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Ecology and Diversity of Cyanobacteria in *Kuttanadu* Paddy Wetlands, Kerala, India

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Abstract

Algae are one of the major groups of soil microflora in agricultural lands. Among algae, the blue-greens are considered to be very valuable in agriculture. The role of them in soil fertility enhancement has been extensively studied worldwide. Sustainable utilization of an organism for any human purpose depends on how successfully the ecology of the same is thoroughly understood. *Kuttanadu* is a unique tropical paddy-wetland. Ecology of blue-green-algae and the exact diversity of the same in the zone remained unexplored. This is the first report of the blue-green-algal community of *Kuttanadu* in relation to different soil-regions, seasons, and crop-growth-stages. A rich blue-green-algal diversity of 64 species, with Oscillatoriales as the dominants (38%), is observed in these paddy-fields. The highest values for all the ecological parameters analyzed were found in the Lower *Kuttanadu* soil region, during *Virippu* season, at panicle stage of the crop whereas the lowest values for most of the parameters were observed in Upper *Kuttanadu* soils during *puncha* season at the seedling and panicle stages. The species richness and diversity index showed positive correlation to crop seasons. Apart from the specific soil and climatic factors, the total number of blue green algal isolates showed positive correlation to total nitrogen and phosphorus in the soils.

Keywords

Blue Green-Algae, Paddy-Wetland, Seasons, Soil-Regions, Growth-Stages

1. Introduction

Nitrogen deficiency is a common problem of rice soils worldwide. Several species of blue-green-algae or cyanobacteria with nitrogen fixing capacity are currently used as bio-fertilizer, especially to wetland paddy, in many

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parts of the world [1]. Cyanobacteria as a fertilizer supplement are capable of replacing 30 - 40 percent of urea nitrogen requirement to paddy and they have other positive roles in soil management [2]. Role of cyanobacteria in paddy fields is a much explored theme of research [3]-[9]. Since most blue-greens are cosmopolitan species with wide ecological amplitude to occupy diverse environmental conditions, exploration of the diversity and ecology of them from specific paddy zones has global relevance towards the development of sustainable paddy farming everywhere in the world. Moreover, as they are photosynthetic species, quantitative assessment of them in such soils will be significant to the accounting of global carbon sequestration potentials of paddy soils in general. These algae are also suggested as solution to soil pollution [10]. Their roles in soil crust formation and surface stabilization [11], soil genesis, soil conservation [12], general soil fertility enhancement [13] are well known. Some algae are also known as agents of producing plant growth promoting substances [14]. Very many specific reports of cyanobacteria from paddy fields of Kerala region are available [15]-[18], but those of specific zones of *Kuttanadu* fields are quite rare [19] [20] and pretty old.

In these contexts, a comprehensive evaluation of the ecology and diversity of blue-greens of *Kuttanadu* rice fields is carried out. Major objectives included isolation and identification of all the specific species of blue-greens in the paddy fields of *Kuttanadu*, Kerala, South India in relation to soil regions, seasons and crop-growth-stages. Quantitative ecological aspects of the entire cyanobacterial community in terms of population dynamics and relative abundance in relation to soil pH, Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), and Magnesium (Mg) from three different soil regions of *Kuttanadu* in relation to two crop seasons (*puncha* and *virippu*) and two growth stages of paddy (seedling and panicle stage) are compared and analyzed. As such, this is the pioneer attempt to explore the ecology and diversity of blue-green-algae in *Kuttanadu* wetland-paddy soils.

2. Materials and Methods

Kuttanadu (90˚17'N to 90˚40'N; 760˚19'E to 760˚33'E) is a unique tropical flooded paddy land of global interest situated in the South India **Figure 1**. It is the traditionally well known rice bowl of Kerala, spread around the *Vembanadu Ramsar zone* with a size of approximately 25 km in east-west direction and 60 km in north-south, direction, spread over 54 revenue villages of the three districts of Kerala State. This inland backwater zone had an estuarine character; but the construction of the "Thannirmukkam-barrage" during 1970s to protect paddy cultivation in the area from saline incursion during the non-monsoon season has caused the entire zone to become an artificially maintained freshwater system. These paddy fields lie at an average of 2 to 2.5 m below the mean sea level and remain freshwater-flooded all throughout the year except during the crop seasons when water is pumped out from the fields.

Major paddy crop seasons of the zone are *Puncha* (the summer crop—December to March) and *Virippu* (the monsoon crop—May to October). In general, the soil of *Kuttanadu* is highly compressible dark brown "alluvial" clay of high organic and specific mineral constituents [21]-[23] with slight variations over soil regions. Upper *Kuttanadu*, Lower *Kuttanadu* (Kari soils) and Kayal-lands are the three major soil regions of *Kuttanadu* [22].

On the basis of geological features and biochemical characteristics, soils of *Kuttanadu* are grouped into three categories such as *Karappadom* (found mostly in the upper *Kuttanadu*), *Kari* (mostly lower *Kuttanadu*) and *Kayal* (mostly in *Kayal* lands) soils. *Karappadom* soils spreads over a large part in the upper *Kuttanadu* covering an area of about 33,000 hectares. They are river-borne alluvial soils. They are located more towards the interior and exhibit salinity less than that of the *Kari* and *Kayal* soils. They are deep and poorly drained soils. Soil colour varies from dark grey to deep brown or black. The surface soils are generally clay loams and characterized by high acidity and a fair amount of decomposing organic matter and nitrogen. They are generally deficient in available plant nutrients, phosphorus and lime.

Kari soils are characterized by acidity and salinity, which are deep black in colour due to relatively higher proportion of organic matter. They are seen in both the upper and lower *Kuttanadu* regions. They are peat soils found in large isolation patches in *Alappuzha* and *Kottayam* districts covering an area of about 9000 hectares. They exhibit characteristics of submerged and burned mangrove forest area, but are not silted up. Soils are characterized by heavy texture, poor aeration, bad drainage and low content of available plant nutrients. The natural formation of sulphuric acid is reported in *Kari* soils. Free sulphuric acid is formed by the oxidation of sulphur compounds present in the wood fossils under the soil. Large amounts of woody matter at various stages of decomposition occur embedded in this soil.

