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Biodiversity of Microalgae in Western and Eastern Ghats, India

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Abstract: The systematic study was conducted on the microalgal flora of Western Ghats and other parts of Eastern Ghats revealed a rich wetland algal resource for biotechnological exploration. The present study reveals with the diversity of microalgal flora in the region of Kodaikanal (10°14' N, 77°28' E), Gudalur (9°19'N 77°12'E), Agasthiyar falls (9°58'N, 78°10'E) and Kolli hills (10°12'N, 77°56'E) located in Western and Eastern Ghats of Tamilnadu, India collected in May 2011. In total, 97 species of micro algae belonging to three taxonomic groups were identified, of which 41 species belonging to Cyanophyceae, 38 species from Chlorophyceae and 18 species from Bacillariophyceae. The predominant species in Cyanophyceae were *Aphanothece microscopica*, *Chroococcus minutus*, *Coelospharium dubium*, *Hydrococcus rivularism*, *Oscillatoria princeps*, *Nostoc muscorum*, *Nostoc puncteforme*, *Nostoc commune*, *Gleotricha gausii*, *Calothrix braunii*, *Rivellaria* sp., *Tolypothrix tenuis*, *Scytonema schmidtii*, whereas in Chlorophyceae, *Chlorella* sp., *Scenedesmus* sp., *Pediastrum duplex*, *Cosmarium consperum*, *Euastrum elagans*, *Micrasterias americana* and in Bacillariophyceae, *Navicula hallophyla*, *Rhophaldia gebrella*, *Fragellaria intermedia*, *Pinnularia virdis*, *Nitzchia palliate*. Physicochemical nature of water samples were analyzed and correlated with the total microalgal diversity. Based on the correlation coefficient data, the micro algae showed positive relationship with dissolved oxygen, salinity, nutrients and negative relationship with temperature and turbidity. The species diversity index (H'), Species Richness (SR) and species evenness (J') were calculated and analyzed for microalgal population dynamic variation in the Western and Eastern Ghats.

Key words: Biodiversity, microalgae, physico-chemical parameters, biodiversity indices, western and eastern ghats

INTRODUCTION

Biodiversity is the degree of variability among all living organisms from marine, terrestrial, aquatic ecosystems and diversity within species and of ecosystem, However microalgae diversity in high mountain ecosystems and their geographical distribution have received considerable attention, especially with respect to physico-chemical parameters of water (Huber *et al*., 2005). The western ghats is one of the hotspots of biodiversity (Myers *et al*., 2000) with tremendous species richness and levels of endemisum and also this region occupies about 2100 km^2 covering seven districts and it covers various types of vegetation including evergreen, tropical deciduous, scrub, subtropical temperature forests and grasslands. The complex geography, wide variations in annual rainfall from 1000-6000 mm and altitunal decrease in temperature, coupled with anthropogenic factors, have produced a variety of vegetation types in the western ghats. It is one of the identified hotspots of biological diversity globally and comprises about 12,000 species ranging from cyanobacteria to angiosperms. The forest ecosystem in the Western Ghats is one among the 18 biodiversity hotspots of the world selected for conservation. This accounts does not include the microalgae diversity of this region. Most of the research works related to the mountain system so far have been on the flora and fauna of the region. No specific literature is available on microalgae in the region. Sugunan (1995) stressed detailed investigations of the reservoirs in the Western Ghats. There are also only few papers dealing with epilithic microalgae of high mountain lakes and rock moist soil from other regions in Tamilnadu hill station (Rajakumar *et al*., 2006; Sankaran, 2005). Among these, Kodaikanal (1850 m a.s.l.) and Gudalur (2000 m a.s.l), Agesthiyar falls (100 m a.s.l) are located in the Western Ghats and one eastern ghats Kolli hills (1415 m a.s.l.) (Tamilnadu) (Fig. 1). They lie on peat soil, over a rocky substratum of quartziferous porphyry, surrounded by a sphagnum- and sedge-rich vegetation (Festi and Prosser, 2000). In this study, we assessed whether abiotic factors

