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Research Article

Species diversity of *Oscillatoria* in the Pokkali paddy fields of Chandiroor, Alappuzha District, Kerala, India

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Abstract

The Pokkali paddy fields of Alappuzha District represent a highly productive ecosystem characterized by rich algal biodiversity. The distribution of algal communities in this region is significantly influenced by climatic variations, biological interactions, physicochemical parameters, and cropping patterns. In the present study, the algal population in the Pokkali paddy fields of Chandiroor, Alappuzha was monitored across post-monsoon, pre-monsoon, and monsoon seasons from February 2023 to January 2024. The physicochemical parameters analyzed include temperature, pH, alkalinity, salinity, dissolved oxygen, and nutrient analysis such as nitrate, phosphate, and silicate. Water temperature reached its minimum during the monsoon season and was highest in the period preceding the rains. During the post-monsoon season, both pH and salinity levels showed an increase relative to the other seasonal periods. Alkalinity also showed an increase in the post-monsoon period. The concentration of dissolved oxygen increased during the monsoon period compared to the other seasons. Nitrate concentrations peaked during the monsoon, while phosphate content was highest in the pre-monsoon season. Silicate levels were lowest during the monsoon. Cyanophycean members were dominant in the study area, contributing significantly to the nitrogen-fixing biomass in the paddy fields. Among them, species of *Oscillatoria* were observed to be the most frequent and abundant throughout the study period. A total of fifteen *Oscillatoria* species were collected and identified using standard taxonomic references.

Keywords: *Oscillatoria* species, Blue-green algae, Pokkali paddy fields, Physicochemical parameters, Alappuzha District

Introduction

Paddy fields create ideal conditions such as suitable light, temperature, nutrients, and water that support the proliferation and metabolic activity of diverse blue-green algae. The importance of blue-green algae in enhancing rice field fertility through nitrogen fixation was first highlighted by De (1939). These algae play a significant part in the production of crops and are considered as a promising biofertilizers. According to Pimentel *et al.* (1992), cyanobacteria have the potential to replace up to 30 kilograms of nitrogen fertilizer per hectare. Renowned for their nitrogen-fixing and carbon-assimilating abilities, blue-green algae also contribute to the solubilization of rock phosphate and the production of growth-promoting substances (Venkataraman, 1993). Functioning as a self-sustaining system, cyanobacteria have the ability to transform nitrogen from the atmosphere into usable organic compounds, serving as a natural biofertilizer that improves soil quality and promotes better rice growth and productivity (Song *et al.,* 2005). Blue-green algae used as a sustainable nitrogen source can lead to a 20.9% increase in rice yield (Paudel *et al.,* 2012). The cyanobacteria, in turn, offer an adequate amount of nutrients, like nitrogen and phosphorus, required for rice cultivation (Singh *et al.,* 2014). The application of nitrogen-fixing blue-green algae as green manure has shown promising results in paddy fields across several Asian countries (Asuming-Brempong, 2014). Nitrogen-fixing blue-green algae proliferate extensively in tropical regions, particularly those rice-growing areas (Singh *et al.,* 2014, 2016). Cyanophycean members were found to be the most abundant in the paddy fields, which correlated with a pH range of 6.5 to 7.5 in natural conditions and they thrive best in an optimal pH range of 7.5 to 10 under cultured conditions (Petkar, 2022).

Pokkali paddy is a unique, salt-tolerant rice variety cultivated organically in the waterlogged coastal regions of Kerala through a traditional rotational system that integrates rice farming during the monsoon season with prawn cultivation in the remaining months. This sustainable practice supports ecological balance and promotes biodiversity. The algal community in Pokkali paddy fields exhibits distinct characteristics influenced by factors such as water quality, seasonal monsoon variations, crop growth stages, fallow periods, and other physicochemical conditions. However, research focusing on the algal composition within the Pokkali paddy fields of Alappuzha district remains quite limited. This preliminary survey involved a comprehensive assessment of blue-green algal diversity within the Pokkali paddy fields located at Chandiroor. Among the various cyanophycean members observed, the genus *Oscillatoria* exhibited the greatest species diversity during the study period. This study primarily focused on isolating and identifying *Oscillatoria* species from the Pokkali paddy fields of Chandiroor, in addition to evaluating water quality parameters across three distinct seasons. This pioneer attempt provides valuable insights into the diversity and distribution of *Oscillatoria* species in the Pokkali paddy fields of Chandiroor.