Kayal soils are found in rice fields reclaimed from the *Vembanadu* lake beds at the *Kottayam* and *Alappuzha*

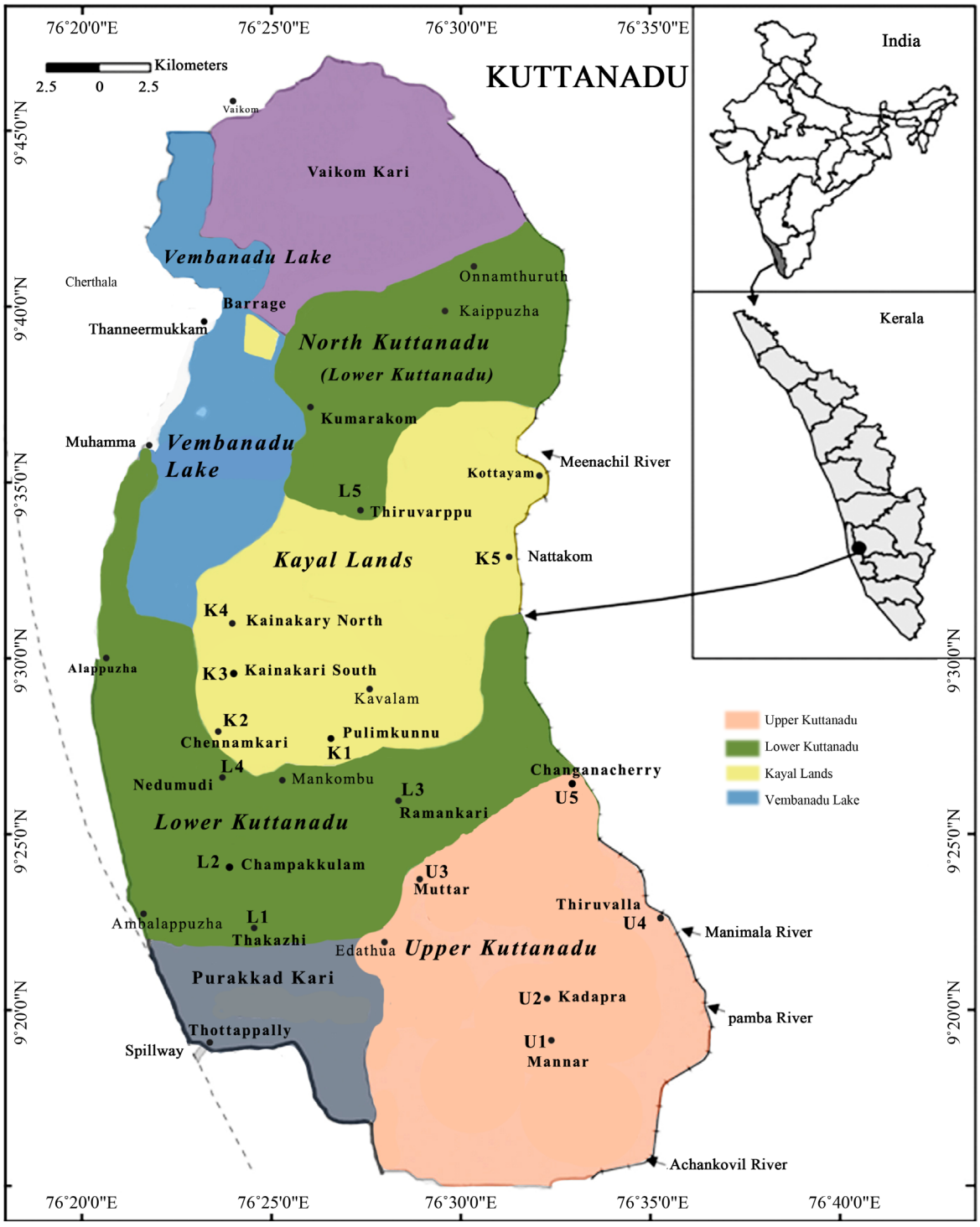

Figure 1. Map of *Kuttanadu*.

districts and occupy an area of about 13,000 hectares. They are deep and poorly drained soils with a dark brown colour. The texture varies from silt loam to silty clay loam. They are slightly acidic to neutral in reaction. They are low in inorganic matter content, poor in total and available plant nutrients, but are fairly rich in calcium.

In all tables R1 represents the Upper *Kuttanadu*, R2 the Lower *Kuttanadu* and R3 the Kayal Lands; S1 represents the Pre-monsoon (*Puncha*) crop and S2 the Monsoon crop (*Virippu*); G1 represents the seedling

growth stage and G2 the panicle stage.

Soil Sampling

Separate soil samples were collected simultaneously for algal studies and physico-chemical analyses of soils. All the analyses were carried out using standard Methods. Soil sampling for blue-green-algae was the same as that for soil and green algal studies of the zone already reported [23]. Soil sampling was carried out from five different paddy fields located about- 2 km intervals for each of the three soil regions. Two different composite soil samples of 1 - 5 cm depth were collected from each paddy field. At each field, samples were collected from several random plots of 10 m^2 size and mixed them together to a composite soil sample. Altogether 40 different composite samples (5 fields × 2 plots × 2 crop seasons-*Puncha* and *Virippu* × 2 crop-growth stages-seedling stage and panicle stage) were collected from a soil region. Parallel to soil sample collection for physico-chemical analyses, surface samples for algal studies were also collected in the same pattern from all the fields.

Overall, 120 composite soil samples (40 × 3 soil regions) were collected from the three different areas of *Kuttanadu* for both the soil and algal studies. Algae were identified according to the keys of Desikachary, 1959 [24] and the classification of Guiry and Guiry, 2012 [25]. The morphological parameters such as nature of the filaments, the shape and size of vegetative cells, heterocysts, akinetes, width and length of intercalary cells, presence or absence of constriction at the cross wall and of the sheath; colour of the sheath; nature of trichomes and filaments; presence or absence of heterocyst; width and length of heterocyst were taken into consideration during the identification of the taxa. Statistical analyses such as ANOVA and Pearson's correlation coefficient were carried out using the SAS 9.2 (2010) version software.

Physico-chemical characteristics of the soil, such as pH, total organic carbon (C), total Kjeldal N, plant available P, K, Ca and Mg studied in relation to crop seasons and different stages of paddy growth in the three different regions of *Kuttanadu* are already reported [23].

3. Results

Altogether 64 species of blue-greens belonging to 22 genera and 6 orders have been found out from *Kuttanadu* paddy fields during the study period (2009-11). Overall distribution of them in the three soil regions in different crop-seasons and growth stages of paddy are given in **Table 1**. The genus Oscillatoria with 12 species dominated the soils, followed by Anabaena (9 species) and Notoc (7 species). Phormidium and Leptolyngbya with 5 species each were also found out. Out of the sixty four species, thirty species were observed in culture only, thirty three were found out from fresh soil samples and *Leptolyngbya cf. battersi* was the only species appeared in both culture and fresh soil samples. Relative abundance of all species is given in **Figure 2**. The six orders of algae observed were Chroococcales (5 genera, 9 species; 14%), Synechocystales (3 genera, 4 species; 6%), Nostocales (4 genera, 18 species; 28%), Stigonematales (3 genera, 4 species; 6%), Pseudoanabenales (1 genus and 5 species; 8%) and Oscillatoriales (5 genera, 24 species; 38%). Population characteristics of all species are given in **Table 1**. Species richness and diversity index of all groups are given in **Table 2** and soil chemical characteristics in **Table 3**. **Plates 1-4** show photographs of all the 64 species found out from *Kuttanadu*.