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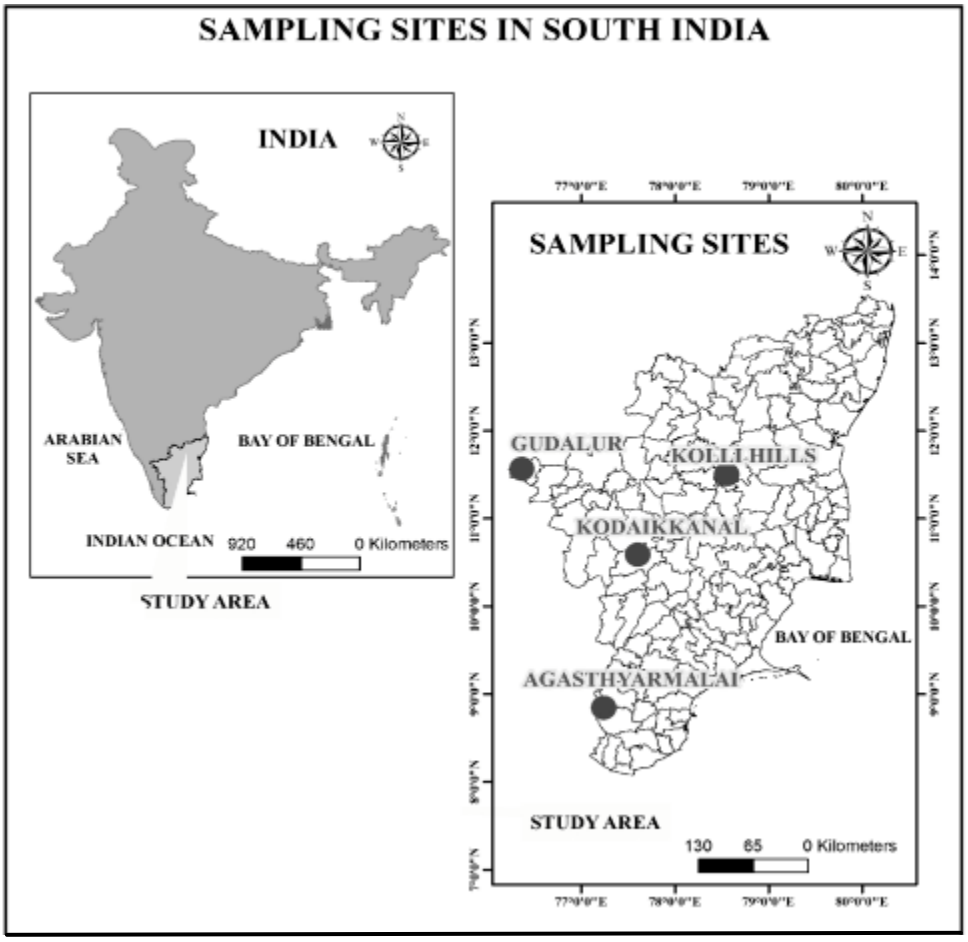

Fig. 1: Sampling site of microalgal collection

(altitude and soil physico-chemical composition) and biotic factors (vegetation types) predict the taxonomic composition in the Western Ghats of south India (Kodaikanal, Gudalur, Mountains, Agesthiyar falls and Eastern Kolli kills).

MATERIALS AND METHODS

Study site: The work conducted in (January-May) 2011 at four sites in four mountain areas of Western Ghats, Kodaikanal (10°14' N, 77°28' E) is located in the southern crest of the Palani hills, Gudalur (9°19'N 77°12'E) and Agasthiyar falls (9°58'N, 78°10'E) are located in the Western Ghats mountain range of Tamilnadu and Kolli hills (10°12'N, 77°56'E) is located in the Eastern Ghats in the State of Tamil Nadu (Fig. 1). The Western Ghats consists mainly of metamorphic rocks (biotite gneiss, quartzose gneiss felspar, biotite and garnet). In total, 22 moist soil and water samples were collected along with four altitudinal transects at the four mountain sites.

Collection of samples and cultivation of microalgae: Random samples were taken from six different substrate-rocks, fine gravel, moist soil, water sediment moss in pools and riffles. The algae samples were scraped and transferred into a sterile plastic bottles using sterile blades and forceps and were transported to the Department of Microbiology, Bharathidasan University, India for taxonomic and cultural studies. One set of samples were preserved in 4% formaldehyde and then analyzed under a light microscope. Samples were transferred to Erlenmeyer flasks containing Chu's 13 medium (Largeau *et al*., 1980), BG11 medium (Rippka *et al*., 1979), f/2 medium. They were maintained in culture room under white fluorescence lamps (3000 lux), 14"10 L/D at 25 "2°C until they were examined. Microphotographs of these species were taken using Optica Labomed microscope E-400 with H-III photo micrographic attachment.

Physicochemical analysis: The physico-chemical analysis of water like pH, dissolved oxygen, total

hardness, nitrate, phosphate were estimated by standard procedure (Strickland and Parsons, 1972; Wetzel and Likens 1979; APHA, 1998). Algae for the qualitative analysis were collected from several rocks of the sample site, which had a visible growth of algae. Diatoms were removed from stones (about 10 stones) using a toothbrush and washed directly from the surface of the stones into a sample bottle. Diatoms were identified by examining permanent slides of them prepared by the hot hydrogen peroxide method (Hindak, 1978) and mounted in Naphrax. Identification of these samples was carried out using the taxonomic publications of Desikachary (1959), Smith (1950), Prescott (1951) and Anand (1988). Correlation coefficients (r) were calculated for microalgal abundance and physico-chemical parameters and the analysis of variance (F) tests were made for hydrological parameters in relation to the station.

Biodiversity and statistical analysis: All the statistical analysis were performed using SPSS statistical software (Version 17.0 for Windows, SPSS, Chicago, IL, USA).The diversity indices like Simpson's index, Shannon index, Shannon evenness, species richness, Margalef index, Brillouin, Equitability, Fisher alpha, Berger paker and dominant index were performed using Paleontological Statistics software package (version 2.10 for windows, PAST, copy right (Hammer *et al*., 2001).

