Chapter 11
Spatiotemporal Assessment of Phytoplankton Communities in the Chilika Lagoon

Suchismita Srichandan and Gurdeep Rastogi

Abstract Phytoplankton are the primary producers in aquatic ecosystem and play crucial role in the nutrient cycling, carbon fixation, and regulating the overall food-web dynamics. In addition to ensuring ecological services, phytoplankton species composition is also considered an efficient bio-indicator of the water quality. Thus, phytoplankton composition, diversity, and their distribution could be used as a biological proxy to assess the ecological health of a water body. Considering the ecological significance of phytoplankton, various studies have targeted them to understand their spatiotemporal variation and environmental drivers in the Chilika lagoon. Phytoplankton community structure of Chilika lagoon is influenced by several environmental factors (nutrients, light, and salinity) of which salinity predominantly determines the composition and distribution of phytoplankton communities. In Chilika lagoon, spatial variation in salinity regime provides a variety of habitats (e.g. oligohaline (0–5 ppt), mesohaline (5–18 ppt), and polyhaline (>18 ppt)) for the proliferation of freshwater, estuarine, and marine phytoplankton forms. Based on the published literature, a total of 739 phytoplankton species have been documented from the Chilika lagoon, which included a diverse assemblage of species spectrum represented by Bacillariophyta (270 species), Dinophyta (88 species), Cyanophyta (103 species), Chlorophyta (178 species), Euglenophyta (92 species), Chrysophyta (5 species) and Xanthophyta (3 species). Among these, Bacillariophyta has been shown to be the most diverse and abundant in the phytoplankton communities. The total inventory of 709 phytoplankton species during the post-restoration study (2000–2014) included 612 new records which were documented for the first time from Chilika lagoon. Long-term systemic monitoring of phytoplankton is essential to understand their intrinsic spatiotemporal variability and also to recover maximum species diversity in lagoon. Further, continuous and detailed observation of phytoplankton community is necessary to monitor the occurrence of toxic species and harmful algal blooms. In addition to the application of classical microscopy based taxonomic approach to document phytoplankton

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species diversity, efforts should also be directed to integrate the molecular tools such as high-throughput DNA sequencing to understand the genetic diversity of smaller size nano-phytoplankton and pico- phytoplankton in the lagoon ecosystem.

Keywords Phytoplankton · Coastal Lagoon · Chilika · Brackish · Salinity

11.1 Background

Coastal lagoons are commonly distinguished as highly productive ecosystems due to their shallow depth and restricted water exchange with the sea (Bec et al. 2011). In addition, the productivity of coastal lagoons are influnced by development of strong boundaries and salinity gradients. Depth profiles also plays pivotal role by regulating solar insolation and controls benthic-pelagic coupling (Pérez-Ruzafa et al. 2011). Most of the coastal lagoons are simultaneously influenced by riverine and seawater influx resulting in brackish water salinity regime. The brackish water habitat hosts a wide array of biodiversity including major feeding and breeding grounds of fishes and birds. Lagoons also extends ecological services by providing food (largely fishes), stock of freshwater, maintainance of hydrobiology, climate regulation, flood protection, water purification, oxygen production, fertility, recreation and ecotourism (Newton et al. 2018). Hence, coastal lagoons have immense ecological, economic, and social values by supporting livelihoods of fisher folks and coastal communities (Newton et al. 2014). Coastal lagoons are typically characterized by shallow depth, bi-directional horizontal flows, and frequent mixing in the water column which results in a highly variable gradient in the physicochemical properties (Rakhesh et al. 2015). The variability in these properties also influences the phytoplankton community composition over the spatial and temporal scales in a lagoonal environment.

The challenge of deciphering the roles of phytoplankton community assembly remains a central problem of aquatic ecology (Cloern and Dufford 2005) and aquatic ecosystems are characterized by remarkable phytoplankton diversity (Goebel et al. 2013). Long-term changes in phytoplankton communities have been a major concern for global changes, which could be used to track ecosystem's response to the eutrophication and climate changes (Chen et al. 2010). Therefore, knowledge of phytoplankton community structure and associated variability at larger temporal scales covering multiple years is essential to understand underlying environmental changes, caused due to various drivers and pressures, which are accentuated by climate change. Krebs (1994) has opined that phytoplankton dynamics is influenced by bottom-up and/or top-down factors. Bottom-up factors (e.g., temperature, light intensity, salinity, nutrients, nitrogen, and phosphorus) control species growth, while top-down factors (e.g., predation and competition) control their biomass (Wehr and Descy 1998).

Phytoplankton are recognized as a major entity in global biogeochemical cycles (Myklestad 2000) and supply intermittently new, potentially labile dissolved organic carbon to aquatic systems (Sondergaard et al. 1985; Kirchman et al. 1991). Phytoplankton are also an important source of primary production and determine the potential productivity of entire aquatic food webs (Wissel and Fry 2005). Some species of phytoplankton are considered to be an important food source for pelagic and benthic species (e.g. fishes, and molluscs) (Pasquaud et al. 2010). For example, larval oysters feed on smaller phytoplankton cells (Olson and Olson 1989). Further, phytoplankton are generally considered as indicators of climate change due to their short lifespan and ability to produce resting stages (Guerrero and Rodriguez 1998; McQuoid et al. 2002). Studies have also shown that besides their role as bio-indicators of climate change, phytoplankton are also reliable indicators for assessing the pollution and eutrophication in aquatic ecosystems. For instance, spatiotemporal distribution of phytoplankton composition and biomass with emphasis on harmful algal blooms as indicators of eutrophication has been studied in the Cienfuegos Bay (Cuba) (Moreira-González et al. 2014). In another study, phytoplankton species composition was applied as a bio-diagnostic tool in relation to associated pollution in the Iyagbe lagoon (South-western Nigeria) (Onyema 2013).

Phytoplankton community represents an assemblage of heterogeneous microscopic algal forms, more or less dependent upon prevailing water currents (Kudela and Peterson 2009). Phytoplankton distribution in an estuarine lagoonal ecosystem is closely linked to several physicochemical and biological factors. Of these, salinity has been recognised as an important factor in determining community composition and their distribution (Huang et al. 2004; Lionard et al. 2005; Varona-Cordero et al. 2010; Lueangthuwapranit et al. 2011; Harris and Vinobaba 2012; Canini et al. 2013). Other environmental factors such as pH, temperature, light (influenced by turbidity) and nutrients also regulate the spatiotemporal distribution of these communities. For example in Bach Dang estuary (Vietnam) phytoplankton community structure was influenced by nutrient, turbidity, and heavy metals (Rochelle-Newall et al. 2011). In another study, temperature, salinity, silicate, and total phosphorus affected phytoplankton structure in Tagus estuary (Portugal) (Brogueira et al. 2007).

The Chilika lagoon represents a biologically diverse and ecologically unique ecosystem located along the east coast of India (19°28′–19°54′ N and 85°06′–85°35′ E). The lagoon is a shallow bar-built estuary with a surface area of 906 km^2 in summer and 1165 km^2 in monsoon (Mohanty et al. 2015). The lagoon experiences tropical monsoon-forced climate with average annual precipitation of 1238 mm (Gupta et al. 2008). Semi-diurnal tides facilitate seawater influx into the lagoon, mostly restricted to seawater inlet (Ganguly et al. 2015). Simultaneous mixing of river water and seawater makes the hydrological regime highly dynamic in lagoon. About 78% of the freshwater flows into the lagoon are from 12 major rivers located in the northern and western catchment of the lagoon (Srichandan et al. 2015a). Historically, based on the salinity gradient, the lagoon has been spatially delineated into four ecological sectors; northern sector, central sector, southern sector, and outer channel (Fig. 11.1).

Phytoplankton are frequently characterized in relation to discrete size classes–picoplankton (<2 μm), nanoplankton (2–20 μm), microplankton (20–200 μm) and macroplankton (>200 μm) (Brewin et al. 2010). Majority of studies on

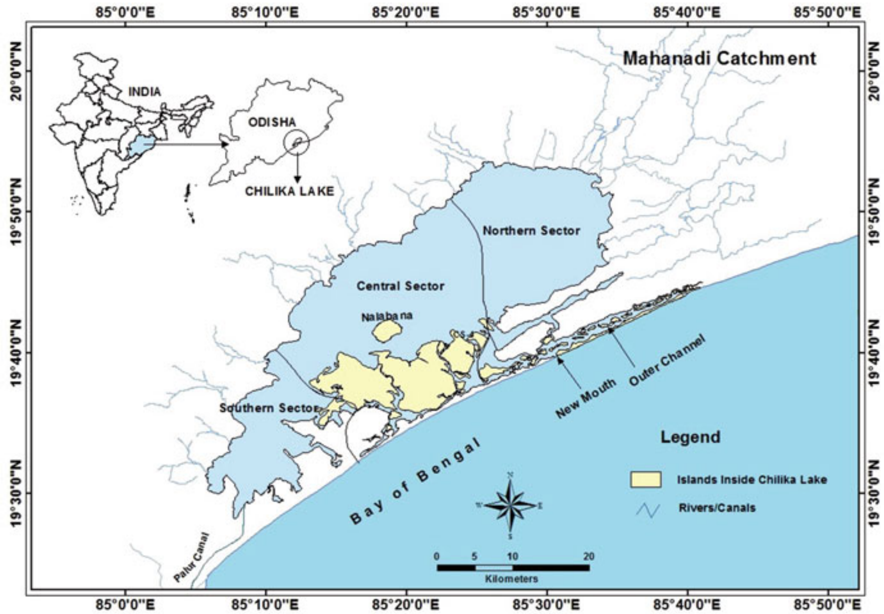

Fig. 11.1 Map of Chilika lagoon showing four sectors (northern sector, central sector, southern sector, outer channel) of the lagoon

phytoplankton diversity and distribution in Indian coastal ecosystems have relied on the classical morphological identification using light microscopy (Selvaraj et al. 2003; Srichandan et al. 2015a; b). Conventional light microscopy is only suited to discriminate large size (>10 μm) phytoplankton cells and has minimal use in assessing genetic diversity of smaller size ($\leq$ 2 μm) phytoplankton. Although, electron microscopy generally allows assignment to taxonomic classes, but most of the picoplankton do not have enough ultra-structural features for the identification at lower taxonomic level. Recent studies on natural plankton assemblages have also employed flow cytometry and photosynthetic pigment analysis which provide information on the structure and dynamics of the phototrophic and/or autotrophic behaviour of the planktonic organism, but phylogenetic information supplied by these methods is limited (Diez et al. 2001).