3.1. Number of Species and Total Isolates

The highest number of species (45 species) and total isolates (287) were observed in the Lower *Kuttanadu* fields during the *Virippu* season in the panicle crop-growth-stage. The lowest number of species (16) was found in the two crop-growth-stages of *puncha* season in Upper *Kuttanadu*; the lowest total number of isolates (76) was also observed in the Upper *Kuttanadu* during the *puncha* season at the seedling stage (**Table 2**). *Chroococcus turgidus* was the most abundant species both in the upper and Lower *Kuttanadu* regions. Gleothecerupestris was the most abundant one in Kayal lands. The most abundant blue-green-algae observed in *Puncha* season was *Chroococcusturgidus*, whereas the same observed in the *Virippu* season were *Nostoccarneum* and *Anabaena spherica*. Seven species were found specific to upper *Kuttanadu* soils, ten species to Lower *Kuttanadu* soils, whereas no cyanobacterium was found specific to Kayal lands.

3.2. Ecological Characteristics

The ecological characteristics studied were relative abundance, species richness, species evenness and diversity

Table 1. Distribution and relative abundance (%) of blue green algae of three different soil regions of *Kuttanadu* in relation to crop-seasons and paddy growth stages.

No	Cyanaophyceae sp.	R1				R2				R3				Abund %
		S1		S2		S1		S2		S1		S2		
		G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	
	Order: Chroococcales													
1	*Microcystis aeruginosa***	5	-	7	-	-	-	-	8	4	9	-	-	27.50
2	*Gleocapsa punctata**	-	-	9	10	6	8	-	-	5	6	9	10	52.50
3	*Gleothece rupestris**	7	9	-	-	-	-	-	-	7	10	6	9	40.00
4	*Aphanothece conferta**	6	7	4	9	-	-	-	-	-	-	-	-	21.67
5	*Chroococcus turgidus**	5	8	8	9	8	8	7	9	8	4	-	-	61.67
6	*C. limneticus***	-	6	-	-	5	7	-	-	6	-	-	-	20.00
7	*Chroococcus minutes***	7	7	-	-	-	7	8	10	7	6	-	-	43.33
8	*Chroococcus minor**	6	-	-	7	5	-	6	8	5	8	6	-	42.50
9	*Spirulina laxissima**	4	3	-	-	-	-	-	-	-	-	-	-	5.83
	Order: Synechocystales													
10	*Synechocystis aquatilis***	-	-	-	-	-	-	5	6	-	-	-	-	9.17
11	*Aphanocapsa crassa**	5	8	6	9	-	-	-	-	-	-	-	-	23.33
12	*Merismopedia punctata**	4	8	4	9	-	-	-	-	-	-	-	-	20.83
13	*Merismopedia glauca**	5	7	-	-	-	-	-	-	-	-	-	-	10.00
	Order: Nostocales													
14	*Nostoc punctiforme***	-	-	-	-	6	9	4	-	-	3	5	-	22.50
15	*Nostoc padulosum**	-	6	6	-	-	-	7	8	-	-	8	9	36.67
16	*Nostoc linckia**	5	-	5	7	-	4	-	9	4	-	7	9	41.67
17	*Nostoc spongiaeforme**	3	4	2	3	-	-	-	-	-	-	-	-	10.00
18	*Nostoc carneum**	2	-	6	9	4	-	8	10	3	-	8	-	41.67
19	*Nostoc ellipsosporum**	-	4	5	8	5	7	9	9	-	7	9	-	52.50
20	*Nostoc commune**	6	-	4	8	5	6	8	10	-	-	-	7	45.00
21	*Anabaena sphaerica***	-	-	5	7	-	-	7	9	4	6	6	7	42.50
22	*Anabaena oryzae***	-	-	4	5	-	-	2	4	3	-	4	6	23.33
23	*Anabaena fertilissima**	-	-	5	6	-	-	5	5	4	5	5	5	33.33
24	*Anabaena gelatinicola**	-	-	1	2	-	-	1	2	2	-	2	2	10.00
25	*Anabaena orientalis***	-	-	2	3	-	-	1	1	1	1	2	3	11.67
26	*Anabaena variabilis**	-	-	2	2	-	-	2	2	-	2	3	3	13.33
27	*Anabaena torulosa**	-	-	5	7	-	-	4	6	4	7	5	-	31.67
28	*A. oscillatorides***	-	-	2	2	-	-	5	7	5	6	6	-	27.50
29	*Anabaena constricta***	-	-	2	2	-	-	2	3	4	4	6	-	19.17
30	*Nodularia spumigena**	-	-	-	-	-	7	-	9	-	-	-	-	13.33
31	*Aulosira prolifica**	-	-	6	7	-	5	-	5	-	-	-	-	19.17
	Order: Stigonematales													
32	*Hapalosiphon welwitschii**	-	8	7	7	-	-	-	-	8	9	-	-	32.50

Continued

33	*H. flagelliformae*[*]	-	9	8	8	-	-	-	-	10	10	9	-	45.00
34	*Westiellopsis prolifica*[*]	-	-	-	-	9	10	-	-	-	-	-	-	15.83
35	*Scytonema stuposum*[**]	-	-	-	-	-	-	4	5	-	4	-	4	14.17
	Order: Pseudoanabenales													
36	*Leptolyngbya boryana*[*]	-	-	6	4	4	2	8	9	-	-	-	-	27.50
37	*Leptolyngbya tenui*[**]	-	-	-	7	7	5	-	10	-	-	-	-	24.17
38	*L. cf. battersi*[***]	-	-	9	-	7	-	8	8	-	-	-	-	26.67
39	*L. circumcreta*[*]	-	-	3	5	1	3	4	5	-	-	-	-	17.50
40	*Leptolyngbya sp*[*]	-	-	2	2	2	2	5	7	-	-	-	-	16.67
	Order: Oscillatoriales													
41	*Arthrospira jenneri*[**]	2	3	-	-	-	-	-	-	-	-	-	-	4.17
42	*Oscillatoria margaritifera*[**]	-	-	-	-	-	7	8	8	-	-	-	-	19.17
43	*Oscillatoria sancta*[**]	-	-	-	-	8	-	-	9	-	-	-	10	22.50
44	*Oscillatoria limosa*[**]	-	-	-	-	-	-	10	10	-	-	9	9	31.67
45	*Oscillatoria curviceps*[**]	-	-	-	-	-	-	7	7	-	-	8	9	25.83
46	*Oscillatoria princeps*[**]	-	-	-	-	6	7	9	8	5	5	10	10	50.00
47	*Oscillatoria amphibia*[*]	4	4	-	-	-	-	-	-	-	-	-	-	6.67
48	*Oscillatoria tenuis*[**]	-	-	-	-	3	2	7	7	-	-	6	8	27.50
49	*Oscillatoria proteus*[**]	-	-	-	-	-	-	1	2	-	-	2	1	5.00
50	*O. simplicissima*[**]	-	-	-	-	-	-	2	2	-	-	3	5	10.00
51	*Oscillatoria irrigua*[**]	-	-	-	-	-	-	1	1	-	-	1	1	3.33
52	*Oscillatoria amoena*[**]	-	-	-	-	-	-	1	-	-	-	1	2	3.33
53	*Oscillatoria rubescens*[**]	-	-	-	-	-	5	4	-	-	3	4	5	17.50
54	*Phormidium tenue*[**]	-	-	-	-	1	1	1	1	-	-	1	1	5.00
55	*P. purpurascens*[**]	-	-	-	-	-	-	7	9	-	-	-	-	13.33
56	*P. ambiguum*[**]	-	-	-	-	-	3	3	5	-	-	-	-	9.17
57	*Phormidiumin undatum*[**]	-	-	-	-	-	-	-	-	-	-	2	4	5.00
58	*P. papyraceum*[**]	-	-	-	-	-	1	-	3	1	-	-	-	4.17
59	*Lyngbya dendrobia*[**]	-	-	-	-	-	-	9	8	9	-	-	-	21.67
60	*Lyngbya ceylanica*[**]	-	-	-	-	4	-	3	7	-	-	4	4	18.33
61	*Lyngbya confervoides*[**]	-	-	-	-	-	-	-	-	1	1	1	2	4.17
62	*Lyngbya martensiana*[**]	-	-	-	-	-	-	2	3	-	-	-	-	4.17
63	*Microcoleus vaginatus*[*]	-	-	-	-	-	-	7	7	-	-	-	8	18.33
64	*M. accutissimus*[*]	-	-	-	-	5	-	8	6	-	-	7	7	27.50
	Total species/genera	**16/9**	**16/10**	**28/11**	**27/9**	**20/9**	**22/8**	**41/10**	**45/13**	**23/10**	**21/9**	**32/10**	**28/8**	