RESULTS

Microalgal diversity: A total of 97 micro algal species belonging to three families (Cyanophyceae, Chlorophyceae and Bacillariophyceae) were detected from all the locations (Table 1). Out of the 97 species detected, 18 species were diatoms, 37 were green algae and 41 were cyanobacteria. A maximum of 30 species of 24 genera were recorded from the Kodaikanal, followed by 31 species of 12 genera from the Kolli hills, 24 species belonging to 16 genera from the Gudalur and 75 species of 46 genera from the Agesthiyar falls. As per the diversity and abundance of microalgae, the members of the order Nostocals were the dominant species in all the samples. The most abundant groups were Cyanophyta (52.0%; dominated by *Aphanothece nidulans*, *Chroococcus turgidus*, *Hydrococcus rivularis*, *Oscillatoria princeps*, *Nostocmuscorum*, *N. punteforme*, *Nostoccommune*, *Gloeotrichiaechinulata*, *Scytonemaschmidtii*, *Tolypothrix tenuis* and *Calothrix braunii*), Bacillariophyta (20%; dominated by *Navicula hallophyla*, *Rhophaldia gebrella*, *Fragellaria intermedia*, *Pinnularia virdis*, *Nitzchia palliae*) and Chlorophyta (28%; dominated by *Chlorella* sp., *Gloeocystis* sp., *Pediastrum boryanum*, *Scenedesmus bijugatus*, *Cosmarium undulatum*, *Micrasterias americana*, *Euastrum elegans*, *Staurastrum aanisacanthum*, *Closterium parvulum* (Plate 1 and 2).

Physical and chemical characteristics: Physico-chemical analysis of water revealed that the water temperature ranged from 20°C to 33°C, pH ranged from 5.8 to 7.9, dissolved oxygen from 6.0 to 10.0 mg L^{-1}, alkalinity (carbonate from 0.0 to 4.0 mg L^{-1} and bicarbonate 0.9 to 2.9 mg L^{-1}), nitrate from 0.24 to 26 mg L^{-1}, silica from 1.0 to 6.1 mg L^{-1}, phosphate 0.04 to 0.1 mg L^{-1}, chloride 0.4 to 6.0 mg L^{-1} in all the hill stations. The rich concentration of nutrient such as sulphates (0.05-0.30 mg L^{-1}), calcium (0.6 -12 mg L^{-1}), magnesium (0.2 -0.8 mg L^{-1}), sodium (0.6 -2.1 mg L^{-1}) and potassium (0.20-0.65 mg L^{-1}) has been observed in all hill stations with increased concentration during the study period.

Correlation between microalgae abundance and physico-chemical parameters: Correlation co efficient matrix is calculated among 16 physico-chemical parameters (Table 2). The positive correlation of microalgae with Temp., pH, dissolved oxygen, bicarbonate, silica and potassium. Negative correlation of microalgae with Ec, carbonate, nitrate, phosphate, chloride, sodium, suggests that the microalgae population is dependent on the nutrient rich hills water.

Biodiversity indices analysis: Values for Simpson Index (d) varied between 0.94-0.97, Menhinick's Index 4.3 -6.0, Shannon and Wiener diversity index (Hs) 3.0 -3.6, Species Equitability (j) 0.97-0.98, Species Evenness (S) 0.91 B0.95, Menhinick index 4.3 B 6.0, Margalef index 6.4-10.4, Berger parker index 0.06-0.11 (Fig. 2).

DISCUSSION

In the present study, species diversity and abundance of microalgal populations and their relationships with physico-chemical variation could be demonstrated considering high altitude regions. The diversity is influenced by geographical factors (latitude, altitude), environmental factors (Fierer and Jakson, 2006). A total 97 species were recorded only 16.5% (18 species) were heterocystous, but, of these *Nostoc commune*, *Nostoc kihlmanii*, *Scytonema myochrous*, *Rivularia minutula*, *Stigonema minutum* were often abundant. Jones (1989) has demonstrated that N2 -fixation is sensitive to water stress. As many as 23 species viz *Aphanothece microscopica*, *Chroococcus minutus*, *Coelospharium dubium*, *Hydrococcus rivularis*,