Recently, advances in high-throughput DNA sequencing has allowed sequencing of hundreds of environmental samples in a very cost-effective manner, generating millions of sequence reads which can provide a realistic estimate on the true extent of the genetic diversity of picophytoplankton. For example, 454 pyrosequencing of 18S rRNA genes from the Pacific coastal waters, for the first time presented a comprehensive picture of the diversity of marine picoeukaryotes (Cheung et al. 2010). The 18S/16S rRNA genes are widely used in picophytoplankton diversity studies allowing discrimination of both heterotrophic and phototrophic picophytoplankton at different taxonomic levels (Xiao et al. 2014). In contrast, sequencing of functional genes, provide direct linkages to the essential functions in carbon biogeochemistry that picophytoplankton performs. Diversity, gene abundance, and gene expression studies based on the *rbcL* (Ribulose-1, 5-bisphosphate carboxylase oxygenase) gene, which encodes the large subunit of the CO_2-fixing enzyme Rubisco (Ribulose-1, 5-bisphosphate carboxylase oxygenase), have produced valuable insights into community composition and environmental patterns in the different aquatic ecosystem (Samanta and Bhadury 2014).

Phytoplankton communities in Chilika are mixed assemblages consisting freshwater, estuarine, and marine species (Panigrahi et al. 2009; Srichandan et al. 2015a). Most of these species have wide salinity tolerance and are eurytopic in nature (Srichandan et al. 2015b). Literature also suggests that Chilika experiences significant seasonal changes in nutrient and salinity regime during dry and wet seasons (Srichandan et al. 2015b). Excessive nutrient loading could lead to eutrophication and may promote the development of Cyanophyta blooms (Conley et al. 2009; Stal 2012). Given the ecological significance of phytoplankton, number of studies have explored the taxonomic diversity of phytoplankton communities in the Chilika lagoon (Biswas 1932; Devasundaram and Roy 1954; Patnaik 1973; Patnaik and Sarkar 1976; Raman et al. 1990; Adhikary and Sahu 1992; Rath and Adhikary 2008; Panigrahi et al. 2009; Jha et al. 2009; Mohanty and Adhikary 2013; Mukherjee et al. 2016). In addition, environmental factors (e.g. salinity, transparency, dissolved nutrients) which drive the spatiotemporal distribution of phytoplankton communities in the Chilika lagoon have been well studied (Srichandan et al. 2015a, b).

In view of the foregoing discussions on the importance of phytoplankton, the present chapter provides a detailed overview of the current knowledge on the species diversity, spatiotemporal distribution, and environmental drivers of phytoplankton communities in the Chilika lagoon. This article also highlights consideration for a future line of phytoplankton research to enable bridging the knowledge gaps, particularly related to smaller size pico and nanophytoplankton.

11.2 Floral Classification of Phytoplankton

Phytoplankton are ususally classed in two major groups, (i) non-motile, fast-growing Bacillariophyta (diatom) and (ii) motile Dinophyta (dinoflagellates), capable of vertical migration in the water column in response to photosynthetically available solar irradiance (Moreno-Díaz et al. 2015). Other groups *viz.* Cyanophyta (blue-green algae), Chlorophyta (green algae), Euglenophyta (euglenoids), Chrysophyta (silicoflagellates) and Xanthophyta (yellow-green algae) are also the members of phytoplankton communities and often predominates under certain favourable circumstances.

In total, 739 phytoplankton species represented by Bacillariophyta (270 species), Dinophyta (88 species), Cyanophyta (103 species), Chlorophyta (178 species), Euglenophyta (92 species), Chrysophyta (5 species) and Xanthophyta (3) have been documented so far from the Chilika lagoon (Tables 11.1, 11.2, 11.3, 11.4,

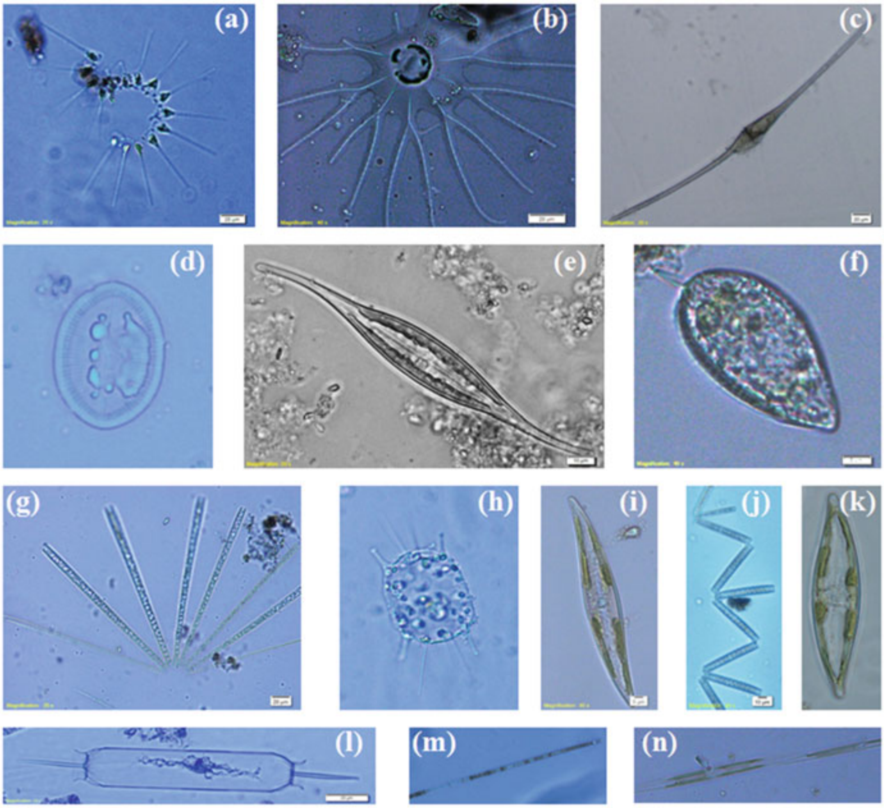

Plate 11.1 Pictures of some dominant phytoplankton species recorded in Chilika Lagoon (**a**) *Asterionellopsis glacialis*[1,2,3,4] (**b**) *Bacteriastrum* sp.[2]; (**c**) *Ceratium fusus*[6]; (**d**) *Cocconeis pediculus*[4]; (**e**) *Gyrosigma fasciola*[6]; (**f**) *Prorocentrum micans*[4,6]; (**g**) *Thalassiothrix frauenfeldii*[2]; (**h**) *Odontell mobiliensis*[1,3,4]; (**i**) *Pleurosigma normanii*[3,4,5,6]; (**j**) *Thalassionema nitzschioides*[3,6]; (**k**) *Navicula transitrans*[6]; (**l**) *Ditylum brightwelli*[2]; (**m**) *Trichodesmium erythraeum*[2,4]; (**n**) *Pseudonitzschia* sp.[5,6]. [1]Devasundaram and Roy (1954), [2]Patnaik (1973), [3]Rath and Adhikary (2008), [4]Panigrahi et al. (2009), [5]Srichandan et al. (2015a), [6]Srichandan et al. (2015b)

11.5, 11.6, and 11.7). The photomicrographs of some dominant phytoplankton species recorded in Chilika lagoon are depicted in Plate 11.1. However, it should be noted that different studies have used various techniques for collection, preservation, concentration, enumeration, and taxonomic identification of phytoplankton communities. Due to this reason, the data would not be directly comparable across different studies. For example, some studies have used plankton nets of 10–20 μm (Rath and Adhikary 2008; Srichandan et al. 2015a, b) and 45 μm (Mohanty and Adhikary 2013) mesh sizes, while others have used a gravity sedimentation method without plankton net (Panigrahi et al. 2009). The studies also differ in sampling frequency and sample size (in terms of the amount of water collected and number of sampling sites). Most of the earlier studies have employed seasonal sampling in the sense that water samples were collected only once during a given season. In recent studies, comprehensive monitoring of phytoplankton communities was carried out on a monthly basis over the period of 3 years (2011–2014) covering sampling locations which spanned all four sectors of the lagoon (Srichandan et al. 2015a, b). Such studies have highlighted the importance of conducting long-term systemic monitoring of phytoplankton communities and provided a detailed understanding of their variability caused either by the intrinsic environmental forces or by the extreme events such as a cyclone.