Species found only in culture[*], Species found in fresh soil sample[**], Species found both in fresh soil sample and in the culture[**].

Table 2. Ecological Characteristics of blue green algae in the *Kuttanadu* paddy soils.

Region	Season	Growth Stage	No. of Species	Total Isolates	Sps rich	Div. Ind	Sps. Evn
U.K	S1	G1	16	76	0.383	1.38	0.498
		G2	16	101	0.383	1.38	0.498
	S2	G1	28	135	0.671	1.68	0.504
		G2	27	164	0.647	1.66	0.504
L.K	S1	G1	20	101	0.479	1.5	0.501
		G2	22	116	0.527	1.55	0.502
	S2	G1	41	210	0.983	1.88	0.507
		G2	45	287	1.078	1.93	0.508
K.L	S1	G1	23	110	0.551	1.58	0.502
		G2	21	116	0.503	1.53	0.501
	S2	G1	32	165	0.767	1.75	0.505
		G2	28	160	0.671	1.68	0.504

Table 3. Average Soil Chemical characteristics of wetland paddy fields of *Kuttanadu* (Ray *et al*., 2014).

No	Location	Crop season	Growth stage	Average p^H	Average TN (%)	Average OC (%)	Average available nutrients (kg/ha)			
							P	K	Ca	Mg
1	U K	*Puncha*	*Seedling*	3.94	0.429	3. 07	10.86	998.6	3858.8	788.8
2	U K	*Puncha*	*Panicle*	3.88	0.392	4.06	18.26	656.9	2378.6	512.2
3	U K	*Virippu*	*Seedling*	3.4	0.289	0.94	129	298.7	441.4	177.7
4	U K	*Virippu*	*Panicle*	3.65	0.459	2.63	110	496.5	758.2	205.5
5	L K	*Puncha*	*Seedling*	4	0.413	3.97	7.14	855	1842.4	785.8
6	L K	*Puncha*	*Panicle*	4.29	0.374	3.54	25.34	389.2	2841.7	840.2
7	L K	*Virippu*	*Seedling*	3.74	0.37	1.68	109	316.7	1078	321.9
8	L K	*Virippu*	*Panicle*	3.7	0.52	2.16	95	408.9	1437.4	377.4
9	K L	*Puncha*	*Seedling*	4.03	0.39	3.28	9.6	391.2	1249.6	748.5
10	K L	*Puncha*	*Panicle*	4.61	0.435	3.7	9.46	396	2331.8	992.1
11	K L	*Virippu*	*Seedling*	4.05	0.4	2.49	129	440.9	1466.6	407.3
12	K L	*Virippu*	*Panicle*	4.23	0.431	2.68	58	408.3	1618.7	399.9

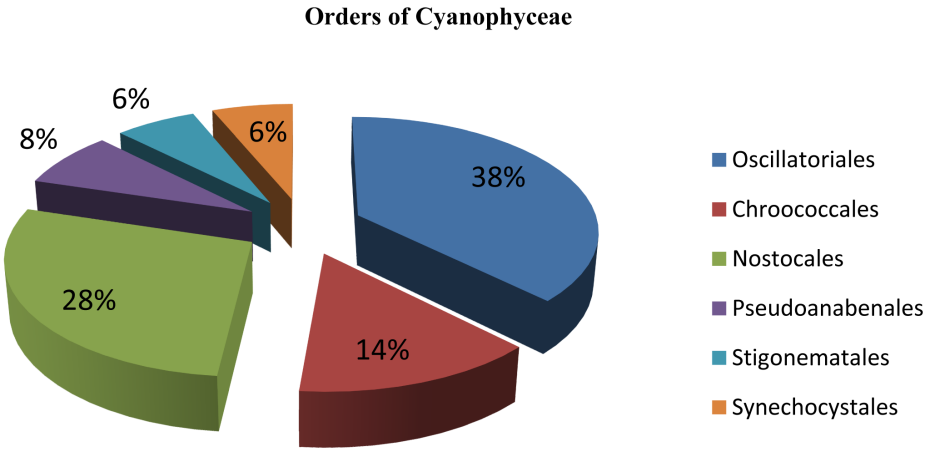

Figure 2. Diversity of bluegreen algae in *Kuttanadu* paddy soils.

