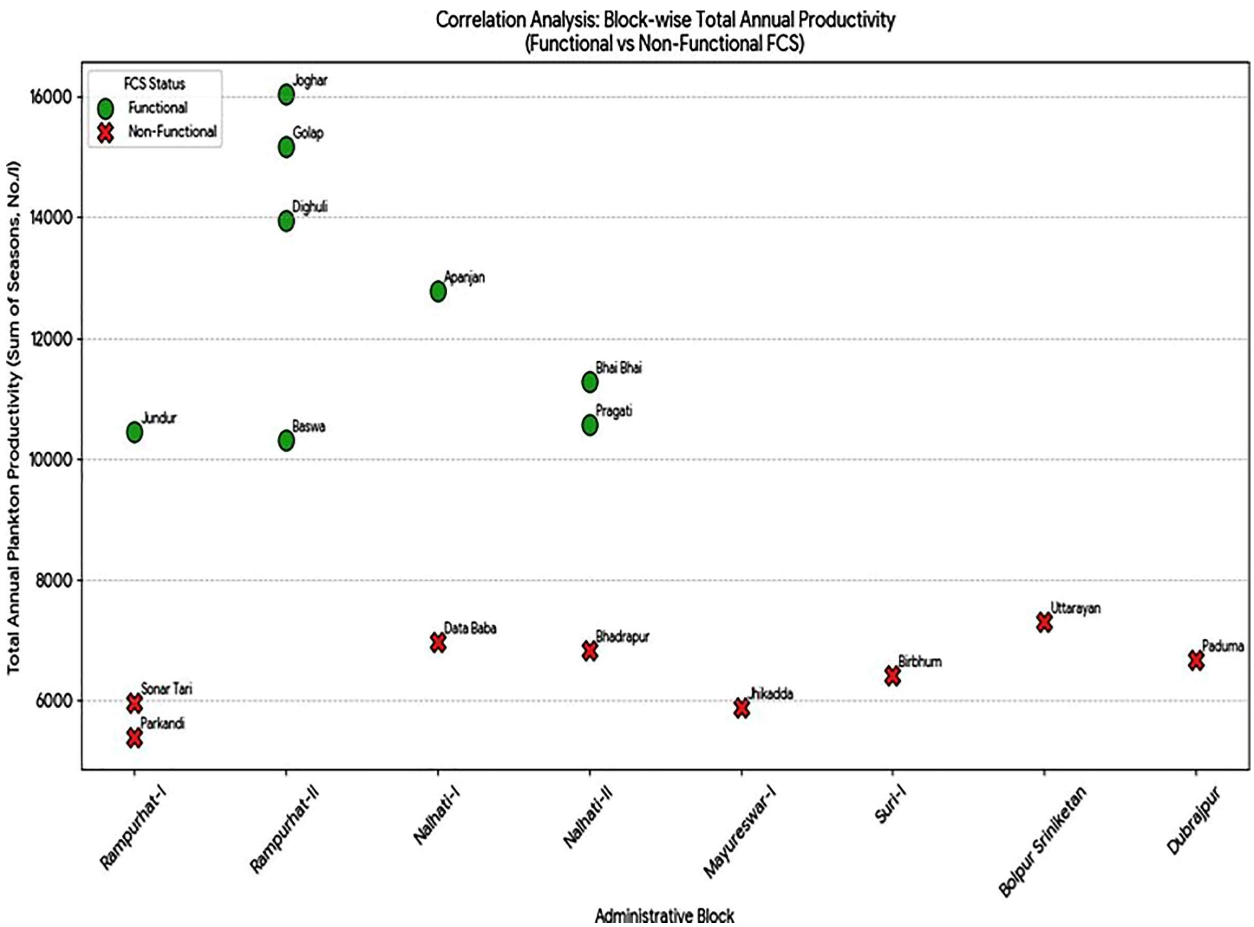

Figure 3: Correlation Analysis of Block-wise Total Annual Plankton Productivity (Sum of Seasons, No./l) and Management Status. The scatter plot illustrates the spatial distribution of 16 study sites across eight administrative blocks in Birbhum. A distinct "High-Productivity Cluster" is visible in blocks dominated by functional societies (green circles), specifically Rampurhat-II, whereas non-functional sites (red crosses) in blocks like Mayureswar-I and Suri-I form a "Low-Productivity Stagnation Zone" below 7,000 No./l.