Table 1: List of microalgae species in all Western Ghats regions

Name of the species	Sampling stations			
	Kolli hills	Agasthiyar falls	Kodaikanal	Gudalur
Cyanophyceae				
Chrococcus minutes (Kuetz) Naeg	+	-	+	-
Chrococcus turgidus (Kütz.) Näg	+	-	-	-
Gleocapsa atrata (Turp) Kuetz	+	+	-	+
Microcystis aeruginosa (Kütz)	-	+	+	-
Microcystis robusta (Wittr)	-	+	-	-
Aphanothece microscopica (Naeg)	+	-	+	+
Aphaothece nidulans (Breb)	+	-	+	-
Aphanothece saxicola (Naeg)	+	-	+	-
Aphanacapsa sp	-	-	+	-
Aphanacapsa muscicola (Meneghini)	-	-	-	+
Coelospharium kuetzinngianum (Nageli)	+	-	-	+
Coelospharium dubium (Grunow)	+	-	-	-
Hydrococcus rivulararis (Kutzing)	+	-	+	-
Chlorogloea fritschii (Mitra)	+	-	-	-
Myxosarcina sp.	+	-	-	-
Dimorphococcus cordatus (Wolle)	-	-	+	-
Xenococcus kerneri (Gold-morgan)	+	-	+	+
Oscilllatoria okaani (Ag. Ex Gom)	-	+	-	+
Oscillatoria limosa (Schemidle*)	+	-	-	+
*Oscillatoria princeps (*Vaucher) ex Gam	-	+	-	+
Oscillatoria tenuis (Bory) ex Gom	-	+	+	-
Oscillatoria quadripunctuta (Bhuhl) biswas	-	-	+	-
Oscilatoria curviceps (Ag.ex Gomont*)	+	-	-	+
Phormidium retzii (L.Agardh) kutzing	-	+	-	-
Lyngbya epiphytica (Fremy)	+	+	-	-
Cylindrospermum spherical (Kutz)	+	-	+	-
Scytonema schmidtii (Gomont)	-	-	-	+
Anabaena gelatin cola (Fritsch)	+	+	-	+
Anabaena variabilis (Kutz) ex Born	-	+	-	+
Nostoc paludosum (Kutz) ex Born	+	-	+	+
Nostoc muscorum (C, Agardh)	-	-	+	-
Nostoc piscinale (Kutz) ex Born	-	-	-	+
Nostoc spongiaeforme (Ag. ex Born)	+	-	+++	+++
Nostoc linckia (Roth) Born	-	-	-	+++
Nostoc commune (Vaucher) ex bornets and flahault)	+	-	-	+
Nostoc kihimanii (kihimani)	+	-	+	+
Gloeotrichia raciborskii var. *conica* (Dixit)	+	-	-	-
Tolypothrix tenuis (Kutz)	-	-	+	+
Gloeotrichia echinulata (Smith) richter	-	-	+	+
Calothrix braunii (Bornet) flahault	-	-	+	+
Calothrix linearis (Gardner)	+	-	-	+
Chlorophyceae				
Chlorella sp	-	-	+	-
Euglena sp	+	-	-	-
Ankistrodesmus curvatus (Turn)	+	-	-	-
Gloeocystis sp	+	-	-	-
Pediastrum tetrus var.*Tetraodon* (Corda) Rabenhorst	+	-	-	+
Pediastrum clathratum var.*Punctatum duplex* (meyen)	+	-		-
Pediastrum var.*Subgranulatum* (Raciborski)	+	+	+	+
Pediastrum simplex (Meyan)	-	+	-	-
Pediastrum boryanum (Turpin) meneghini	-	+	-	+
Pediastrum anguiosum (Ehrenberg ex meneshini)	+	+	-	-
Pediastrum morum (Mull) bory	+	+	-	-
Scenedesus communis (E.Hegewald)	+	+	-	+
Scenedesmus bijugatus (Turpin) Kutz	-	+	-	+
Scenedesmus arcuatus (Lemm)	+	-	-	-
Scenedesmus quadricaududa(Turp) Breb	+	+	-	-
Cosmarium pseudogranatum (Nordst)	+	-	+	-
Cosmarium conspersum (Ralfs)	-	-	+	-
Cosmarium holmiense (P. Lundell)	-	+	-	-
Cosmarium impressulum (Elfving)	-	+	-	-
Cosmarium pachydermedium (Breb)	-	-	+	-
Cosmarium nitidulum (De not)	+	+	+	-
Cosmarium laeve (Rabenh)	+	+	-	-

Table 1: Contiune

Name of the species	Sampling stations			
	Kolli hills	Agasthiyar falls	Kodaikanal	Gudalur
Cosmarium regulare (Schmidle)	+	+	-	-
Cosmarium subcucumis (Schmidle)		+	-	
Cosmarium undulatum (Corda ex ralfs)	+	+	-	-
Cosmarium botrytis (Meneghini) ex ralfs	-	+	-	-
Desmidium swartzii (C.Agardh ex ralfs)	-	+	-	-
Micrasterias americana (Ehrenberg) ex ralfs	-	+	-	-
Euastrum sp	-		-	-
Euastrum elegans (Brebisson)kutz	-	+	-	-
Euastrum platycerum (W.B.Turner)	-	+	-	-
Staurastrum anisacanthum (A.M.Scott) prescott	-	+	-	-
Closterium parvulum (F.Maius schmidle)	-	+	-	-
Closterium dianal (Ehr.ex ralfs)	-	+	-	-
Closteridium lunula (Reinsch) hansgirg	-	+	-	-
Glaucocystis nostochinearum (Itzigsohn)	-	+	-	-
Cylindrocystis brebissonii (Ralfs) de bary	-	+	-	-
Pleurotaeniopsis turgidus (Breb) de toni	-	+	-	-
Bacillariophyceae				
Pinnularia virdis (Nitzsch) ehrenberg	-	+	-	-
Pinnularia aerosphaeria (Breb) kutz	-	-	+	-
*Trachelomonas.*sp	-	-	+	-
Stauronesis sp	-	-	+	-
Nitzschia palea (Kutz) smith	-	+	-	-
Nitzschia paleacea (Grunow) M.peragallo	-	+	-	-
Nitzchia closteridium (Ehrenberg) W.smith	-	-	-	+
Nitzschia obtusa (Smith)	-	-	+	-
Navicula halophila (Grunow) cleve	-	-	+	+
Fragillaria intermedia (Grunow)	-	+	+	+
Achanthes inflate (Kutz) Grunow	+	-	-	-
Achanthes hauckiana (Grunow)	+	-	-	-
Amphora sp	-	-	+	-
Symbella sp	-	-	+	-
Gomphonema parvulum (Kutzing)	+	-	-	-
Rhopalodia gibberula (Ehrenberg) otto muller	-	-	--	-
Gomphonema olivaceum (Hornemann) kutz	-	+	-	-
Staurodesmus sp	+	-	-	-