Materials and Methods

Algae sampling was conducted in the Pokkali paddy fields of Chandiroor, which span approximately 70.5 hectares and include three major Pokkali cultivation areas, over the period from February 2023 to January 2024. The algal samples were collected using a random sampling method with a 20 µm mesh-sized phytoplankton net and stored in bottles. The samples were preserved using 4% formalin. In the laboratory, the samples were analyzed and the algae were identified based on morpho-taxonomic characteristics, referring to standard monographs and publications by Parukutty (1940), Desikachary (1959), Anand and Hopper (1987) and Anand (1989). Microphotographs of each species were taken using an Olympus CX31 binocular microscope equipped with a ToupCam camera, and measurements of the microalgae were recorded. Key indicators of water quality such as temperature, salinity, alkalinity, dissolved oxygen, and pH, along with nutrient levels such as nitrate, phosphate, and silicate, were analyzed. The physicochemical analysis of water samples followed standard methods and protocols (APHA, 1998). The water temperature was recorded with a mercury thermometer, while the pH levels were determined with the help of a digital pH meter. Alkalinity was determined using the phenolphthalein method, salinity was measured by Mohr's method, and dissolved oxygen was assessed using Winkler's method. Nitrate was analyzed according to IS 3025 (Part 34), phosphate was determined by using the stannous chloride method, and silicate by IS 3025 (Part 35).

Results

During the study period, members of the class Cyanophyceae were found to be abundant in the Pokkali paddy fields of Chandiroor in the Alappuzha District. A total of fifteen species of *Oscillatoria* were identified across the post-monsoon, pre-monsoon, and monsoon seasons. The recorded species include *Oscillatoria perornata*, *O. okeni*, *O. limosa*, *O. curviceps*, *O. subbrevis*, *O. pseudogeminata* var. *unigranulata*, *O. proteus*, *O. sancta*, *O.chlorina*, *O. chalybea* var. *insularis*, *O. princeps*, *O. princeps* var. *pseudolimosa*, *O. rubescens*, *O. Nigroviridis* and *O. tenuis*. The taxonomic descriptions of these species, along with illustrative figures, are provided below:

O. perornata Skuja (Figure 1a) (Desikachary, 1959)

The trichomes are upright and flexuous, featuring slightly attenuated and curved apices, with noticeable constrictions at the cross-walls. Trichome diameter ranges from 13 to 13.8 µm, while individual cells measure 3 to 4 µm in length and display a finely granular texture. The septa are granulated, and the terminal cell is shaped like a depressed hemisphere, with no calyptra present.

O. okeni Ag. ex Gomont (Figure 1b) (Parukutty, 1940; Desikachary, 1959)

The trichomes appear dull blue-green in color and are straight, with distinct constrictions at the cross-walls, measuring 8.8 to 9 µm in width. They taper gradually toward the ends, becoming slightly bent and undulating. Cell length ranges from 2.8 to 4.2 µm, extending up to 8 µm near the terminal regions. The end cells are obtuse, lack capitation, and do not possess a calyptra.

O. limosa Ag. ex Gomont (Figure 1c) (Desikachary, 1959)

The trichomes are blue-green in color, generally straight, and exhibit slight constrictions at the cross-walls, with a width ranging from 13.9 to 14.1 µm. Cells are 2.8 to 3 µm in length, and the cross-walls are often granulated. The terminal cell is flatly rounded with a slightly thickened membrane.