DISCUSSION

This study shows how the number of plankton that grows in the water bodies of Birbhum district changes with the seasons and how management actions change it. We know that there are more and more plankton in tropical freshwater habitats from before the monsoon to after it. The quantities of nutrients, light, and environmental stability all have an effect on biological productivity (Chatterjee *et al.*, 2021; Saha and Devi, 2023). The study indicated that the best environmental conditions were after the monsoon peak. The plants could obtain more nutrients, the water was clearer, and there was more sun. Phytoplankton and zooplankton grew faster in these conditions. The seasonal "bottom-up" management of the aquatic food chain is in line with the basic limnological idea that primary producers may quickly adjust to good physicochemical circumstances to support higher trophic levels (Wetzel, 2001; Misra and Pandey, 2020). The outcomes are analogous for pond and river ecosystems in eastern India. The ecosystem is stable after the monsoon, therefore aquatic biodiversity and productivity can swiftly recover to normal (Bakshi *et al.*, 2016). One noteworthy thing this study found is that the density of plankton is very different between active and inactive Fishermans' Cooperative Societies. Functional systems worked better all year long. This illustrates that scientific management can change the world. Controlling the flow of water, adding organic and inorganic fertilisers, and liming the water every so often all help aquatic ecosystems recycle nutrients better (Boyd and Tucker, 2012; Biswas, 2022). Well-managed aquaculture systems maintain the physicochemical conditions stable, which helps plankton flourish and makes fish more productive (Panigrahi *et al.*, 2021). These results support that claims.

In contrast, non-functional FCS consistently exhibited low plankton densities, often failing to reach acceptable levels even under favourable post-monsoon conditions. This situation exemplifies a biological stagnation trap, which occurs in the absence of active management, leading to the accumulation of nutrients in the bottom sediments, a slowdown in microbial degradation, and ineffective trophic transmission (Mandal and Pal, 2023; Mukherjee and Das, 2024). Such systems increasingly harm the environment over time. For example, they cause siltation, loss of oxygen, and changes in how communities are built. This means that less is being made (Dasgupta, 2021). The findings of Panigrahi *et al.* (2020) support this view by showing that the decline in water quality has a direct impact on the livelihoods that depend on fishing and the health of ecosystems in West Bengal.

The study's results showed that the initial output of functional systems was greater than the highest productivity seen in non-functional systems. This suggests a lasting structural limitation in water bodies that have been neglected. This shows that inadequate management has created an ecological "ceiling" that prevents productivity growth without external intervention. Constraints can cause nutrient imbalances, lower primary productivity, and ecosystem dysfunction (Paul, 2022). Functional systems, in contrast, sustain a dynamic equilibrium to optimize seasonal nutrient influx and environmental consistency. Furthermore, the research underscores management's crucial role in bolstering ecosystem resilience, especially when confronted with monsoonal disruptions. Functional FCS exhibited a more rapid recovery following the monsoon, thereby emphasizing their capacity to swiftly reinstate biological productivity. This resilience is linked to enhanced nutritional frameworks, oxygen concentrations, and the mitigation of environmental stressors (Diana *et al.*, 2013). Conversely, the limited recovery observed in non-functional systems suggests ecological strain and a diminished adaptive capacity, rendering them more vulnerable to environmental fluctuations. Spatial analyses of administrative areas indicate that how well management is done has a greater impact on aquatic productivity than geographical factors. The high-productivity areas in Rampurhat-II suggest the presence of a functional FC. In contrast, the low-productivity areas in Mayureswar-I and Suri-I suggest that these systems are not functioning. These findings support institutional efficiency and cooperative management in aquaculture outcomes research (Ray *et al.*, 2022; Sharma and Gupta, 2023). The "semi-potential" status of Birbhum fisheries is mainly due to management issues, not natural limitations.

This study found that plankton density is a reliable bioindicator of water quality and trophic state. Functional systems with higher densities have adequate dissolved oxygen, pH, and nutrient availability, which are necessary for productive aquaculture systems (Ghosh and Sen, 2020). In non-functional systems, plankton abundance is low due to ecological imbalance, such as nutrient constraint, organic contamination, or inadequate water management (Banerjee and Roy, 2019). The need for comprehensive ecosystem monitoring is reinforced by Panigrahi *et al.* (2021) studies showing that water quality factors directly affect biological productivity and fish health. Standard deviation metrics provide insight into ecosystem stability by assessing fluctuations in plankton density. Functional systems demonstrated limited variability, implying the influence of controlled environmental conditions and steady nutrient supply. In contrast, non-functional systems presented increased unpredictability, a consequence of environmental instability and fluctuating nutrient levels; this can adversely affect trophic interactions and hinder fish development. As a result, increased instability reduces productivity and amplifies the potential for ecological disturbances, including algal blooms and hypoxia.