11.2.1 Bacillariophyta

Bacillariophyta represents unicellular and uni-nucleate algae with a size range of about 15 mm–400 mm in maximum dimension, although some smaller and a few considerably larger forms exist in the aquatic ecosystem. Bacillariophyta can be used as a suitable bioindicator for water quality assessments due to their short generation time and sensitivity to subtle environmental changes (Stevenson and Pan 1999; Goma et al. 2005). Bacillariophyta have been reported to constitute the bulk of the phytoplankton assemblages in many estuarine ecosystems. For instance, in Tagus (Portugal), Mahanadi (India), Batticaloa (Sri Lanka), and Bach Dang (Vietnam) estuaries, phytoplankton communities were dominated by Bacillariophyta (Cabeçadas 1999; Naik et al. 2009; Harris and Vinobaba 2012; Chu et al. 2014). In Chilika lagoon, Bacillariophyta has also been reported to dominate the phytoplankton community due to their eurythermal and euryhaline adaptations (Srichandan et al. 2015a). Literature also suggests that Bacillariophyta can tolerate a wide range of fluctuation in salinity and temperature (Sasamal et al. 2005). For instance, Aquino et al. (2015), while studying seasonal and spatial variation in phytoplankton community structure of Passos River estuary in Brazil remarked that Bacillariophyta are spatially affected by salinity and occurs in most estuaries in the world. However, nutrient availability and their stoichiometry regulates bacillariophytic metabolism and often results in a change in species composition in response to changing water quality (Lie et al. 2011). Molar ratios of available macronutrient concentration as dissolved silicate (16): dissolved inorganic nitrogen (16): dissolved inorganic phosphorus (1) is required for optimum growth of Bacillariophyta (Redfield et al. 1963). Apart from the nutrient availability in estuarine ecosystems, the growth and distribution of Bacillariophyta is also governed by water transparency that determines the availability of light in the water column (Resende et al. 2005; Masuda et al. 2011).

In Chilika lagoon, 270 Bacillariophyta species belonging to 95 genera have been reported (Table 11.1). Devasundaram and Roy (1954) investigated plankton community assemblages particularly in Balugaon, Kalupadaghat, Rambha, Satpara and Arkhakuda regions of Chilika lagoon and documented 31 species of Bacillariophyta, mostly marine in nature. Later, Patnaik (1973) identified 40 taxa of Bacillariophyta of which *Chaetoceros* sp., *Coscinodiscus* sp., *Asterionellopsis glacialis*, *Rhizosolenia* sp., *Bacteriastrum hyalinum*, *Grammatophora* sp. and *Nitzschia*

Table 11.1 List of Bacillariophyta species from Chilika

Phylum	Bacillariophyta
Class	Coscinodiscophyceae
Order	Coscinodiscales
Family	Heliopeltaceae
	Actinoptychus sp. Ehrenberg 1843[11, *, **]
Family	Coscinodiscaceae
	Coscinodiscopsis jonesiana (Greville) E.A.Sar & I.Sunesen in Sar, Sunesen & Hinz 2008[11,*,**], *Coscinodiscus centralis* Ehrenberg 1839[1,6,10,11,*], *Coscinodiscus curvatulus* Grunow in A.Schmidt 1878[10,*,**], *Coscinodiscus granii* L.F.Gough 1905[2], *Coscinodiscus marginatu*s Ehrenberg 1843[6,7,9,*,**], *Coscinodiscus radiatus* Ehrenberg 1840[10,*,**], *Coscinodiscus gigas* Ehrenberg 1841[6,7,10,11,*,**], *Coscinodiscus* sp. Ehrenberg 1839[2,3,6,7,10,11,*], *Palmerina hardmaniana* (Greville) G.R.Hasle 1996[11,*,**]
Family	Hemidiscaceae
	Azpeitia neocrenulata (S.L.VanLandingham) G.Fryxell & T.P.Watkins[8,*,**], *Hemidiscus cuneiformis* Wallich 1860[11,*,**], *Hemidiscus kanayanus* Simonsen[8,*,**], *Hemidiscus* sp. Wallich 1860[10,11,*,**]
Order	Asterolamprales
Family	Asterolampraceae
	Asteromphalus flabellatus (Brébisson) Greville 1859[10,*,**], *Asteromphalus hookeri* Ehrenberg 1844[10,*,**], *Asteromphalus wyvillii* F.S.Castracane degli Antelminelli[10,*,**], *Asteromphalus* sp. Ehrenberg 1844[10,11,*,**]
Order	Aulacoseirales
Family	Aulacoseiraceae
	Aulacoseira granulata (Ehrenberg) Simonsen 1979[8,*,**], *Aulacoseira granulata var. angustissima* (Otto Müller) Simonsen 1979[8,*,**], *Aulacoseira italica* (Ehrenberg) Simonsen 1979[8,11,*,**], *Aulacoseira* sp. Thwaites, 1848[11,*,**]
Order	*Cocconeidales*
Family	Cocconeidaceae
	Cocconeis pediculus Ehrenberg 1838[6,7,9,11,*,**], *Cocconeis placentula* Ehrenberg 1838[7,8,10,11,*,**], *Cocconeis* sp. Ehrenberg, 1836[1,10,11,*]
Order	Corethrales
Family	*Corethraceae*
	Corethron hystrix Hensen 1887[2,10,*], *Corethron* sp. Castracane 1886[11,*,**]
Order	*Rhizosoleniales*
Family	Rhizosoleniaceae
	Dactyliosolen fragilissimus (Bergon) Hasle 1996[2,10,*], *Guinardia delicatula* (Cleve) Hasle 1997[1,2,7,8,*], *Guinardia striata* (Stolterfoth) Hasle 1996[1,2,8,10,11,*] *Guinardia flaccida* (Castracane) H.Peragallo 1892[6,8,10,*,**], *Pseudosolenia calcar-avis* (Schultze) B.G.Sundström 1986[1], *Rhizosolenia bergonii* H.Peragallo 1892[1], *Neocalyptrella robusta* (G.Norman ex Ralfs) Hernández-Becerril & Meave del Castillo 1997[1,10,11,*], *Rhizosolenia castracanei* H.Peragallo 1888[10,*,**], *Rhizosolenia crassispina* J.L.B. Schröder 1906[11,*,**], *Rhizosolenia imbricata* Brightwell 1858[1,10,11,*], *Rhizosolenia setigera* Brightwell 1858[1,2,6,8,10,11,*], *Rhizosolenia setigera f. pungens* (A.Cleve) Brunel 1962[10,*,**], *Rhizosolenia styliformis* T.Brightwell 1858[1,8,10,11,*], *Rhizosolenia* sp. Brightwell 1858[3,4,10,11,*]

(continued)

Table 11.1 (continued)

Family	Probosciaceae
	Proboscia alata (Brightwell) Sundström 1986[1,2,8,10,11,*]
Order	Melosirales
Family	Melosiraceae
	Melosira borreri Greville 18,336,[10,11,*,**], *Melosira decussata* (Ehrenberg) Kützing[9,*,**], *Melosira sulcata* (Ehrenberg) Kützing 1844[10,11,*,**], *Melosira* sp. C. Agardh 1824[10,11,*,**]
Family	Paraliaceae
	Paralia sulcata (Ehrenberg) Cleve 1873[10,11,*,**], *Paralia* sp. Heiberg 1863[11,*,**]
Order	*Stephanopyxales*
Family	*Stephanopyxidaceae*
	Stephanopyxis turris (Greville) Ralfs in Pritchard 1861[1,6,10,11,*]
Order	*Triceratiales*
Family	*Triceratiaceae*
	Triceratium sp. Ehrenberg 1839[4,10,11,*]
Class	Bacillariophyceae
Order	Cymbellales
Family	Anomoeoneidaceae
	Adlafia minuscula (Grunow) Lange-Bertalot in Lange-Bertalot & Genkal 1999[6,8,*,**]
Order	Rhaphoneidales
Family	Rhaphoneidaceae
	Adoneis pacifica G.W.Andrews & P.Rivera 1987[10,*,**], *Rhaphoneis amphiceros* (Ehrenberg) Ehrenberg 1844[10,*,**], *Asterionellopsis glacialis* (Castracane) Round 1990[1,2,3,6,7,10,11,*]
Order	Naviculales
Family	Amphipleuraceae
	Amphiprora gigantea Grunow 1860[6,*,**], *Amphiprora obtusa* W.Gregory[10, *,**], *Amphiprora* sp. Ehrenberg 1843[11,*,**]
Family	Diploneidaceae
	Diploneis elliptica (Kützing) Cleve 1894[8,10,11,*,**], *Diploneis oblongella* (Nägeli ex Kützing) Cleve-Euler 1922[8,10,11,*,**], *Diploneis puella* (Schumann) Cleve 1894[8,10,11,*,**], *Diploneis smithii* (Brébisson) Cleve 1894[10,11,*,**], *Diploneis robustus* R.Subrahmanyan[11,*,**], *Diploneis weissflogii* (A.W.F.Schmidt) Cleve 1894[10,11,*,**], *Diploneis* sp. Ehrenberg ex Cleve 1894[10,11,*,**]
Family	*Plagiotropidaceae*
	Ephemera sp. Paddock 1988[11,*,**], *Meuniera membranacea* (Cleve) P.C.Silva 1996[10,11,*,**], *Plagiotropis* sp. Pfitzer 1871[10,11,*,**], *Manguinea rigida* (M.Peragallo) Paddock 1988[11,*,**]
Family	Stauroneidaceae
	Craticula cuspidata (Kutzing) D.G.Mann 1990[6,*,**], *Stauroneis pusilla* Ehrenberg[6,*,**]
Family	Sellaphoraceae
	Fallacia pygmaea (Kützing) Stickle & D.G.Mann 1990[7,*,**]
Family	Naviculaceae
	Gyrosigma acuminatum (Kützing) Rabenhorst 1853[6,8,10,*,**], *Gyrosigma balticum* (Ehrenberg) Rabenhorst 1853[10,11,*,**], *Gyrosigma fasciola* (Ehrenberg) J.W.Griffith &