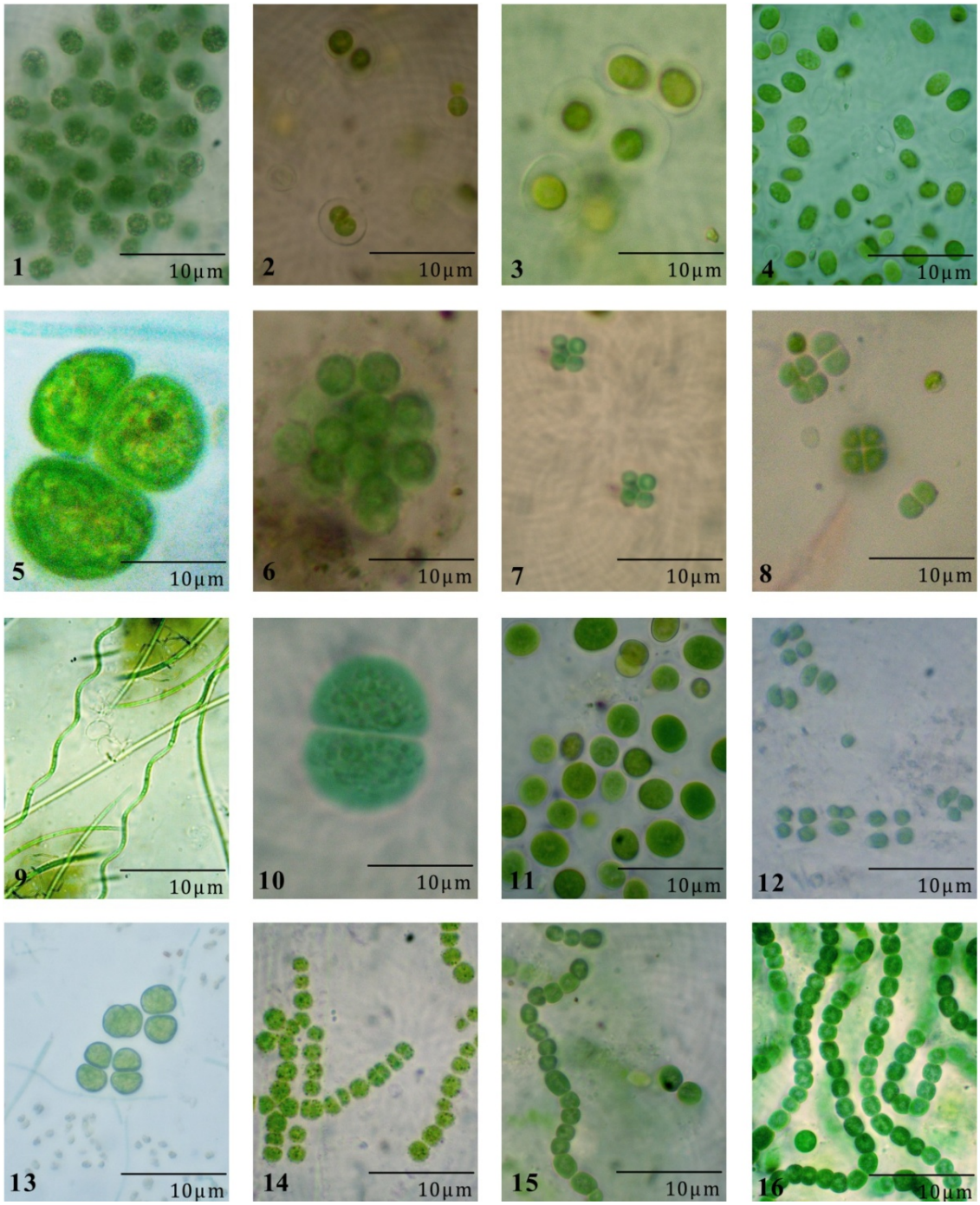

Plate 1. Figures 1-16: 1. *Microcystis aeruginosa* (Kutzing) Kutzing[**], 2.*Gleocapsa punctata* Nageli[*], 3. *Gleothece rupestris* (Lyngb) Bornet[*], 4. *Aphanothe ceconferta* Richter[*], 5. *Chroococcus turgidus* (Kutzing) Nageli[*], 6. *Chroococcus limneticus* Lemmermann[**], 7. *Chroococcus minutes* (Kutz.) Nageli[**], 8. *Chroococcus minor* (Kutz) Nageli[*], 9. *Spirulina laxissima* G. S. West[*], 10. *Synechocystis aquatilis* Sauv[**], 11. *Aphanocapsa crassa* Ghose[*], 12. *Merismopedia punctata* Meyen[*], 13. *Merismopedia glauca* (Ehrenb.) Nag.[*], 14. *Nostoc punctiforme* (Kuz.) Hariot[**], 15. *Nostoc padulosum* Kutzing ex Born.et Flah[*], 16. *Nostoc linckia* (Roth) Bornet ex Born. Flah[*].

index [26]. The relative abundance of the all sixty four green algal species was calculated from 120 soil samples representing the three different soil regions of *Kuttanadu*. The most dominant species in *Kuttanadu* was *Chroococcus turgidus* with relative abundance of 61.67%, followed by *Gleocapsa punctata* (52.5%), *Nostoc ellipsorum*