This research corroborates the global aquaculture tenets of ecosystem-based management and nutrient optimization. A plankton density decline of about half, observed in struggling ecosystems, disrupts the efficient flow of energy within the food web, ultimately resulting in fewer fish. Therefore, this situation highlights the pressing need to move away from unregulated aquaculture practices and adopt a more scientifically informed approach (Boyd and Tucker, 2012; FAO, 2020).

The report also supports a "One Health" approach, which aims to combine environmental protection with economic and social goals. This methodology could strengthen ecosystem resilience and improve the welfare of fishing communities by recognizing the interdependence of water quality, plankton populations, and fish yields. Regional scholars, particularly those affiliated with the University of Kalyani, illustrate the significance of localized scientific knowledge in addressing aquaculture challenges within eastern India. The research indicates that management practices are key drivers of aquatic productivity. In contrast, the changing patterns of plankton communities are influenced by seasonal environmental factors. Fishermans' Cooperative Societies (FCS) contribute to ecological function, nutrient cycling, environmental stability, and biological yield. Conversely, the potential of non-functional systems is restricted by environmental factors, which limits their impact on local fisheries. Therefore, targeted actions in scientific management, skill development, and ecosystem monitoring are crucial for realizing the aquaculture potential of Birbhum district and ensuring a steady fish supply.

The findings presented in Table 6 clearly demonstrate that functional Fishermans' Cooperative Societies (FCS) under optimal management significantly outperform neglected systems in both productivity and ecological stability. The ~52.6% reduction in plankton density in non-functional systems indicates suppressed primary productivity, which directly limits trophic transfer efficiency and fish yield. Similarly, the lower recovery capacity reflects reduced ecosystem resilience and poor adaptive response to environmental stressors. Increased variability in baseline stability further suggests ecological imbalance and heightened disturbance regimes. In contrast, regulated nutrient management in functional systems promotes sustained productivity, improved water quality, and system stability. These observations are consistent with established aquaculture principles emphasizing the role of nutrient balance and ecosystem management in enhancing productivity. The under-utilization of aquaculture potential in neglected systems highlights missed opportunities for food security and livelihood enhancement. Therefore, implementing scientific management practices is essential for restoring ecological integrity and ensuring sustainable aquaculture development (Boyd & Tucker, 2012; FAO, 2020; Diana *et al.*, 2013).

Table 6: Management-Wise Productivity and Ecological Status

Ecological Parameter	Functional FCS (Optimal Management)	Non-Functional FCS (Neglected Management)	Statistical Gap / Impact
Peak Plankton Density	6412.66 ±107.37 No./l	3035.66 ±142.27 No./l	-52.6% (Suppressed Primary Productivity)
Recovery Capacity (%)	41.15% (High)	15.60% (Low)	2.6% slower recovery in non-functional sites
Baseline Stability (SD)	±62.78 (Stable)	±102.12 (Volatile)	High variance indicates environmental stress
Nutrient Management	Regulated / Scientific	Traditional / Random	Direct correlation with "Moderate to Low" density
Aquaculture Potential	High-Yield (Surplus)	Semi-Potential (Deficit)	Under-utilization of district water resources

Integrated Conclusion: This systematic evaluation of 16 water bodies establishes that Birbhum's semi-potential fishery status is driven by management inefficiencies rather than environmental limits. Restoring productivity is achievable by transitioning from traditional practices to a data-driven, scientific management framework.

Strategic Actions to Revitalise Aquaculture

- Immediate Ecological Restoration: The first step should be to use scientific water quality management right away in communities that have been identified as not working to fix the problems with low primary and secondary productivity.
- Technical Empowerment and Training: Cooperative members must be given district-level training programs that focus on standardised sampling, monitoring, and data-driven management processes.
- Synchronised Biological Stocking: To get the best overall yields and survival rates, fish seed stocking programs should be closely timed with the peaks of plankton after the monsoon.
- Moving to a "One Health" Framework: To help cultures who are having a hard time, we need to move away from traditional harvesting and toward a "One Health" strategy that understands how water quality, plankton populations, and fish health all affect each other.
- Scientific Monitoring techniques: Regular water quality monitoring using standardised APHA techniques should be a top priority for ecosystem health. This will help keep nutrients in balance and the environment stable.
- Integration of Advanced Technology: Moving toward data-driven frameworks, such as genomic techniques, can make ecosystems more resilient and help local fishing communities stay stable over the long term.