(continued)

Table 11.1 (continued)

	Henfrey 1856[11,*,**], *Gyrosigma* sp. Hassall 1845[10,11,*,**], *Navicula cryptocephala* Kützing 1844[8,*,**], *Navicula distans* (W.Smith) Ralfs 1861[11,*,**], *Navicula lanceolata* Ehrenberg 1838[6,8,10,*,**], *Navicula protracta* (Grunow) Cleve 1894[6,*,**], *Navicula rhynchocephala* Kützing 1844[8,*,**], *Navicula salinarum* Grunow 1880[6,*,**], *Navicula transitans* Cleve 1883[10,11,*,**], *Navicula veneta* Kützing 1844[8,*,**] *Navicula* sp. Bory 1822[6,10,11,*,**]
Family	Neidiaceae
	Neidium affine var. *amphirhynchus* (Ehrenberg) Cleve 1894[9,*,**]
Family	Pinnulariaceae
	Pinnularia alpina W.Smith 1853[6,7,10,*,**], *Pinnularia major* (Kützing) Rabenhorst 1853[9,*,**], *Pinnularia subsimilis* H.P.Gandhi[9,*,**], *Pinnularia nobilis* (Ehrenberg) Ehrenberg 1843[6,*,**], *Pinnularia nodosa* (Ehrenberg) W.Smith 1856[9,*,**], *Pinnularia viridis* (Nitzsch) Ehrenberg 1843[8,*,**], *Pinnularia* sp. Ehrenberg 1843[10,11,*,**]
Family	*Pleurosigmataceae*
	Pleurosigma angulatum (J.T.Quekett) W.Smith 1852[11,*,**], *Pleurosigma directum* Grunow 1880[10,11,*,**], *Pleurosigma elongat*um W.Smith 1852[2,3,5,7,10,11,*], *Pleurosigma naviculaceum* Brébisson 1854[9,*,**], *Pleurosigma normanii* Ralfs 1861[4,6,7,8,9,10,11,*], *Pleurosigma* sp. W.Smith 1852[2,3,10,11,*]
Order	Thalassiophysales
Family	Catenulaceae
	Amphora lineolata Ehrenberg 1838[10,*,**], *Amphora ostrearia* Brébisson ex Kützing 1849[10,11,*,**], *Amphora ovalis* (Kützing) Kützing 1844[6,10,*,**], *Amphora pediculus* (Kützing) Grunow ex A.Schmidt 1875[8,*,**], *Amphora* sp. Ehrenberg ex Kützing 1844[3,11,*]
Order	Tabellariales
Family	Tabellariaceae
	Asterionella formosa Hassall 1850[8,11,*,**], *Asterionella* sp. Hassall 1850[3,11,*], *Diatoma elongata* (Lyngbye) C.Agardh 1824[6,*,**], *Diatoma vulgaris* Bory 1824[8,*,**], *Diatoma* sp. Bory 1824[11,*,**], *Tabellaria fenestra*ta (Lyngbye) Kützing 1844[5,6,10,11,*], *Tabellaria flocculosa* (Roth) Kützing 1844[9,*,**], *Tabellaria* sp. Ehrenberg ex Kützing 1844[10,11,*,**]
Order	Bacillariales
Family	Bacillariaceae
	Bacillaria paxillifera (O.F.Müller) T.Marsson 1901[2,3,6,7,10,11,*], *Bacillaria* sp. J.F. Gmelin 1791[1,10,*], *Fragilariopsis oceanica* (Cleve) Hasle 1965[10,*,**] *Cylindrotheca closterium* (Ehrenberg) Reimann & J.C.Lewin 1964[2,4,6,7,8,10,11,*], *Hantzschia amphioxys* (Ehrenberg) Grunow 1880[9,*,**], *Nitzschia acicularis* (Kützing) W.Smith 1853[8,10,*,**], *Nitzschia clausii* Hantzsch 1860[8,10,*,**], *Nitzschia fibula-fissa* Lange-Bertalot 1980[8,*,**], *Nitzschia intermedia* Hantzsch 1880[8,*,**], *Nitzschia longissima* (Brébisson) Ralfs 1861[1,2,3,8,10,11,*], *Nitzschia obtusa* W.Smith 1853[6,7,11,*,**], *Nitzschia pacifica* Cupp 1943[10,*,**], *Nitzschia pungens* Grunow ex Cleve 1897[1,2,10,*], *Nitzschia recta* Hantzsch ex Rabenhorst 1862[8,*,**], *Nitzschia sigma* (Kützing) W.Smith 1853[6,10,11,*,**], *Nitzschia* sp. Hassall 1845[3,10,11,*], *Pseudo-nitzschia pungens* (Grunow ex Cleve) Hasle 1993[10,11,*,**], *Pseudo-nitzschia seriata* (Cleve) H.Peragallo 1899[2,7,10,*], *Pseudo-nitzschia seriata f. obtusa* (Hasle) Hasle 1993[8,*,**], *Pseudo-nitzschia* sp. H.Peragallo 1900[10,11,*,**], *Psammodictyon panduriforme* (W.Gregory) D.G.Mann 1990[6,10,*,**], *Tryblionella acuta* (Cleve) D.G.Mann 1990[9,*,**]

(continued)

Table 11.1 (continued)

Order	Surirellales
Family	Surirellaceae
	Campylodiscus clypeus (Ehrenberg) Ehrenberg ex Kützing 1844[8,*,**], *Campylodiscus horologium* W.C.Williamson 1848[2], *Campylodiscus* sp. Ehrenberg ex Kützing 1844[2,3,10,11,*], *Iconella tenera* (W.Gregory) Ruck & Nakov 2016[2], *Surirella elegans* Ehrenberg 1843[2,10,*], *Surirella birostrata* Hustedt ex Ant.Mayer 1917[8,*,**], *Surirella brebissonii* Krammer & Lange-Bertalot 1987[8,10,*,**], *Surirella eximia* Greville 1857[10,*,**], *Surirella fastuosa* (Ehrenberg) Ehrenberg 1843[10,11,*,**], *Surirella fluminensis* Grunow 1862[10,*,**], *Surirella minuta* Brébisson ex Kützing 1849[8,10,*,**], *Surirella robusta* Ehrenberg 1841[10,*,**], *Surirella* sp. Turpin 1828[10,11,*,**]
Family	Entomoneidaceae
	Entomoneis alata (Ehrenberg) Ehrenberg 1845[8,*,**], *Entomoneis paludosa* (W.Smith) Reimer 1975[10,*,**]
Order	Cymbellales
Family	Cymbellaceae
	Cymbella affinis Kützing 1844[9,*,**], *Cymbella aspera* (Ehrenberg) Cleve 1894[8,*,**], *Cymbella cistula* (Ehrenberg) O.Kirchner 1878[8,*,**], *Cymbella tumida* (Brébisson) Van Heurck 1880[8,10,*,**], *Cymbella* sp. C.Agardh 1830[3,6,10,11,*]
Order	Fragilariales
Family	Fragilariaceae
	Fragilaria acus (Kützing) Lange-Bertalot 2000[8,10,*,**], *Fragilaria capucin*a Desmazières 1830[8,*,**], *Fragilaria crotonensis* Kitton 1869[6,7,8,9,*,**], *Fragilaria radians* (Kützing) D.M.Williams & Round 1987[9,*,**], *Fragilaria* sp. Lyngbye, 1819[6,10,11,*,**], *Synedra crystallina* (C.Agardh) Kützing 1844[9,*,**], *Synedra* sp. Ehrenberg 1830[3,10,11,*]
Order	Cymbellales
Family	Gomphonemataceae
	Gomphonema constrictum var. *capitatum* (Ehrenberg) Grunow 1880[8,*,**], *Gomphonema grunowii* R.M.Patrick & Reimer 1975[8,*,**], *Gomphonema intricatum* Kützing 1844[8,*,**], *Gomphonema micropus* Kützing 1844[9,*,**], *Gomphonema olivaceum* (Hornemann) Brébisson 1838[8,*,**], *Gomphonema truncatum* Ehrenberg 1832[8,*,**], *Gomphonema* sp. Ehrenberg 1832[10,11,*,**]
Order	Rhabdonematales
Family	Grammatophoraceae
	Grammatophora undulata Ehrenberg[3,6,*], *Grammatophora* sp. Ehrenberg 1840[2,3]
Order	Licmophorales
Family	Licmophoraceae
	Licmophora abbreviata C.Agardh 1831[6,10,11,*,**], *Licmophora* sp. C.Agardh 1827[10,11,*,**]
Family	Ulnariaceae
	Tabularia fasciculata (C.Agardh) D.M.Williams & Round 1986[4,9,10,*], *Ulnaria ulna* (Nitzsch) Compère 2001[3,6,7,8,9,10,*]
Order	Thalassionematales
Family	Thalassionemataceae
	Lioloma pacificum (Cupp) Hasle 1996[10*,**], *Thalassionema frauenfeldii* (Grunow) Tempère & Peragallo 1910[1,2,3,8,10,11,*], *Thalassionema nitzschioides* (Grunow) Mereschkowsky 1902[1,2,6,8,10,11,*], *Thalassionema* sp. Grunow ex Mereschkowsky