O. curviceps Ag. ex Gomont (Figure 1d) (Parukutty, 1940; Desikachary, 1959)

The trichome appears light blue-green in color, straight, and slightly attenuated, without constrictions at the cross-walls. It measures 7 to 7.3 µm in width, with cells ranging from 1.5 to 2 µm in length. The cross-walls are granulated, and the terminal cells are flatly rounded and non-capitate.

O. subbrevis Schmidle (Figure 1e) (Desikachary, 1959)

The trichome is solitary, nearly straight, and measures 5.8 to 6 µm in width, with no attenuation at the apices. Cells are 1 to 1.3 µm in length, with smooth cross-walls lacking granulation. The terminal cell is rounded, and a calyptra is absent.

O. pseudogeminata var. *unigranulata* Biswas (Figure 1f) (Desikachary, 1959)

The trichomes are blue-green in color, measuring 2.9 to 3 µm in diameter, and appear delicate and straight without constrictions at the cross-walls or tapering at the apices. The apices are broadly rounded, non-capitate, and lack a calyptra. Individual cells range from 3.5 to 3.9 µm in length, with a thick and clearly defined cell wall. Each cross-wall contains a single prominent central granule, and the cell contents are finely and uniformly granular.

O. proteus Skuja (Figure 1g) (Desikachary, 1959)

The trichomes are curved, with apices that are shortly attenuated and slightly bent, measuring 6.8 to 7 µm in width. They exhibit distinct constrictions at the cross-walls, with clearly visible and granulated dissepiments. The cells, containing pale olivaceous contents, are 2.7 to 3 µm in length, and the apical cell is rounded-conical in shape.

O. sancta (Kutz) Gomont (Figure 1h) (Parukutty, 1940; Desikachary, 1959; Anand & Hopper, 1987)

The trichome is blue-green and straight, showing clear constrictions at the cross-walls. The ends are briefly attenuated, with a width of 10-12 µm and a cell length of 2.6-3 µm. Granulation is evident at the cross-walls. The terminal cell is flattened, hemispherical, slightly capitate, and possesses a thickened membrane.