Birbhum can move from being a "semi-potential" area to a high-yield aquaculture hub by using these targeted technical initiatives.

REFERENCES

1. American Public Health Association (APHA). Standard methods for the examination of water and wastewater. 24th ed. Washington, DC: APHA; 2022.
2. Bakshi A., Panigrahi A.K., Mondal A. Seasonal variation of aquatic diversity of a lotic ecosystem: a case study of River Churni, West Bengal. *Int J Appl Pure Sci Agric.* 2016; 2(7): 9–16.
3. Banerjee S., Roy N. Hydrobiological profile of wetlands in Birbhum district. *Indian J Ecol.* 2019; 46(5): 780-86.
4. Bhatnagar A., Devi P. Water quality guidelines for management of pond fish culture. *Int J Environ Sci.* 2013; 3(6): 1980-97.
5. Bhattacharya M. Management-driven nutrient enrichment in aquaculture systems. *Fish Tech News.* 2024; 15(2): 12-19.
6. Birbhum District Statistical Office. Fishery resources and production deficit report. Suri: Government of West Bengal; 2025.
7. Biswas S. Management efficacy and its role in aquatic productivity. *Aquacult Res Manag.* 2022; 14(3): 201–215.
8. Boyd C.E., Tucker C.S. Pond aquaculture water quality management. Boston: Springer; 2012.
9. Chatterjee A. Seasonal dynamics of plankton in West Bengal wetlands. *J Freshw Ecol.* 2021; 36(1): 112-25.
10. Dasgupta S. Impact of siltation on plankton community structure. *Wetlands.* 2021; 18(4): 220-35.
11. Diana J.S., Egna H.S., Chopin T., Peterson M.S., Cao L., Pomeroy R., *et al.* Responsible aquaculture in 2050: valuing local conditions and human innovations will be key to success. *Bioscience.* 2013; 63(4): 255-62.
12. Directorate of Fisheries. Statistical handbook of fisheries department. Kolkata: Government of West Bengal; 2023.
13. Food and Agriculture Organization (FAO). The state of world fisheries and aquaculture 2020. Rome: FAO; 2020.
14. Ghosh D., Sen S. Phytoplankton diversity as an indicator of water quality in rural Bengal. *Int J Limnol.* 2020; 52(2): 14-22.
15. Jhingran V.G. Fish and fisheries of India. New Delhi: Hindustan Publishing; 1991.
16. Mandal B., Pal S. Role of organic manuring in community-managed ponds. *Aquat Sci Rev.* 2023; 12(1): 33-41.
17. Misra V., Pandey L. Seasonal fluctuations of zooplankton in semi-arid regions. *J Arid Environ.* 2020; 33(1): 55-67.
18. Mukherjee T., Das K. Ecological traps in neglected freshwater ecosystems. *Environ Conserv Bull.* 2024; 19(1): 88-94.

19. One Health Initiative. Interdisciplinary approaches to aquatic ecosystem health. *One Health J.* 2024; 12: 45-58.

20. Panigrahi A.K., Bakshi A., Pattanayak S. A comprehensive review on uptake and accumulation of heavy metals in freshwater fishes. *Biosci Biotechnol Res Commun.* 2021;14(1).

21. Panigrahi A.K., Pattnaik S. Water pollution effects of river Saraswati and Kunti on livelihood: a case study of Fishermans' communities in West Bengal. *J Fish.* 2020; 8(3): 928– 934.

22. Paul A. Nutrient cycling in managed vs unmanaged tropical ponds. *J Water Manag.* 2022; 25(2): 150-63.

23. Ray M., Khan A., Singh J. Spatial correlation of plankton density in administrative blocks of Birbhum. *J Aquat Biol.* 2022; 31(4): 310–318.

24. Saha P., Devi R. Impact of monsoon runoff on nutrient loading in Birbhum water bodies. *Indian J Fish Sci.* 2023; 58(2): 45-52.

25. Sharma U., Gupta P. Comparative analysis of functional and defunct cooperatives. *Soc Econ Rev.* 2023; 21(3): 214–228.

26. Wetzel R.G. Limnology: lake and river ecosystems. 3rd ed. San Diego: Academic Press; 2001.