(continued)

Table 11.1 (continued)

	1902[3,11,*], *Thalassiothrix longissima* Cleve & Grunow 1880[1,10,11,*], *Thalassiothrix* sp. Cleve & Grunow 1880[3,10,11,*]
Order	Lyrellales
Family	Lyrellaceae
	Lyrella clavata (Gregory) D.G.Mann 1990[10,11,*,**], *Lyrella hennedyi* (W.Smith) Stickle & D.G.Mann 1990[10,11,*,**]
Order	Mastogloiales
Family	Mastogloiaceae
	Mastogloia elliptica (C.Agardh) Cleve 1893[9,*,**], *Mastogloia exigua* F.W.Lewis 1861[4], *Mastogloia exilis* Hustedt 1933[10,*,**], *Mastogloia* sp. Thwaites ex W.Smith 1856[11,*,**]
Order	Rhopalodiales
Family	Rhopalodiaceae
	Rhopalodia gibberula (Ehrenberg) Otto Müller 1895[9,*,**]
Class	Mediophyceae
Order	Toxariales
Family	Ardissoneaceae
	Ardissonea formosa (Hantzsch) Grunow[11,*,**]
Family	Climacospheniaceae
	Climacosphenia moniligera Ehrenberg 1843[6,*,**]
Family	Toxariaceae
	Toxarium undulatum J.W.Bailey 1854[10,*,**]
Order	Eupodiscales
Family	Eupodiscaceae
	Auliscus sculptus (W.Smith) Brightwell 1860[6,10,*,**], *Odontella aurita* (Lyngbye) C. Agardh 1832[10,11,*,**], *Odontella granulata* (Roper) R.Ross 1986[7,*,**], *Odontella litigiosa* (Van Heurck) Hoban 1980[9,*,**], *Odontella longicruris* (Greville) M.A.Hoban 1983[10,11,*,**], *Odontella* sp. C.Agardh 1832[3,6,10,11,*], *Odontella sinensis* (Greville) Grunow 1884[1,2,7,8,10,11,*]
Order	Chaetocerotales
Family	Chaetocerotaceae
	Bacteriastrum comosum Pavillard 1916[8,11,*,**], *Bacteriastrum delicatulum* Cleve 1897[8,11,*,**], *Bacteriastrum furcatum* Shadbolt 1854[6,8,11,*,**], *Bacteriastrum hyalinum* Lauder 1864[1,2,6,8,11,*], *Bacteriastrum varians* Lauder 1864[10,11,*,**], *Bacteriastrum* sp. Shadbolt 1854[3,10,11,*]
Order	Biddulphiales
Family	Biddulphiaceae
	Biddulphia biddulphiana (J.E.Smith) Boyer 1900[3,5], *Eucampia cornuta* (Cleve) Grunow 1883[8,*,**], *Eucampia zodiacus* Ehrenberg 1839[8,10,11,*,**], *Eucampia* sp. Ehrenberg 1839[3]
Order	Hemiaulales
Family	Hemiaulaceae
	Cerataulina pelagica (Cleve) Hendey 1937[10,11,*,**], *Hemiaulus hauckii* Grunow ex Van Heurck 1882[8,10,11,*,**], *Hemiaulus sinensis* Greville 1865[8,10,11,*,**], *Hemiaulus* sp. Heiberg 1863[3,11,*]

(continued)

Table 11.1 (continued)

Order	Eupodiscales
Family	Eupodiscaceae
	Cerataulus heteroceros (Grunow) P.A.Sims & J.Witkowski 2012[4,6,7,10,11,*], *Trieres mobiliensis* (J.W.Bailey) Ashworth & Theriot 2013[1,6,7,10,11,*]
Order	Chaetocerotales
Family	Chaetocerotaceae
	Chaetoceros aequatorialis Cleve 1901[11,*,**], *Chaetoceros affinis* Lauder 1864[1,2,3,5,6,8,11,*], *Chaetoceros atlanticus* Cleve 1873[8,*,**], *Chaetoceros borealis* Bailey 1854[8,*,**], *Chaetoceros brevis* F.Schütt 1895[3], *Chaetoceros coarctatus* Lauder 1864[2], *Chaetoceros compressus* Lauder 1864[1,2,3,7,8,10,11,*], *Chaetoceros curvisetus* Cleve 1889[1,2,6,10,11,*], *Chaetoceros decipiens* Cleve 1873[9,10,11,*,**], *Chaetoceros densus* (Cleve) Cleve 1899[7,*,**], *Chaetoceros diadema* (Ehrenberg) Gran 1897[8,11,*,**], *Chaetoceros didymus* Ehrenberg 1845[7,10,11,*,**], *Chaetoceros diversus* Cleve 1873[2,6,7,10,*], *Chaetoceros eibenii* Grunow1882[1,6,*], *Chaetoceros laciniosus* F.Schütt 1895[2], *Chaetoceros laevis* Leuduger-Fortmorel 1892[1,8,11,*], *Chaetoceros lauderi* Ralfs ex Lauder 1864[7,*,**], *Chaetoceros lorenzianus* Grunow 1863[1,2,6,7,8,10,11,*], *Chaetoceros messanensis* Castracane 1875[11,*,**], *Chaetoceros mitra* (Bailey) Cleve 1896[8,*,**], *Chaetoceros paradoxus* Cleve 1873[6,7,*,**], *Chaetoceros pendulus* Karsten 1905[2], *Chaetoceros perpusillus* Cleve 1897[2], *Chaetoceros peruvianus* Brightwell 1856[1,2,7,8,10,11,*], *Chaetoceros protuberans* Lauder 1864[8,*,**], *Chaetoceros seriacanthus* Gran 1897[8,*,**], *Chaetoceros subtilis* Cleve 1896[1,11,*], *Chaetoceros teres* Cleve 1896[8,*,**], *Chaetoceros wighamii* Brightwell 1856[8,*,**], *Chaetoceros* sp. Ehrenberg 1844[3,4,6,10,11,*]
Family	Leptocylindraceae
	Leptocylindrus danicus Cleve 1889[6,10,11,*,**], *Leptocylindrus minimus* Gran 1915[10,11,*,**], *Leptocylindrus* sp. Cleve 1889[2,10,*]
Order	Stephanodiscales
Family	Stephanodiscaceae
	Cyclotella maxima Kützing 1844[9,*,**], *Cyclotella meneghiniana* Kützing 1844[9,10,*,**], *Cyclotella striata* (Kützing) Grunow 1880[8,11,*,**], *Cyclotella* sp. (Kützing) Brébisson 1838[10,11,*,**], *Pantocsekiella kuetzingiana* (Thwaites) K.T.Kiss & E.Ács 2016[8,*,**], *Stephanodiscus* sp. Ehrenberg 1845[4]
Order	Lithodesmiales
Family	Lithodesmiaceae
	Ditylum brightwellii (T.West) Grunow 1885[2,6,10,11,*], *Ditylum sol* (A.Schmidt) Cleve 1901[1,10,11,*], *Ditylum* sp. J.W.Bailey ex L.W.Bailey 1861[3], *Lithodesmium undulatum* Ehrenberg 1839[10,11,*,**], *Lithodesmium* sp. Ehrenberg 1839[11,*,**]
Order	Briggerales
Family	Streptothecaceae
	Helicotheca sp. M.Ricard 1987[11,*,**], *Streptotheca* sp. Shrubsole 1890[11,*,**]
Order	Thalassiosirales
Family	Lauderiaceae
	Lauderia annulata Cleve 1873[2,6,7,10,11,*]
Family	Thalassiosiraceae
	Minidiscus sp. Hasle 1973[11,*,**], *Planktoniella* sp. F.Schütt 1892[2], *Thalassiosira eccentrica* (Ehrenberg) Cleve 1904[8,10,11,*,**], *Thalassiosira gravida* Cleve 1896[11,*,**], *Thalassiosira subtilis* (Ostenfeld) Gran 1900[5,6,10,*], *Thalassiosira* sp. Cleve 1873[3,11,*]

(continued)

Table 11.1 (continued)