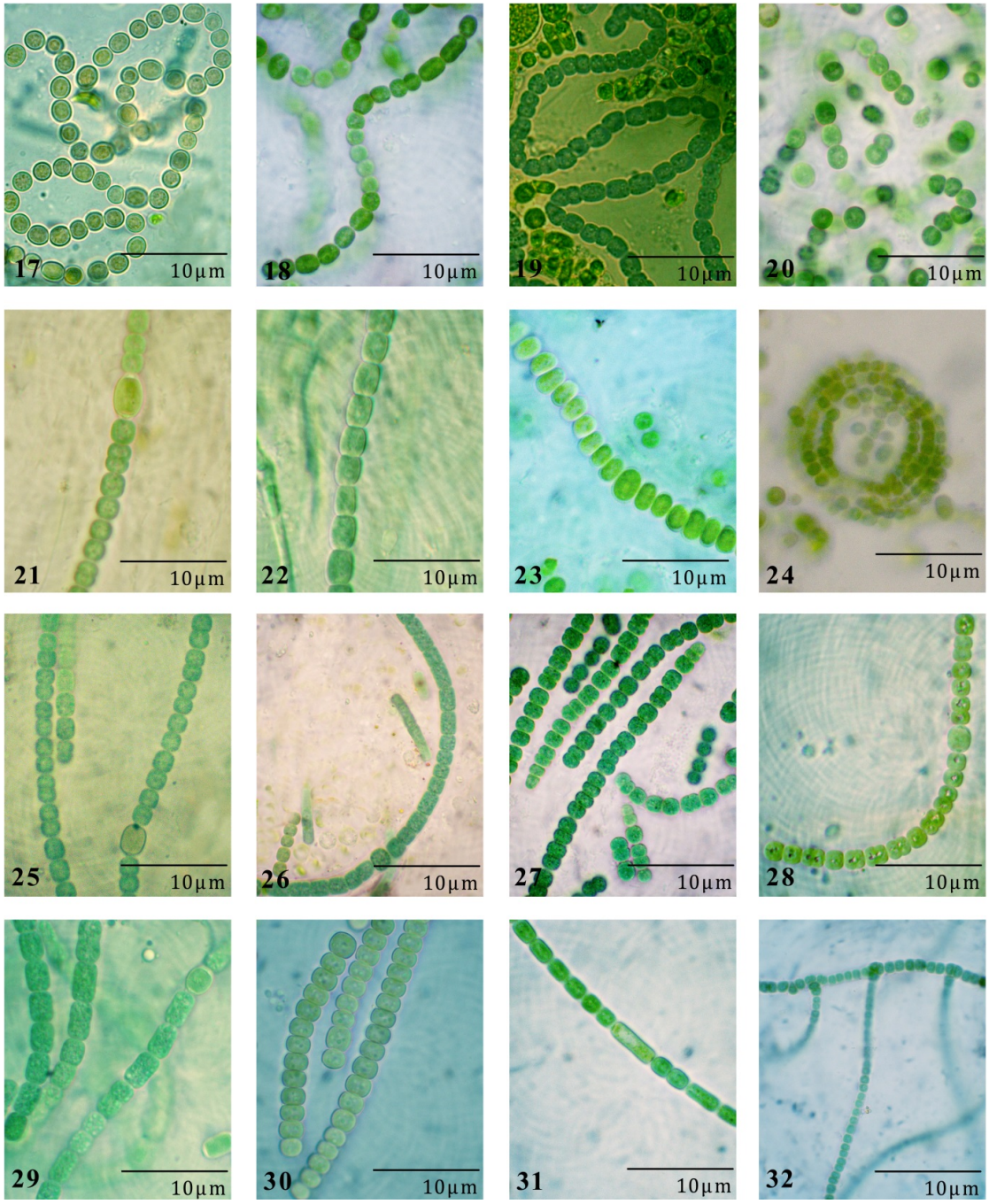

Plate 2. Figures 17-32: 17. *Nostoc spongiaeforme* Agardh ex Born.et Flah, 18. *Nostoc carneum* Ag.ex Born.et Flah*, 19. *Nostoc ellipsosporum* (Desm.) Rabenh.ex Born.et Flah., 20. *Nostoc commune* Vaucher ex Born.et. Flah*, 21. *Anabaena sphaerica* Bornet et Flahault**, 22. *Anabaena oryzae***, 23. *Anabaena fertilissima* Rao, C. B*, 24. *Anabaena gelatinicola* Ghose*, 25. *Anabaena orientalis***, 26. *Anabaena variabilis* Kutzing ex Born. Flah*, 27. *Anabaena torulosa* (Carm.) Lagerh.ex Born.et Flah*, 28. *Anabaena oscillatorides***, 29. *Anabaena constricta***, 30. *Nodulariaspumigena* Mertens ex Born.et Flah*, 31. *Aulosira prolific* Bharadwaja*, 32. *Hapalosiphon welwitschii* West & West*.

(52.5%) and *Oscillatoria princeps* (50%). The least abundant algae were *Oscillatoria irrigua and O. amoena*; each with a relative abundance 3.33%. *Chroococcus turgidus* was the most abundant species in Upper and Lower *Kuttanadu* with relative abundances 75% and 80% respectively. *Gleothece rupestris* was found to be the most

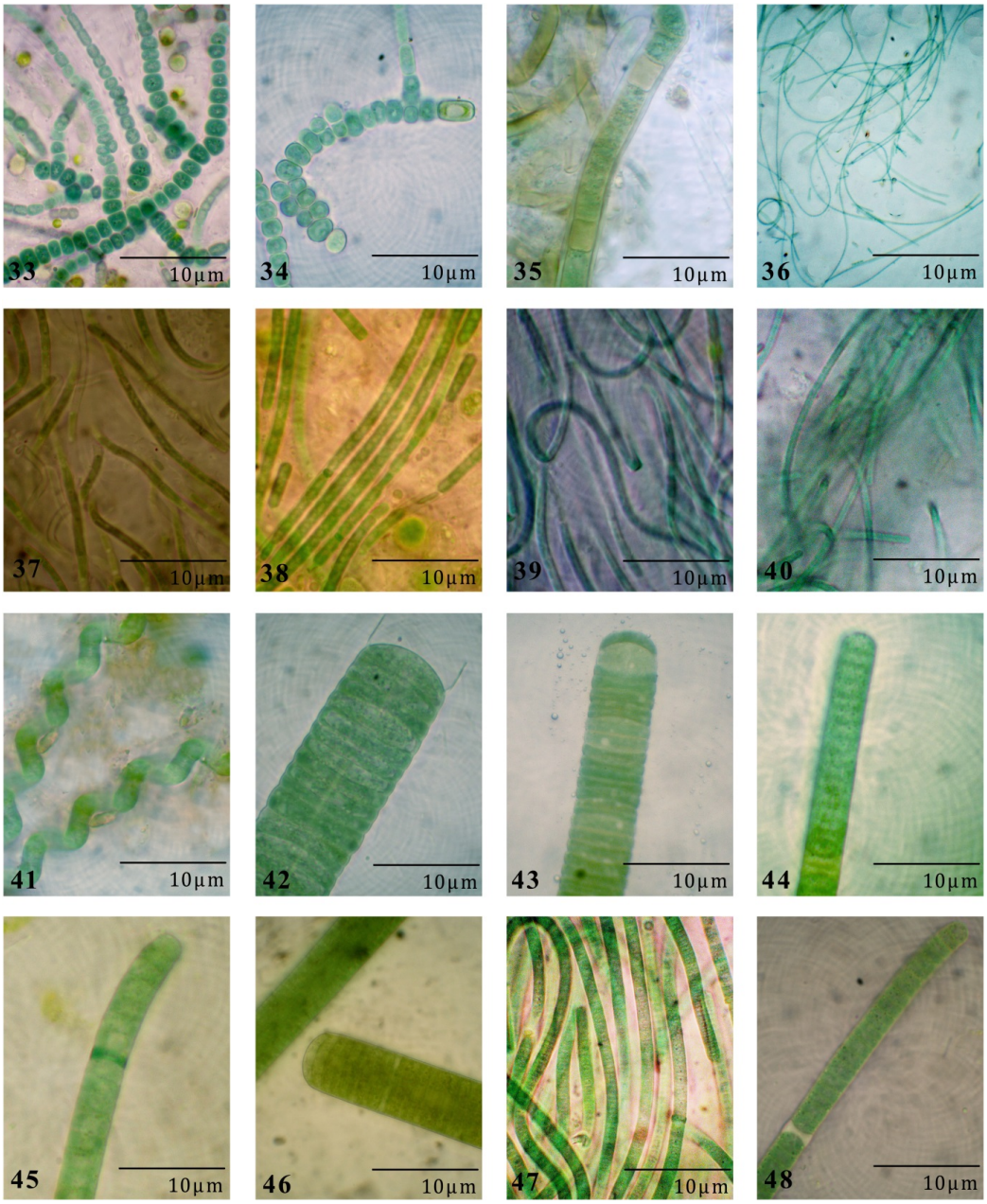

Plate 3. Figures 33-48: 33. *Hapalosiphon flagelliformae* (Schmidle) Forti*, 34. *Westiellopsis prolifica* Janet*, 35. *Scytonema stuposum* (Kutzing) Bornet ex Born.et Flah**, 36. *Leptolyngbya boryana**, 37. *Leptolyngbya tenuis***, 38. *Leptolyngbya cf. battersi****, 39. *Leptolyngbya circumcreta*, 40. *Leptolyngbya sp**, 41. *Arthrospira jenneri* Stizenb.ex Gomont**, 42. *Oscillatoria margaritifera* (Kutz.) Gomontt**, 43. *Oscillatoria sancta* (Kutz.) Gomontt **, 44. *Oscillatoria limosa* C. Agardh**, 45. *Oscillatoria curviceps* Ag.ex Gomont**, 46. *Oscillatoria princeps*Vaucher ex Gomont**, 47. *Oscillatoria amphibian* Ag.ex.Gomont*, 48. *Oscillatoria tenuis* Ag. exGomont*.