+++ Abundant , + present, - absent

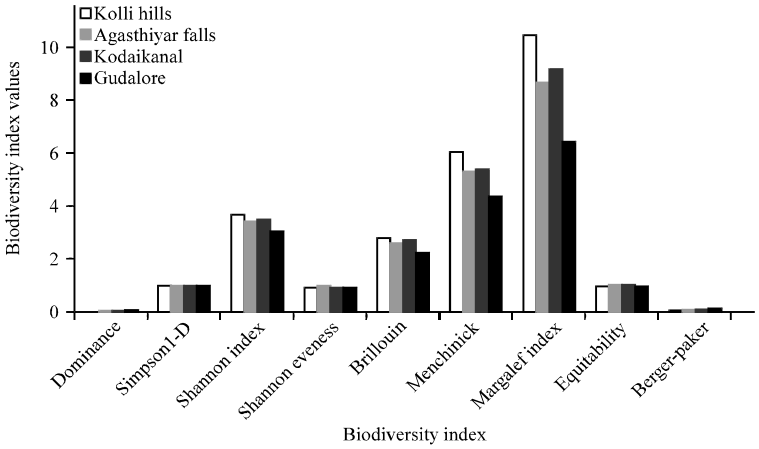

Fig. 2: Diversity indices of microalgae at four sites of Western Ghats

Oscillatoria princeps, *Nostoc muscorum*, *Nostoc puncteforme*, *Nostoc commune*, *Gleotricha gausii*, *Calothrix braunii*, *Rivellaria* sp., *Tolypothrix tenuis*, *Scytonema schmidtii*, *Chlorella* sp., *scenedesmus* sp., *pediastrum duplex*, *cosmarium consperum*, *Euastrum elagans*, *micrasterias Americana*, *Fragellaria intermedia*, *Nitzahia palliate*, *Vavicula hallophyla*, *Rhophaladia gebrella*, *Pinnularia virdis*, were

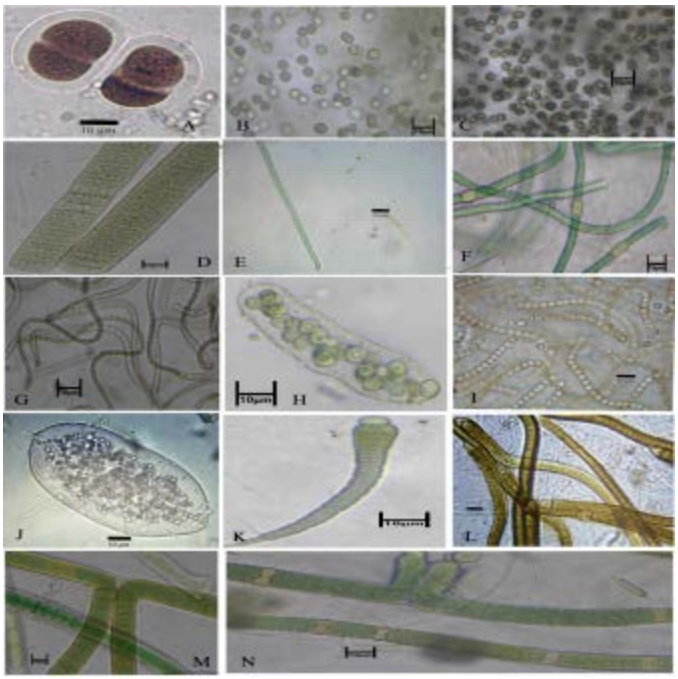

Plate 1: (a) *Chrococcus turgidus*, (b) *Aphanocapsa muscicola*, (c) *Microcystis robusta*, (d) *Oscillatoria princeps*, (e) *Oscillatoria quadripunctuta*, (f) *Aulosira* sp., (g) *Anabaena gelatinicola*, (h) *Nostoc spongiaeforme*, (i) *Nostoc commune*, (j) *Nostoc moscorum*, (k) *Calothrix braunii*, (l) *Tolypothrix tenuis*, (m) *Scytonema schmidtii* and (n) *Dichlothrix orsiniana*