Family	Skeletonemataceae
	Skeletonema costatum (Greville) Cleve 1873[2,5,6,8,*], *Skeletonema subsalsum* (Cleve-Euler) Bethge 1928[8,*,**], *Skeletonema* sp. Greville 1865[11,*,**]
Class	Bacillariophyta incertae sedis
Order	Bacillariophyta incertae sedis
Family	Bacillariophyta incertae sedis
	Mediopyxis helysia Kühn, Hargreaves & Halliger 2006[10,11,*,**], *Mediopyxis* sp. Medlin & Kühn 2006[10,11,*,**]

[1]Devasundaram and Roy (1954), [2]Patnaik (1973), [3]Patnaik and Sarkar (1976), [4]Raman et al. (1990), [5]Adhikary and Sahu (1992), [6]Rath and Adhikary (2008), [7]Panigrahi et al. (2009), [8]Jha et al. (2009), [9]Mohanty and Adhikary (2013), [10]Srichandan et al. (2015a), [11]Srichandan et al. (2015b)

*Inventorized during survey in post-restoration period (2000–2014)

**New records during survey in post-restoration period (reported for the first time from the lagoon)

sp. were found to be abundant across the outer channel of Chilika lagoon. The Bacillariophyta such as *Chaetoceros perpusillus*, *Chaetoceros peruvianus*, *Cheatoeceros lorenzianus*, *Asterionellopsis glacialis*, *Thalassionema frauenfeldii*, and *Ditylum brightwellii* were mostly represented in the central sector while *Chaetoceros affinis*, *Chaetoceros pendulus*, and *Chaetoceros* sp. were dominant in the northern sector. Patnaik and Sarkar (1976) documented 29 species of Bacillariophyta in Chilika lagoon out of which 18 species were new records. Raman et al. (1990) have mentioned the name of only 9 species (*Cerataulus heteroceros*, *Chaetoceros* sp., *Cylindrotheca closterium*, *Mastogloia exigua*, *Pleurosigma normanii*, *Rhizosolenia* sp., *Stephanodiscus* sp., *Synedra affinis*, and *Triceratium* sp.) of Bacillariophyta in their publication. Subsequently, Adhikary and Sahu (1992) did the sampling from stations spanning the entire lagoon and reported an additional two species (*Tabellaria fenestrata* and *Thalassiosira subtilis*) of Bacillariophyta. A study undertaken by Rath and Adhikary (2008) documented 57 species of Bacillariophyta in Chilika lagoon. Later, Panigrahi et al. (2009) recorded a total of 30 Bacillariophyta species during sampling between the years 2001–2003. The species such as *Chaetoceros paradoxus*, *Coscinodiscus gigas*, *C. marginatus*, *Coscinodiscus* sp., *Lauderia annulata*, and *Cylindrotheca closterium* were dominant in outer channel. Subsequently, the study of phytoplankton carried out in Chilika lagoon over the period 2003–2006 by Jha et al. (2009) led to documentation of 80 species of Bacillariophyta. Mohanty and Adhikary (2013) carried out an investigation on changes in the algal diversity subsequent to the opening of a new seawater inlet in the lagoon and recorded 20 more species (*Mastogloia elliptica*, *Odontella litigiosa*, *Chaetoceros decipiens*, *Cyclotella maxima*, *Cyclotella meneghiniana*, *Cymbella affinis*, *Rhopalodia gibberula*, *Gomphonema micropus*, *Hantzschia amphioxys*, *Melosira decussata*, *Neidium affine var. amphirhynchus*, *Pinnularia major*, *Tryblionella acuta*, *Pinnularia subsimilis*, *Pinnularia nodosa*, *Pleurosigma naviculaceum*, *Synedra crystallina*, *Fragilaria radians*, *Tabularia fasciculata* and *Tabellaria flocculosa*) to the existing Bacillariophyta species inventory of Chilika lagoon.

Recently, based on monthly sampling between year 2011–2012 from 13 stations of Chilika lagoon, 138 Bacillariophyta species belonging to 54 genera have been reported (Srichandan et al. 2015a). Out of these 138 Bacillariophyta, 53 species were new reports from Chilika lagoon. Among the encountered genera, *Chaetoceros* and *Surirella* have been found to be represented by the highest number of species (8 species). Bacillariophyta such as *Pleurosigma* sp., *P. normanii*, *Synedra* sp., *Thalassionema nitzschioides*, *Surirella* sp., *Chaetoceros* sp., *Coscinodiscus* sp., *Lithodesmium undulatum*, *Hemiaulas sinensis*, and *Paralia sulcata* have been found to be dominant throughout Chilika lagoon. The diversity of Bacillariophyta was higher during pre-monsoon season which has a higher salinity. In a recent study, 136 Bacillariophyta species have been registered in Chilika lagoon (Srichandan et al. 2015b). *Synedra* sp., *Nitzschia* sp., *Diploneis weissflogii*, *Surirella* sp., *Navicula* sp., *Pseudonitzschia* sp., *Thalassiosira* sp., *Coscinodiscus* sp., *Chaetoceros* sp. and *Cyclotella* sp. were dominant species and present in a wide range of salinity (oligohaline, mesohaline, and polyhaline). Srichandan et al. (2015b) have also reported the dominance of centric Bacillariophyta over pennate as also reported from other estuarine habitats, globally (Patil and Anil 2008; Canini et al. 2013). Thus, the post-restoration status of Bacillariophyta in Chilika lagoon stood at 252 species and a total of 188 Bacillariophyta were documented as new reports.

11.2.2 Dinophyta

Dinophyta are common to abundant in fresh, marine, and estuarine environments. In general, Dinophyta occupy the second position next to Bacillariophyta in the aquatic environment (Sahu et al. 2014). Dinophyta belongs to the diverse group of unicellular eukaryotes (Leander and Keeling 2004). Some Dinophyta are autotrophs and heterotrophs (Glibert and Legrand 2006; Gaines and Elbrächter 1987) while some lead mixotrophic mode of nutrition (Burkholder et al. 2008). Further, the heterotrophic and mixotrophic Dinophyta are able to feed on diverse prey items (e.g. bacteria, picoeukaryotes, nanoflagellates, bacillariophyta, other dinophyta, heterotrophic protists, and metazoans) due to their diverse feeding mechanisms (Jeong et al. 2010). In turn they are ingested by several kinds of predators. Thus, the role of the Dinophyta in food chain and food webs are very diverse. The variation in abundance, diversity, and composition of Dinophyta depend on changes in salinity, pH, nitrogen and phosphate (Yoo 1991; Cremer et al. 2007). For instance, a study from Chapora estuary (India) has reported that the major influential agents for Dinophyta distribution were temperature and salinity (Alkawri and Ramaiah 2010). In another study, salinity, nutrient, temperature and pH were the determining factors for the growth of Dinophyta in Santo Andre lagoon (Portugal) (Macedo et al. 2001).

In Chilika lagoon, Devasundaram and Roy (1954) documented 6 species of Dinophyta: *Dinophysis caudata*, *D. miles*, *Peridinium* sp., *Tripos furca*, *Ceratium trichoceros*, and *C. breve* (Table 11.2). Patnaik (1973) investigated seasonal fluctuations of plankton in the Chilika lagoon and recorded 7 species (*Tripos furca*, *Ceratium tripos*, *Tripos fusus*, *Tripos longipes*, *Noctiluca scintillans*, *Dinophysis*