abundant species in Kayal lands with relative abundance of 80% (**Table 1**). Species richness (Sps rich) of blue-greens in *Kuttanadu* wetlands showed a variation from 0.383 - 1.078 along the three different soil regions during the different crop seasons and crop stages. The species richness was found maximum (1.078) in Lower *Kuttanadu*, during *Virippu* season at panicle stage. Minimum species richness 0.383 was noticed in Upper *Kuttanadu* during seedling stage and panicle stage of *Puncha* cultivation (**Table 2**). Diversity index (Div. Ind) of blue-greens varied from 1.38 to 1.93 in different regions of *Kuttanadu* during the diferent crop seasons and crop

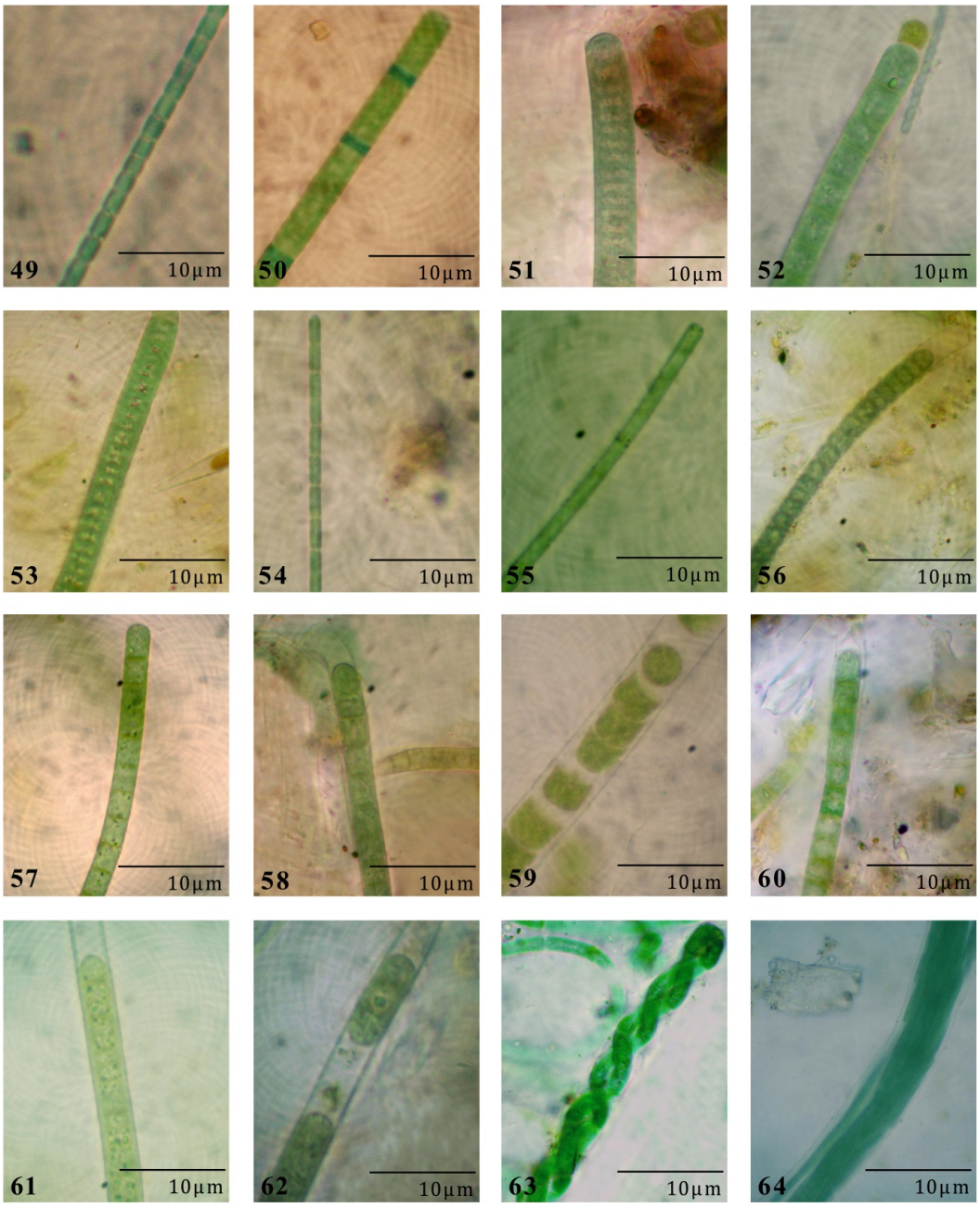

Plate 4. Figures 49-64: 49. *Oscillatoria proteus*Skuja**, 50. *Oscillatoria simplicissima* Gomont**, 51. *Oscillatoria irrigua* (Kutz.) Gomont**, 52. *Oscillatoria amoena* (Kutz.) Gomont**, 53. *Oscillatoria rubescens* DC ex Gomont**, 54. *Phormidium tenue* (Menegh.) Gomont**, 55. *Phormidium purpurascens* (Kutz.) Gomont**, 56. *Phormidium ambiguum* Rao, C. B.**, 57. *Phormidium inundatum* Kutzing ex Gomont**, 58. *Phormidium papyraceum* Kutzing ex Gomont**, 59. *Lyngbya dendrobia* Bruhl et Biswas**, 60. *Lyngbya ceylanica* Wille**, 61. *Lyngbya confervoides* C. Ag.exGomont**, 62. *Lyngbya martensiana* Menegh. exGomont**, 63. *Microcoleus vaginatus* (Vaucher) Gomont*, 64. *Microcoleus accutissimus* Gardner*.

stages. The diversity index was found maximum in Lower *Kuttanadu*, during *Virippu* season at both the seeding and panicle stage. Minimum diversity index was noticed in upper *Kuttanadu* during *Puncha* season at the seedling stage (**Table 2**). Species evenness (Sps. Evn) varied from 0.498 to 0.508 in different soil regions of *Kuttanadu* during the different crop-seasons and crop-growth-stages. The species evenness was found maximum in lower *Kuttanadu*, during *Virippu* season at the panicle stage. Minimum species evenness was noticed in upper

Kuttanadu during the seedling and panicle stage of *Puncha* cultivation (**Table 2**).

3.3. Environmental Correlations

Correlations of species richness, diversity index, number of species and total isolates to soil regions, crop seasons and crop-growth-stages of paddy and to soil parameters such as pH, N, P, K, Ca and Mg using were assessed using Pearson's correlation coefficient. The species richness and diversity index of blue-greens showed significant negative correlation to organic carbon ($P < 0.000$), phosphorus, potassium ($P < 0.000$), calcium ($P < 0.000$), and magnesium ($P < 0.000$). The species richness and diversity index showed positive correlation ($P < 0.000$) to crop seasons. Soil regions and crop-growth-stages had no correlation to species richness and diversity index. Total number of isolates and number of species present were positively correlated ($P < 0.000$) to crop seasons. The number of blue-greens were found negatively correlated to pH ($P < 0.000$), Organic Carbon ($P < 0.000$), Potassium ($P < 0.000$), Calcium ($P < 0.000$) and Magnesium ($P < 0.000$). A positive correlation was found between Phosphorus ($P < 0.000$) and number of species observed. Total number of blue green algal isolates were positively correlated with Total Nitrogen ($P < 0.005$), and total Phosphorus ($P < 0.000$). Negative correlation existed between Organic Carbon ($P < 0.000$), Potassium ($P < 0.002$), Calcium ($P < 0.001$) and Magnesium ($P < 0.000$).