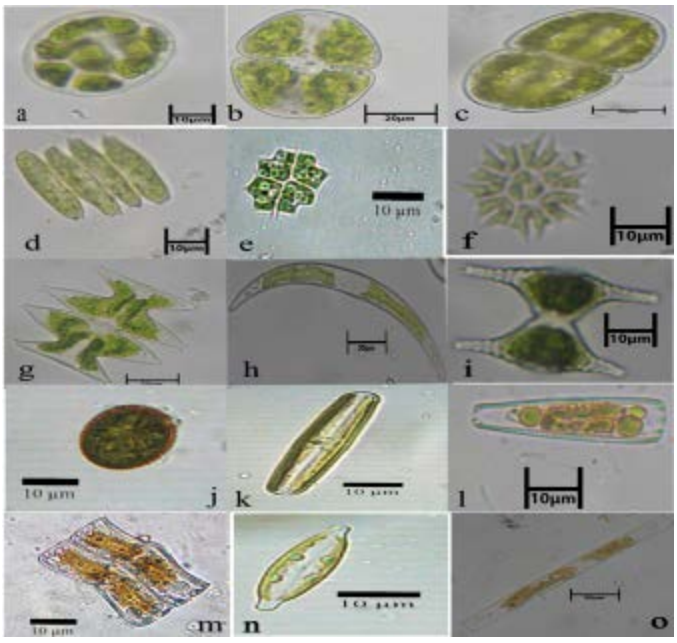

Plate 2: (a) *Pandorina moram*, (b) *Cosmarium botryti*, (c) *Cosmarium subcucumis*, (d) *Scenedesmus aculeolatus*, (e) *Pediastrum simplex*, (f) *Pediastrum boryanum*, (g) *Micrasterias Americana*, (h) *Closterium pavulum*, (i) *Staurastrum anisacanthum*, (j) *Trichelomonos* sp, (k) *Pinnularia aerosphaeria*, (l) *Gomphonema olivilus* (m) *Achninthushauckina*, (n) *Navicula hallophyla*, (o) *Fragillaria intermedia*

Table 2: Correlation coefficient between total microalgal species and physic-chemical parameters in western ghats region

	Temp	PH	EC	DO	Carbonate	Bicarbonate	NO_3	PO_4	Cl	SO_4	Si	Ca	Mg	Na	K	TAS
Temp	1															
PH	-0.198	1														
EC	-0.319	-0.763	1													
DO	0.818	-0.469	-0.206	1												
Carbonate	-0.156	-0.694	0.957*	-0.211	1											
Bicarbonate	-0.202	-0.750	0.985*	-0.181	0.992**	1										
NO_3	-0.491	-0.750	0.834	-0.075	0.640	0.731	1									
PO_4	0.279	-0.645	0.743	0.056	0.892	0.845	0.297	1								
Cl	-0.507	-0.710	0.751	-0.036	0.530	0.632	0.991**	0.173	1							
SO_4	0.038	-0.741	0.906	-0.054	0.981*	0.964*	0.551	0.957*	0.436	1						
Si	-0.141	0.226	0.295	-0.646	0.507	0.405	-0.217	0.564	-0.334	0.485	1					
Ca	-0.533	-0.325	0.226	0.051	-0.065	0.059	0.724	-0.425	0.811	-0.171	-0.715	1				
Mg	-0.545	-0.682	0.750	-0.079	0.527	0.628	0.990*	0.157	0.999**	0.426	-0.314	0.814	1			
Na	-0.254	-0.636	0.961*	-0.310	0.994**	0.987*	0.653	0.850	0.544	0.956*	0.541	-0.040	0.545	1		
K	-0.431	-0.715	0.992**	-0.282	-0.426	0.959*	0.872	0.660	0.798	0.849	0.269	0.309	0.801	0.938	1	
TAS	0.183	0.862	-0.985*	0.034	-0.939	0.973*	-0.841	-0.767	-0.763	-0.914	0.185	-0.243	0.754	-0.925	0.964*	1

Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). Temp: Temperature, EC: Electrical conductivity, No_3 Nitrate, po_4: phosphate, Cl: Chloride, So_4: Sulphate, Si: Silica, Ca: Calcium, Mg: Magnesium, Na: Sodium, K: potassium TAS: Total algal species