Table 11.2 List of Dinophyta species from Chilika

Phylum	Miozoa (=Dinophyta)
Class	Dinophyceae
Order	Gymnodiniales
Family	Gymnodiniaceae
	Akashiwo sanguinea (K.Hirasaka) G.Hansen & Ø.Moestrup 2000[11,*,**], *Gymnodinium catenatum* H.W.Graham 1943[8,9,*,**], *Gymnodinium heterostriatum* Kofoid & Swezy 1921[6,*,**], *Gymnodinium* sp. F.Stein 1878[10,11,*,**], *Gyrodinium* sp. Kofoid & Swezy 1921[10,*,**], *Polykrikos kofoidii* Chatton 1914[8,9,*,**]
Order	Gonyaulacales
Family	Goniodomataceae
	Alexandrium minutum Halim 1960[8,9,11,*,**], *Alexandrium monilatum* (J.F.Howell) Balech 1995[8,9,10,11,*,**], *Alexandrium* sp. Halim 1960[1,*,**], *Alexandrium ostenfeldii* (Paulsen) Balech & Tangen 1985[9,*,**], *Alexandrium tamarense* (Lebour) Balech 1995[8,9,*,**]
Family	Ceratiaceae
	Ceratium breve (Ostenfeld & Schmidt) Schröder 1906[1,9,*], *Ceratium gibberum* Gourret 1883[8,*,**], *Ceratium trichoceros* (Ehrenberg) Kofoid 1881[1,9,10,11,*], *Ceratium tripos* (O.F.Müller) Nitzsch 1817[2,3,6,7,8,9,10,11,*], *Ceratium symmetricum* Pavillard 1905[10,*,**], *Ceratium tripos var. atlanticum* Ostenfeld 1903[9,*,**], *Ceratium* sp. F.Schrank 1793[3,11,*], *Tripos brevis* (Ostenfeld & Johannes Schmidt) F.Gómez 2013[9,*,**], *Tripos contortus* (Gourret) F.Gómez 2013[8,11,*,**], *Tripos dens* (Ostenfeld & Johannes Schmidt) F.Gómez 2013[9,*,**], *Tripos extensus* (Gourret) F.Gómez 2013[10,*,**], *Tripos falcatus* (Kofoid) F.Gómez 2013[9,*,**], *Tripos furca* (Ehrenberg) F.Gómez 2013[1,2,3,5,7,8,9,10,11,*], *Tripos fusus* (Ehrenberg) F.Gómez 2013[2,3,8,9,10,11,*] *Tripos kofoidii* (Jörgenen) F.Gómez 2013[11,*,**], *Tripos lineatus* (Ehrenberg) F.Gómez 2013[6,7,10,11,*], *Tripos vultur* (Cleve) F.Gómez 2013[11,*,**], *Tripos longipes* (J.W.Bailey) F.Gómez 2013[2,6,9,*], *Tripos macroceros* (Ehrenberg) F.Gómez 2013[9,11,*,**], *Tripos minutus* (Jörgensen) F.Gómez 2013[3]
Family	Gonyaulacaceae
	Gonyaulax minima Matzenauer 1933[10,11,*,**], *Gonyaulax spinifera* (Claparède & Lachmann) Diesing 1866[8,9,10,*,**], *Gonyaulax scrippsae* Kofoid 1911[9,*,**], *Gonyaulax* sp. K.M.Diesing 1866[10,11,*,**], *Lingulodinium polyedra* (F.Stein) J.D. Dodge 1989[9,*,**]
Family	Protoceratiaceae
	Protoceratium reticulatum (Claparède & Lachmann) Bütschli 1885[9,10,11,*,**]
Family	Pyrophacaceae
	Pyrophacus horologium F.Stein 1883[8,9,10,11,*,**], *Pyrophacus steinii* (Schiller) Wall & Dale 1971[8,9,10,11,*,**], *Pyrophacus* sp. F.Stein 1883[10,11,*,**]
Order	Dinophysiales
Family	Amphisoleniaceae
	Amphisolenia astragalus Kofoid & Michener 1911[10,*,**]
Family	Dinophysaceae
	Dinophysis caudata Saville-Kent 1881[1,2,3,5,6,9,10,11,*], *Dinophysis fortii* Pavillard 1923[8,*,**], *Dinophysis miles* Cleve 1900[1,9,*], *Ornithocercus magnificus* Stein 1883[9,*,**]
Order	Peridiniales
Family	Glenodiniaceae
	Glenodinium pulvisculus (Ehrenberg) Stein 1883[8,10,11,*,**], *Glenodinium* sp. Ehrenberg 1836[10,11,*,**]

(continued)

Table 11.2 (continued)

	Peridiniopsis penardiformis (Lindemann) Bourrelly 1968[8,10,11,*,**], *Peridiniopsis quadridens* (Stein) Bourrelly 1968[8,*,**]
Family	Diplopsalidaceae
	Oblea Balech ex Loeblich Jr. & Loeblich III 1966[8,*,**], *Preperidinium meunieri* (Pavillard) Elbrächter 1993[11,*,**]
Family	Peridiniaceae
	Peridinium willei Huitfeldt-Kaas 1900[8,*,**], *Peridinium* sp. Ehrenberg 1830[1,3], *Parvodinium inconspicuum* (Lemmermann) S.Carty 2008[8,10,11,*,**]
Family	Peridiniales incertae sedis
	Peridiniella catenata (Levander) Balech 1977[8,*,**]
Family	Thoracosphaeraceae
	Scrippsiella acuminata (Ehrenberg) Kretschmann, Elbrächter, Zinssmeister, S. Soehner, Kirsch, Kusber & Gottschling 2015[8,*,**]
Order	Prorocentrales
Family	Prorocentraceae
	Prorocentrum arcuatum Issel 1928[11,*,**], *Prorocentrum balticum* (Lohmann) Loeblich 1970[10,11,*,**], *Prorocentrum gracile* Schütt 1895[10,11,*,**], *Prorocentrum belizeanum* M.A.Faust 1993[8,9,*,**], *Prorocentrum rostratum* Stein 1883[11,*,**], *Prorocentrum micans* Ehrenberg 1834[7,9,10,11,*,**], *Prorocentrum compressum* (J.W.Bailey) Abé ex J. D.Dodge 1975[11,*,**], *Prorocentrum cordatum* (Ostenfeld) J.D.Dodge 1975[8,9,10,11,*,**], *Prorocentrum lima* (Ehrenberg) F.Stein 1878[8,9,11,*,**], *Prorocentrum maximum* (Gourret) Schiller 1937[10,*,**], *Prorocentrum* sp. Ehrenberg 1834[10,11,*,**]
Family	Protoperidiniaceae
	Protoperidinium brevipes (Paulsen) Balech 1974[4,7,*], *Protoperidinium conicum* (Gran) Balech 1974[10,*,**], *Protoperidinium crassipes* (Kofoid) Balech 1974[11,*,**], *Protoperidinium depressum* (Bailey) Balech 1974[3,7,9,10,11,*], *Protoperidinium diabolus* (Cleve) Balech 1974[2,3], *Protoperidinium divergens* (Ehrenberg) Balech 1974[8,11,*,**], *Protoperidinium elegans* (Cleve) Balech 1974[9,*,**], *Protoperidinium leonis* (Pavillard) Balech 1974[8,10,11,*,**], *Protoperidinium minimum* A.J.Schilling 1891[9,*,**], *Protoperidinium oceanicum* (Vanhöffen) Balech 1974[8,9,10,11,*,**], *Protoperidinium ovatum* Pouchet 1883[8,*,**], *Protoperidinium pallidum* (Ostenfeld) Balech 1973[8,10,*,**], *Protoperidinium pedunculatum* (Schütt) Balech 1974[8,10,11,*,**], *Protoperidinium pellucidum* Bergh 1881[9,*,**], *Protoperidinium steinii* (Jørgensen) Balech 1974[9,10,11,*,**], *Protoperidinium* sp. R.S.Bergh, 1881[10,11,*,**]
Order	Pyrocystales
Family	Pyrocystaceae
	Pyrocystis lunula (Schütt) Schütt in Engler & Prantl 1896[10,11,*,**], *Pyrocystis* sp. Wyville-Thompson, 1876[10,11,*,**]
Class	Noctilucea
Order	Noctilucales
Family	Noctilucaceae
	Noctiluca scintillans (Macartney) Kofoid & Swezy 1921[2,5,9,11,*]
Family	Kofoidiniaceae
	Pomatodinium impatiens J.Cachon & Cachon-Enjumet 1966[8,*,**]

[1]Devasundaram and Roy (1954), [2]Patnaik (1973), [3]Patnaik and Sarkar (1976), [4]Raman et al. (1990), [5]Adhikary and Sahu (1992), [6]Rath and Adhikary (2008), [7]Panigrahi et al. (2009), [8]Jha et al. (2013), [9]Mukherjee et al. (2016), [10]Srichandan et al. (2015a), [11]Srichandan et al. (2015b)
*Inventorized during survey in post-restoration period (2000–2014)
**New records during survey in post-restoration period (reported for the first time from the lagoon)

caudata and *Protoperidinium diabolus*) of Dinophyta. Patnaik and Sarkar (1976) added two more species; *Tripos minutus* and *Protoperidinium depressum* to the previous list. Raman et al. (1990) reported *Protoperidinium brevipes* as the most dominant species in the lagoon. Subsequently, Adhikary and Sahu (1992) documented the occurrence of *Tripos furca*, *Noctiluca scintillans* and *Dinophysis caudata*. Rath and Adhikary (2008) reported the presence of five species, adding *Gymnodinium heterostriatum* and *Tripos lineatus* while Panigrahi et al. (2009) reported six species with *Prorocentrum micans* as new additions. A study undertaken by Jha et al. (2009) documented 33 species of Dinophyta in the Chilika lagoon, out of which 30 species were included in existing Dinophyta species list. Later, Mukherjee et al. (2016) has carried out investigation on Dinophyta diversity and distribution in Chilika lagoon with description of new records including toxic species namely *Alexandrium minutum*, *A. ostenfeldii*, *A. tamarense*, *A.monilatum*, *Lingulodinium polyedrum*, *Dinophysis caudata*, *D. fortii*, *Prorocentrum cordatum*, *P. micans*, *P. belizeanum*, *P. lima*, *Noctiluca scintillans*, and *Gymnodinium catenatum*. Among the reported 38 species, 12 species (*Alexandrium ostenfeldii*, *Lingulodinium polyedrum*, *Protoperidinium pellucidum*, *Protoperidinium elegans*, *Protoceratium reticulatum*, *Tripos brevis*, *Tripos dens*, *Tripos falcatus*, *Tripos macroceros*, *Ceratium tripos var. atlanticum*, *Amphisolenia astragalus* and *Ornithocercus magnificus*) were new records for Chilika lagoon which mostly prevailed in the outer channel followed by southern sector and central sector. Mukherjee et al. (2016) have also demonstrated salinity as the key factor that drives the Dinophyta distribution in the lagoon. For example, *Tripos macroceros*, and *Prorocentrum micans* were observed in a salinity range of 8.9–33.1 ppt where as, *A. ostenfeldii* was observed between 30.5 and 33.10 ppt (Mukherjee et al. 2016).