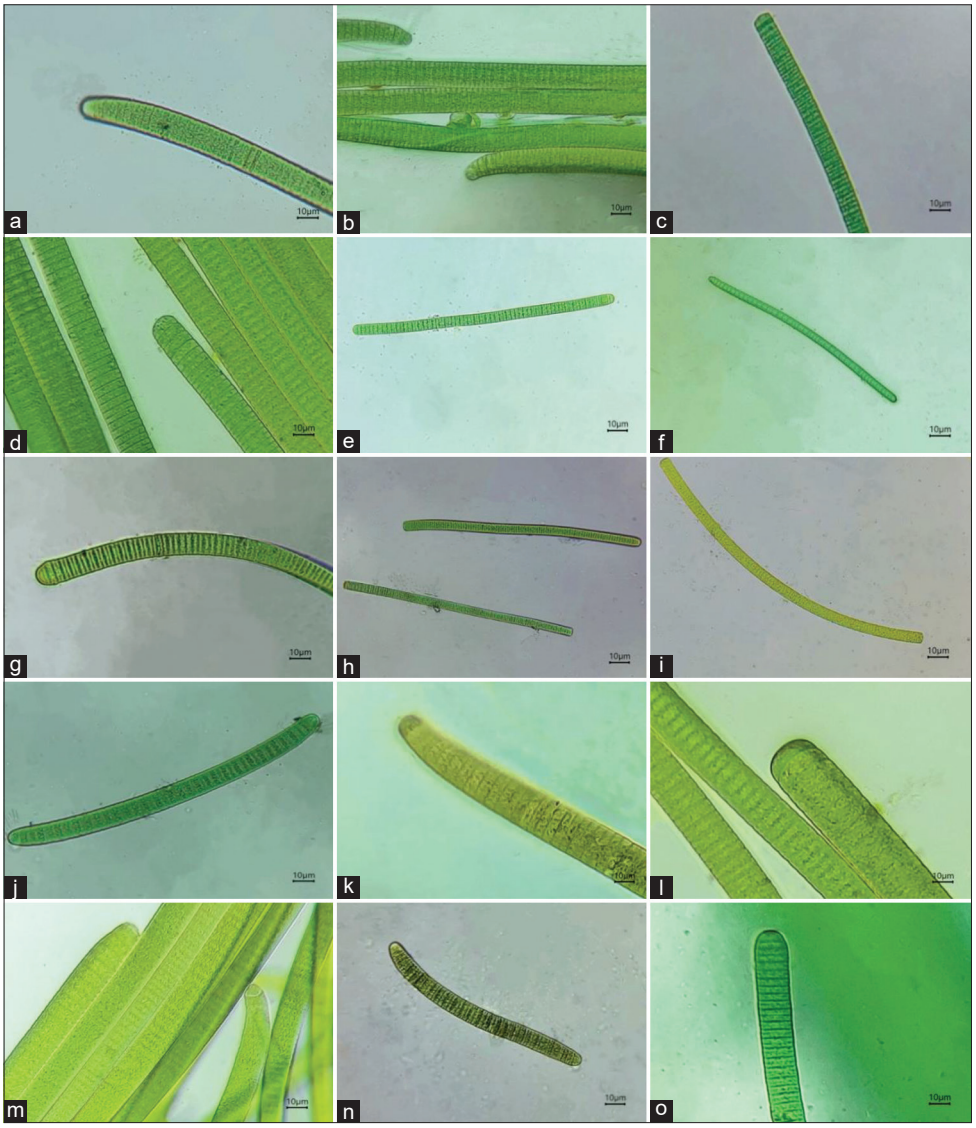

Figure 1: a) *Oscillatoria perornata*, b) *Oscillatoria okeni*, c) *Oscillatoria limosa*, d) *Oscillatoria curviceps*, e) *Oscillatoria subbrevis*, f) *Oscillatoria pseudogeminata* var. *unigranulata*, g) *Oscillatoria proteus*, h) *Oscillatoria sancta*, i) *Oscillatoria chlorina*, j) *Oscillatoria chalybea* var. *insularis*, k) *Oscillatoria princeps*, l) *Oscillatoria princeps* var. *pseudolimosa*, m) *Oscillatoria rubescens*, n) *Oscillatoria nigroviridis* and o) *Oscillatoria tenuis*

O.chlorina Kutz. ex Gomont (Figure 1i) (Desikachary, 1959)

The trichomes are yellowish-green and curved, measuring 3.8 to 4 µm in width, without constrictions at the cross-walls. Gas vacuoles are absent. Cells range from 3.9 to 8 µm in length, with smooth, non-granulated cross-walls, and the calyptra is absent.

O. chalybea var. *insularis* Gardner (Figure 1j) (Parukutty, 1940; Desikachary, 1959)

The trichomes exhibit a blue-green coloration, with ends that are curved and sickle-shaped. They measure 7 to 7.2 µm in width, with the length approximately equal to the breadth, and show no constriction at the cross-walls.

O. princeps Vaucher ex Gomont (Figure 1k) (Desikachary, 1959)

The trichomes are brownish and straight, measuring 21-22 µm in width, with no constrictions at the cross-walls. They exhibit slight attenuation and bending at the apices. Cells are 4-4.5 µm in length, and the terminal cells are flatly rounded, slightly capitate, and possess a mildly thickened membrane.

O. princeps var. *pseudolimosa* Ghose (Figure 1l) (Desikachary, 1959; Anand & Hopper, 1987)

The trichome is blue-green and straight, measuring 32 to 33 µm in width. Cross-walls are smooth without granulation, and the cells are short, containing granular protoplasm. The apices remain straight, with the apical cell slightly convex, and no calyptra is present.

O. rubescens DC ex Gomont (Figure 1m) (Desikachary, 1959)

The trichomes are straight and tapering at the ends,

measuring 7.8 to 9 µm in width, with no constriction at the cross-walls. Cells are 3.4 to 3.9 µm in length and frequently exhibit granulation at the septa. The terminal cell is capitate and bears a convex calyptra.