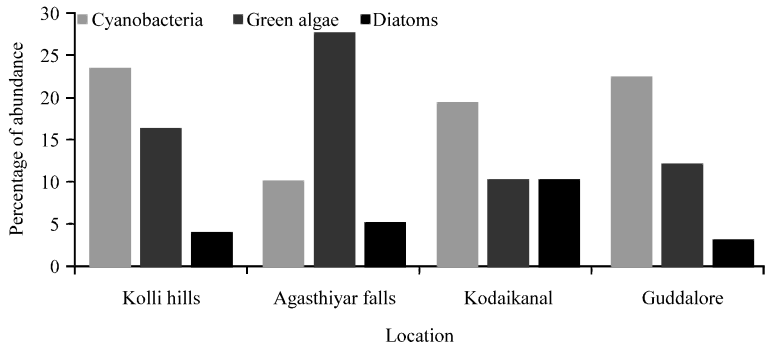

Fig. 3: Percentage of microalgae in the four locations of Western Ghats during the study period

considered as versatile species in all altitudes. The present study brings out that the members of the order Nostocales were in abundance at all sampling location. The maximum percentage of Nostocales has been recorded from Gudalur (10%) , whereas minimum from Kolli hills (3%). The members of Chroococcales were at the second position in respect to abundance. Kolli hills has (7%) of order Chroococcales, which was the highest number of Chroococcales recorded from the area. As against this, Agasthiyar falls, Kodaikanal and Gudalur have (3%), (6%) and (6%) members, respectively. The maximum percentage of Desmids has been recorded from Agasthiyar falls (12%), whereas minimum from Gudalur (2%). Kodaikanal and Kolli hills showed (4%) and (3%), respectively (Fig. 3). The members of Diatoms are at the third position in respect to abundance. Kolli hills has (17%) members, which was the highest number of Diatom recorded from the area. As against this, Agasthiyar falls, Kodaikanal and Gudalur have (5%), (8%) and (5%) members, respectively. Rest two orders, Chamaesiphonales and Stigonematales show a comparatively poor distribution of cyanobacterial members, whereas no members of order Pleurocapsales have been recorded from any sampling sites. It is clear from the above discussion that the members of Nostocales were in abundance with a record of 97 species from 21 genera and 5 families. Nostocales is followed by Chroococcales on the basis of the number of the species. Microalgae species were abundantly present in high altitude regions, it may be due to the high soil pH, high temperature and high UV radiation (Whitton and Potts, 2000). The light and temperature conditions have a direct effect on the population dynamics of microalgal flora. Bright light favours the growth the members of order Chroococcales, whereas dim light enhance the presence of the members of order Nostocales. Similarly, a moderate temperature between 20-40°C was found suitable for the luxurious growth of cyanobacterial taxa at all the sites (Khare, 2007). Similar type of observation was made by (Rehakova *et al*., 2011) in the Microalgal diversity in dry mountains of ladakh, Himalaya. Cyanobacterial tolerance of intense sunlight including UV radiation may have contributed to their success in colonizing high-altitude and high-latitude environments (Sinha and Hader, 2002). Species composition was significantly influenced by altitude, particularly for the orders Nostocales and Chroococcales. Nostocales are usually thought to be able to colonize young undeveloped soils because of their ability to fix nitrogen (Whitton and Potts, 2000) which may be the limiting nutrient in this type of soil. Perhaps Nostoc was better adapted than many other phototrophs to cryoturbation and desiccation because it has a well-developed mucilaginous sheath, which protects against the cold and desiccation. *Nostoc* might also do well at high altitudes because its biovolume is independent on the concentration of organic matter, unlike *Oscillatoria* (Fig. 2). The Chroococcales may have increased with altitude because, as unicellular organisms with rapid growth rates (Nielsen, 2006) they do not require a stable substrate with a fine texture and high organic matter content . In contrast, Oscillatoriales decreased with altitude. Oscillatoriales are more abundant in finer textured soils that contain relatively high concentrations of organic matter, as is typical for alpine meadows, which occurred in the lower altitudes in the current study. Desmids are considered to be very sensitive group of phytoplankton. They are unable to withstand even negligible changes in the quality of aquatic habitats. Seenayya (1971) reported that eutrophic waters do not support the growth of desmids. Karikal (1995) found that soft waters with low nutrients favor the growth of desmids. Zafar (1967) suggested that the water temperature plays an important role in the growth of desmids. Rao (1975) stated that the temperature range between 27 and 30°C is favourable for better development of desmids. In the present study the temperature in

Agesthiyar falls was found 33 to 35°C which may favour the growth of Desmids. Karikal (1995) and Sunkad (2002) reported that calcium does not seem to support the growth of Desmids. In the present study, the Mg content in Gudalur was found between 0.6 mg to 3.5 mg L^{-1} which may have inhibited the growth of desmids.

CONCLUSION

The biodiversity of microalgae in India are still very fragmentary, especially in the moist soil and hill water. Most papers have focused on freshwater algae, such as those from Lakes, ponds, or from paddy field in Tamilnadu. The study was focused on the microalgae at high altitude. Our study from Western Ghats, Eastern Ghats India, has shown that high altitude algae form complex communities with specific environmental associations. Our results will be useful for designing future monitoring schemes and for assessing the effects of global change in these diverse but poorly studied locations in Tamilnadu.

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REFERENCES

APHA, 1998. Standard Methods for the Estimation of Water and Waste Water. 19th Edn., American Public Health Associations, Washington.