4. Discussion

High species diversity of any particular group of organisms in a natural habitat can be interpreted as the essentiality of the same in the system as a major biotic component. Paddy fields are unique wet soil habitats [27], very suitable for blue-green-algae to flourish [12]. In the paddy fields their significant contributions to soil fertility in terms of the physico-chemical, biological and soil-water relations [6] are well known. Roles of cyanobacteria in soil conditioning [28] and as soil bio-indicators [29] are also important. High diversity of cyanobacteria (64 species) in *Kuttanadu* paddy fields reiterates these facts.

In the *Kuttanadu* fields, among the total species 38% are from the order Oscillatoriales. Oscillatoria and Phormi-dium are the common tolerant genera of polluted areas [30] [Therefore, the prevalence of Oscillatoriales as the dominant group in *Kuttanadu*, reveals the current ecological status of the last three decades of green revolution farming in *Kuttanadu* agricultural soils. Nostoc is another genus reported to be common in paddy fields [7]. In these fields also the genus is found common with about 7 species.

Lower *Kuttanadu* with the highest values for species number (47), total isolates, species richness and species evenness have unique soil characteristics. The clayey loam texture with comparatively high amount of decomposing organic matter and nitrogen (0.37% to 0.52%) may be the reason for highest algal community parameters noted here. Role of soil texture in Cyanobacterial variations, growth and distribution [31] and also the significance of physico-chemical properties of soils to blue greens [32] are well known. Moreover, the clayey soil in the region with significantly higher amount of calcium might be another reason for the presence of higher growth of blue-greens in this soil region than in other soil regions.

In terms of soil pH the upper *Kuttanadu* soil was found to be more acidic (3.4 to 3.9) than those of Lower *Kuttanadu* (3.7 to 4.2) and Kayal lands (4 to 4.6). Presence of the lowest values of species number (16) and total isolates (76) in the upper *Kuttanadu* soils may be attributed to this fact as well. In general acidic soils are considered as are stressed environments for Cyanophytes [6] [9] [33]. The negative correlation observed between soil pH and Cyanobacterial population in *Kuttanadu* paddy fields is in agreement with such previous observations. However, report of [20] large number of species of cyanobacteria in extreme acidic environments also exists. Similarly report [34] of plenty of Cyanobacterial population in soils of highly alkaline pH is also available. However, the exact relationship of pH to the growth of specific Cyanobacterial species in soils is yet to be confirmed.

The present study revealed that highest number of species and total isolates were observed in the panicle crop-growth-stage during the monsoon season. Water availability is a primary factor in determining the abundance of algae [35] [36] in soils. In general, Cyanobacteria are observed in plenty during wet seasons and less in dry environment [34]. However, certain authors have reported the occurrence of maximum Cyanophyceae during winter [37]. Light intensity is an important factor that contributes to the algal floral composition in natural environments [14]. In the present study, a gradual increase of Cyanobacterial population was observed along with the advancement in paddy growth stages. This is in agreement with previous findings [38]. But in general, in paddy

fields, the early part of cultivation cycle show more algal growth [27] [33] [39]. Increasing canopy of the crops causes a decrease in light intensity reaching the soil surface and there will be depletion of the nutrients, particularly nitrogen as the rice advances in its growth stage. However, report of decreased light intensity and nitrogen level along with the growth of the crops in fields favoring excessive growth of blue-greens also exists [12]. It is also known that the blue-greens, in general are sensitive to high light intensities [5].

Seasonal variations are main factors that have major roles on microalgal growth and diversity [40] in soils. Cyanobacterial populations are known to exhibit wide seasonal variations in both colony size and prevalence of heterocysts [41]. In *Kuttanadu* fields, total number of isolates, number of species present, species richness and diversity index were found positively correlated to crop seasons.

The concentration and quality of nutrients are probably more important in the blue-green-algal diversity. Availability of phosphates and nitrates are important factors that favor the abundance of cyanophyceae in wetlands [29]. Actually, the N:P ratio has influence on cyanobacterial abundance According to [42]. In the present study also total number of blue-green-algal isolates was found positively correlated to the amount of total N and P in soils. Phosphorus application has immediate effect on the growth blue-greens in soils [43]. In the current investigation, the total number of blue green algal isolates showed negative correlation with organic carbon, Calcium and Magnesium. This is in conformity with the report that low carbon favors richness of cyanophyta in soils [44]. However, calcium and phosphorus have decisive effects on algal abundance in soils [43].

High amount of ecological information on blue-greens in their natural surroundings is essential to the development of correct applications of indigenous blue-greens as bio-fertilizers in paddy fields [27]. Creation of such a data base require information on ecology of blue-greens from as many diverse fields as possible from different corners of the world. Bio-fertilizers are essential to avoid harmful effects of excessive applications of chemical fertilizers. In order to develop procedures of correct applications of blue-greens as bio-fertilizers at successive stages of paddy cultivation, information on the natural community of Cyanophytes from diverse paddy environments is essential. Apart from the simple analysis, documentation and assessment of cyanobacteria from paddy fields, their correlations to nutrient status of paddy fields is also highly relevant ecological information. Since chemical fertilizer applications inhibit natural nitrogen fixation by algae [45] correlations of natural community of Cyanophytes to NPK in soils is highly essential. Therefore, the present kind of investigation on the diversity of blue-greens in cultivated paddy fields is highly relevant. It also offered the possibility of finding out tolerant species of bio-fertilizer grade blue-greens from paddy fields. Knowledge of such species may enable us to find out tolerant groups of blue-greens, which may be able to act along with moderate amount of chemical fertilizers in the paddy fields, essential to optimum yields in integrated approaches.

5. Conclusion

The present investigation has revealed that *Kuttanadu* wetland paddy soils are very rich in blue green algal diversity, dominated mostly by species from the order Oscillatoriales (38%). Certain specific species unique to the soil regions, seasons and growth stages in *Kuttanadu* are also revealed. Species richness and the number of species were found positively correlated to crop seasons. The highest number of isolates (287) and the highest number of species (45) were observed in the Lower *Kuttanadu* soil region, during the *Virippu* season, at panicle growth stage of the crop. Algal biodiversity appeared to be the maximum during monsoon season throughout the region. Species richness was the highest in Lower *Kuttanadu* soils and the lowest in Kayal lands. *Chroococcus turgidus* was the most abundant blue green algae in *Kuttanadu*, in both Upper *Kuttanadu* and Lower *Kuttanadu* soils. In Kayal lands the same was *Gleotheca rupestris*.

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