O. nigroviridis Thwaites ex Gomont (Figure 1n) (Parukutty, 1940; Desikachary, 1959)

The trichomes are olive-green in color, measuring 10.2 to 10.5 µm in width, and exhibit distinct constrictions at the cross-walls. The ends are attenuated and bent, with individual cells ranging from 4.2 to 5 µm in length. Cross-walls are granulated, and the terminal cells are slightly capitate, possessing a convex and moderately thickened outer membrane.

O. tenuis Ag. ex Gomont (Figure 1o) (Desikachary, 1959)

The trichomes are blue-green in colour, straight, and show slight constrictions at the cross-walls. They measure 9.8 to 10 µm in width and maintain uniform thickness without tapering or forming capitate ends. Individual cells are 3.7 to 4 µm in length, with granulation observed at the septa. The terminal cell is hemispherical and possesses a thickened outer membrane.

The seasonal distribution of *Oscillatoria* species in the Pokkali paddy fields of Chandiroor is summarized in Table 1. The symbols (+) and (-) indicates the presence and absence of species, respectively. Seasonal variations in the physicochemical characteristics of water during the post-monsoon, pre-monsoon, and monsoon periods are presented in Table 2. Water temperature reached its maximum during the pre-monsoon season and declined during the monsoon. The pH remained slightly alkaline during the post-monsoon and pre-monsoon seasons, followed by a reduction during the monsoon. Salinity and alkalinity exhibited higher values during the post-monsoon and pre-monsoon seasons and showed a marked decline during the monsoon. Dissolved oxygen concentrations were comparatively elevated during the monsoon season relative to the other seasons. Nutrient concentrations such as nitrate showed relatively higher levels during the monsoon, whereas phosphate and silicate concentrations were comparatively higher during the pre-monsoon season and declined during the monsoon. Overall, these variations highlight the strong influence of seasonal dynamics on the water quality of the Pokkali paddy fields.

Discussion

Kerala is endowed with rich algal biodiversity; however, a significant portion remains unexplored. Research on the algal diversity within the Pokkali paddy fields of the state remains limited in scope. Blue-green algae were investigated in the rice-growing regions across different districts of Kerala, where species such as *O. princeps* var. *pseudolimosa* and *O. sancta* were identified (Anand & Hooper, 1987). Studies on periphytic algae in the Pokkali and prawn cultivation areas of North Paravoor and Vypeen Island have recorded the presence of various blue-green algal species, such as *O. perornata*, *O. curviceps*, *O. chlorine*, and *O. tenuis* (Joshi, 2010). Research on the periphytic algal flora of the Pokkali and prawn fields of Pizhala Island reported the presence of *Oscillatoria* species during the

Table 1: Seasonal occurrence of *Oscillatoria* species in pokkali fields

S. No.	Species	Post-monsoon			Pre-monsoon			Monsoon		
		Field 1	Field 2	Field 3	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3
1	*Oscillatoria perornata*	+	−	−	+	−	+	+	−	−
2	*Oscillatoria okeni*	−	+	−	−	+	+	−	+	+
3	*Oscillatoria limosa*	−	−	+	+	+	−	+	−	+
4	*Oscillatoria curviceps*	+	−	−	+	−	+	−	+	−
5	*Oscillatoriasubbrevis*	−	+	−	+	+	−	+	+	+
6	*Oscillatoria pseudogeminata* var. *unigranulata*	−	−	−	−	+	−	−	+	−
7	*Oscillatoria proteus*	+	−	−	−	+	+	−	−	+
8	*Oscillatoria sancta*	−	−	+	+	+	−	+	−	+
9	*Oscillatoria chlorine*	−	+	−	−	−	+	+	+	−
10	*Oscillatoria chalybea* var. *insularis*	−	−	−	+	−	+	−	+	−
11	*Oscillatoria princeps*	−	−	+	−	+	−	+	−	+
12	*Oscillatoria princeps* var. *pseudolimosa*	+	−	−	−	−	+	−	−	−
13	*Oscillatoria rubescens*	−	−	−	+	+	−	−	+	+
14	*Oscillatoria nigroviridis*	+	−	−	+	−	−	−	−	−
15	*Oscillatoria tenuis*	−	−	−	+	−	+	+	+	−