Anand, N., 1988. Culture studies and taxonomy of blue-green algae-certain identification problems. Arch. Fur Hydrobiol. Suppl., 50-53:: 141-147.

Desikachary, T.V., 1959. Cyanophyta. Indian Council of Agriculture Research, New Delhi, India, Pages: 686.

Festi, F. and F. Prosser, 2000. The flora of the Natural park of paneveggio-pale of S.martino. Supplementary Annals Municipal Museum Rovereto, pp: 438.

Fierer, N. and R.B. Jakson, 2006. The diversity and biogeography of soil bacterial communities. Proc. Natl. Acad. Sci., 103: 626-631.

Hammer, O., D.A.T. Harper and P.D. Ryan, 2001. Past: Paleontological statistics software package for education and data analysis. Palaeontol. Electron., Vol. 4.

Hindak, F., 1978. Freshwater Algae. Slovakian Pedagogic Publishment, Bratislava, Slovakia, Pages: 724.

Huber, U.M., H.K.M. Bugmann and M.A. Reasoner, 2005. Global Change and Mountain Regions: An Overview of Current Knowledge. Springer, New York, USA., ISBN-13: 9781402035067, Pages: 650.

Jones, K., 1989. Interactions between desiccation and dark nitrogen fixation in tropical *Nostoc commune*. New Phytol., 113: 1-6.

Karikal, S.M., 1995. Limnobiotic study on the Bhutnal reservoir from Bijapur area. Ph.D. Thesis, Karnatak University, Dharwad, India.

Khare, A., 2007. Cyanobacterial biodiversity of the Sub-Himalyan belt of Kumaon region. Ph.D. Thesis, MJP Rohilkhand University, Bareilly, India.

Largeau, C., E. Caradevall, C. Berkaloff and P. Dhamliencourt, 1980. Sites of accumulation and composition of hydrocarbons in *Botryococcus braunii*. Phytochemistry, 19: 1043-1051.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca and J. Kent, 2000. Biodiversity hotspots for conservation priorities. Natures, 403: 853-858.

Nielsen, N.S., 2006. Size-dependent growth rates in eukaryotic and prokaryotic algae exemplified by green algae and cyanobacteria: Comparisons between unicells and colonial growth forms. J. Plankton Res., 28: 489-498.

Prescott, G.W., 1951. Algae of the Western Great Lakes Area. W.C. Brown Publishers, Dubuque, Lowa.

Rajakumar, S.S., K. Ayyasamy, P.M. Velmurugan and P. Lakshmanaperumalsamy, 2006. Limnological studies of Kodaikanal Lake in Tamilnadu, India. Nat. Environ. Pollut. Technol., 5: 533-544.

Rao, V.S., 1975. An ecological study of three freshwater ponds of hyderabad-India III. The phytoplankton (Volvocales, Chlorococcales and Desmids). Hydrobiologia, 47: 319-337.

Rehakova, K., Z. Chlumska and J. Dolezal, 2011. Soil cyanobacterial and microalgal diversity in dry mountains of Ladakh, NW Himalaya, as related to site, altitude and vegetation. Microb. Ecol., 62: 337-346.

Rippka, R., J. Deruelles, J.B. Waterbury, M. Herdman and R.Y. Stanier, 1979. Generic assignments, strain histories and properties of pure cultures of cyanobacteria. J. Gen. Microbiol., 111: 1-61.

Sankaran, V., 2005. Fresh water Algal bio-diversity of the Anamalai hill ranges TamilNadu. Chlorophyta-Ulotrichaetophorales. Indian Hydrobiol., 7: 93-97.

Seenayya, G., 1971. Ecological studies in the phytoplankton of certain freshwater ponds of Hyderabad India-II: The phytoplankton. Hydrobiologia, 37: 55-58.

Sinha, R.P. and D.P. Hader, 2002. UV-induced DNA damage and repair: A review. Photochem. Photobiol. Sci., 1: 225-236.

Smith, G.M., 1950. The Freshwater Algae of the United States. 2nd Edn., McGraw-Hill Book Co., New York, Pages: 719.

Strickland, J.D.H. and T.R. Parsons, 1972. A Practical Handbook of Seawater Analysis. 2nd Edn., Fisheries Research Board of Canada, Canada, pp: 187.

Sugunan, V.V., 1995. Reservoir Fisheries of India. FAO Fisheries Technical Paper. No. 345, Rome, FAO., ISBN: 92-5-103673-X.

Sunkad, B.N., 2002. Studies on biodiversity of wetlands with special reference to the physico-chemical factors. PhD. Thesis, Karnatak University, Dharwad.

Wetzel, R.G and G.E. Likens, 1979. Limnological Analysis. WB Saunders Co., Philadelphia, pp: 357.

Whitton, B.A. and M. Potts., 2000. The ecology of Cyanobacteria: Their Diversity in Time and Space. Kluwer Academic Publishers, Dordrecht, The Netherlands, Pages: 668.

Zafar, A.R., 1967. On the ecology of algae in certain fish ponds of Hyderabad, India. Hydrobiologia, 30: 96-112.