Table 2: Physicochemical parameters of water across different pokkali seasons

Physicochemical parameters	Post-monsoon			Pre-monsoon			Monsoon		
	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3
Temperature (°C)	27.5	28	27	32	29	30	27	26.5	27
pH	8	7.7	8.2	7.9	7.5	7.3	6.8	7	6.2
Salinity (mg/L)	20301.9	18560	22431.5	17802.2	15890.1	18352.6	2742.3	3139.5	1475.7
Alkalinity (mg/L)	105	98.9	120	78	80	95	66	59	61
Dissolved Oxygen (mg/L)	6.5	7.5	7	4.9	6	5.2	8.5	4.2	8.8
Nitrate (mg/L)	3.6	1.9	2.2	3.2	2.9	3.6	4	3.8	3.7
Phosphate (mg/L)	3.2	3.4	2.9	5	4.6	4.1	3.9	2.2	3.7
Silicate (mg/L)	6.2	5.7	3.9	7.8	7.3	5.5	3.2	2.8	3.6

post-Pokkali season (Ananthu & Jose John, 2022). Seasonal variation and diversity of blue-green algae were explored in Kerala's Kuttanad region, a tropical wetland paddy ecosystem in South India, leading to the identification of 12 different *Oscillatoria* species (Vijayan & Ray, 2015). The study reported a rich blue-green algal diversity, with members of the order Oscillatoriales being dominant in the region. A similar investigation on the diversity and spatial distribution of cyanobacteria in the paddy fields of Chhattisgarh, India, documented the occurrence of *O. princeps* and *O. curviceps* (Singh *et al.,* 2014). Within the paddy ecosystems of Orissa, *O. chalybea* and *O. subbrevis* emerged as the dominant species. The cyanobacterial communities showed a positive relationship with soil pH across the observed sites (Dey *et al.,* 2011). *Oscillatoria* species have been identified as a natural feed source for prawns (Bakhtiyar *et al.,* 2014). Their populations tend to increase during periods of fertilizer application and elevated feed input for tiger shrimp (Sahabuddin *et al.,* 2019).

The findings of the current study align with earlier reports, with *Oscillatoria* species observed in the period preceding the monsoon and reappearing in the later phase of the monsoon season. Their abundance gradually increased from April, reaching a peak in May. A decline in population was observed during the peak monsoon period; however, as monsoon effects subsided, the species began to recover, attaining maximum abundance by the end of the season. This trend suggests that *Oscillatoria* predominantly emerges following the rice and prawn cultivation cycles. Renowned for its nitrogen-fixing capability and contribution to organic matter, *Oscillatoria* likely plays a vital role in enhancing soil fertility within the Pokkali farming system. In the present investigation, fifteen *Oscillatoria* species were collected and identified in the Pokkali cultivation area of Chandiroor over the course of the study.

Conclusion

The Pokkali cultivation zones provide a conducive environment that supports the proliferation of algal communities. In this study, blue-green algae were notably dominant in the Chandiroor region of Alappuzha, with *Oscillatoria* emerging as the most prevalent and numerically dominant genus throughout the observation period. The investigation aimed to identify the *Oscillatoria* species present and to analyze the physicochemical parameters of the research area. Altogether, 15 distinct *Oscillatoria* species were successfully collected and identified.

Author contributions

Salma Jasmine: Conceptualization, Investigation, Methodology, Visualization, Writing – original draft. Sreeja Krishnan: Validation, Supervision, Writing – review & editing. All authors approved the final manuscript.

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