A survey undertaken for the period 2011–2012 on spatiotemporal distribution of phytoplankton assemblages reported 38 species of Dinophyta (Srichandan et al. 2015a). A recent study between 2012 and 2014 on interannual and cyclone-driven variability in phytoplankton communities recorded 47 species of Dinophyta (Srichandan et al. 2015b). *Protoperidinium* sp., *Gymnodinium* sp., *Prorocentrum cordatum*, *Tripos fusus*, *Prorocentrum micans*, *Protoperidinium oceanicum*, *Alexandrium* sp. and *Gonyaulax* sp. were the dominant species (Srichandan et al. 2015a, b).

An upsurge in the relative dominance of Dinophyta with concurrent increase in toxic dinophyte species namely; *Alexandrium* sp. (565 cells L^{-1}), *Gonyaulax* sp. (999 cells L^{-1}), and *Prorocentrum cordatum* (448 cells L^{-1}) was observed in southern sector after the passage of very severe cyclonic storm *Phailin* (Srichandan et al. 2015b). It was suggested that several physical and physiological processes could have contributed to higher Dinophyta abundance particularly in the southern sector of the lagoon. For example, riverine run-off may contribute to the formation of low saline and nutrient-rich freshwater layer at the surface where Dinophyta could concentrate their cells due to their swimming behaviour (Srichandan et al. 2015b). Till date, 88 Dinophyta species have been reported from the Chilika lagoon. Among these species, 84 Dinophyta have been reported in inventorisation survey during post-restoration phase and 71 species were new reports.

11.2.3 Cyanophyta

Cyanophyta are unicellular or filamentous organisms that are ubiquitous in nature and are found nearly in all aquatic environments. High diversity and abundance of Cyanophyta depend on high temperature and slightly alkaline conditions. Nutrient rich freshwater discharge and high turbidity due to suspended sediments further favor their growth (Harsha and Malammanavar 2004). For example, the growth of Cyanophyta due to high temperature and water column stability has also been reported in Neuse River estuary (North Carolina), York River estuary (Virginia), Florida Bay (Florida), and San Francisco Bay (California) (Phlips et al. 1999; Ning et al. 2000; Sin et al. 2000; Valdes-Weaver et al. 2006). In Na Thap River Estuary (Thailand), turbidity was the major factor responsible for variation in Cyanophyta diversity and abundance (Lueangthuwapranit et al. 2011). In Chilika lagoon, Cyanophyta have also been reported to dominate the phytoplankton community due to their specific adaptation to survive in highly turbid freshwater part (northern sector) of the lagoon (Srichandan et al. 2015b). Further, a combination of physical upward movement, nutrient, and favorable temperature conditions promoted benthic Cyanophyta growth in Chilika lagoon (Srichandan et al. 2015b).

Biswas (1932) initially documented 11 species of Cyanophyta from Chilika lagoon (Table 11.3). Patnaik (1973) have further added 4 Cyanophyta species to the existing species inventory and found that marine species *Trichodesmium erythraeum* was abundant in the outer channel while freshwater species such as *Anabaena* sp., *Nostoc* sp. were largely represented in the southern and northern sectors. Patnaik and Sarkar (1976) added another 3 Cyanophyta species (*Lyngbya* sp., *Microcystis* sp., and *Oscillatoria* sp.) to the existing list.

Raman et al. (1990) have investigated phytoplankton species composition in the Chilika lagoon before the opening of an artificial inlet in September 2000. It was observed that freshwater Cyanophyta *Pseudanabaena limnetica* dominated in the central sector. Another study, reported 8 Cyanophyta species representing freshwater and marine water forms (Adhikary and Sahu 1992). A seasonal survey of phytoplankton communities was conducted in the year 2000–2001 which reported a total of 12 species, of which 8 were the first report from Chilika lagoon (Rath and Adhikary 2008). Later, Panigrahi et al. (2009), Jha et al. (2009), Mohanty and Adhikary (2013), and Srichandan et al. (2015a) have documented 15, 39, 24 and 28 Cyanophyta species, respectively from the lagoon. A recent investigation on phytoplankton community in the lagoon has reported 39 Cyanophyta species (Srichandan et al. 2015b). Among these, three species (*Cylindrospermum* sp., *Phormidium* sp. and *Anabaena* sp.) were found to be most abundant and consistent in central and northern sectors. Thus, in total, updated documentation of Cyanophyta species stands at 103 of which 95 species were inventorized during post-restoration period which includes 81 new records collected for the first time.

Table 11.3 List of Cyanophyta species from Chilika

Phylum	Cyanophyta
Class	Cyanophyceae
Order	Nostocales
Family	Aphanizomenonaceae
	Anabaenopsis arnoldii Aptekar 1926[8,*,**], *Anabaenopsis elenkinii* V.V.Miller 1923[11,*,**], *Anabaenopsis* sp. V.V.Miller 1923[11,*,**],
	Aphanizomenon sp. A.Morren ex É.Bornet & C.Flahault, 1886 '1888'[10,11,*,**], *Dolichospermum spiroides* (Klebhan) Wacklin, L.Hoffmann & Komárek 2009[11,*,**], *Dolichospermum flosaquae* (Brébisson ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J.Komárek 2009[6,7,10,11,*,**], *Sphaerospermopsis aphanizomenoides* (Forti) Zapomelová, Jezberová, Hrouzek, Hisem, Reháková & Komárková 2010[8,*,**]
Family	Chlorogloeopsidaceae
	Chlorogloeopsis fritschii (A.K.Mitra) A.K.Mitra & D.C.Pandey 1967[8,*,**]
Family	Hapalosiphonaceae
	Fischerella sp. (É.Bornet & C.Flahault) M.A.Gomont 1895[6,7,*,**]
Family	Nostocaceae
	Anabaena orientalis S.C.Dixit 1936[8,*,**], *Anabaena oscillarioides* Bory ex Bornet & Flahault 1886[9,*,**], *Anabaena torulosa* Lagerheim ex Bornet & Flahault 1886[1,4,6,10,*], *Anabaena* sp. Bory ex Bornet & Flahault 1886[2,3,5,10,11,*], *Cylindrospermum* sp. Kützing ex É.Bornet & C.Flahault 1886[10,11,*,**], *Nostoc linckia* Bornet ex Bornet & Flahault 1886[8,11,*,**], *Nostoc punctiforme* Hariot 1891[8,*,**], *Nostoc* sp. Vaucher ex Bornet & Flahault 1886[2,3,5,7,11,*], *Trichormus variabilis* (Kützing ex Bornet & Flahault) Komárek & Anagnostidis 1989[9,*,**], *Wollea* sp. É.Bornet & C.Flahault 1886[8,*,**]
Order	Chroococcales
Family	Aphanothecaceae
	Aphanothece sp. C.Nägeli 1849[11,*,**], *Gloeothece rupestris* (Lyngbye) Bornet 1880[8,10,*,**], *Gloeothece* sp. C.Nägeli 1849[11,*,**]
Family	Chroococcaceae
	Chroococcus dispersus (Keissler) Lemmermann 1904[8,11,*,**], *Chroococcus minimus* (Keissler) Lemmermann 1904[8,*,**], *Chroococcus minutus* (Kützing) Nägeli 1849[8,*,**], *Chroococcus turgidus* (Kützing) Nägeli 1849[6,7,9,11,*,**], *Chroococcus* sp. Nägeli 1849[10,11,*,**], *Cyanosarcina spectabilis* (Geitler) Kovácik 1988[8,*,**], *Dactylococcopsis fascicularis* Lemmermann 1898[8,*,**], *Dactylococcopsis raphidioides* Hansgirg 1888[8,*,**],
Family	Cyanobacteriaceae
	Cyanobacterium diachloros (Skuja) Komárek, Kopecky & Cepák 1990[9,*,**]
Family	Gomphosphaeriaceae
	Gomphosphaeria dubium[10,*,**], *Gomphosphaeria* sp.Kützing 1836[10,11,*,**]
Family	Microcystaceae
	Anacystis sp. Meneghini 1837[10,*,**], *Gloeocapsa alpina* Nägeli 1865[11,*,**], *Gloeocapsa coracina* Kützing 1843[8,*,**], *Gloeocapsa livida* (Carmichael) Kützing 1847[8,*,**], *Gloeocapsa* sp. Kützing 1843[5,10,11,*], *Microcystis aeruginosa* (Kützing) Kützing 1846[8,9,11,*,**], *Microcystis wesenbergii* (Komárek) Komárek ex Komárek 2006[9,*,**], *Microcystis flosaquae* (Wittrock) Kirchner 1898[11,*,**], *Microcystis smithii* Komárek & Anagnostidis 1995[8,*,**], *Microcystis* sp. Lemmermann 1907[3,7,10,11,*]
Order	Synechococcales
Family	Coelosphaeriaceae
	Coelosphaerium dubium Grunow 1865[8,*,**], *Snowella* sp. A.A.Elenkin 1938[11,*,**]

(continued)

Table 11.3 (continued)

Family	Leptolyngbyaceae
	Leptolyngbya tenuis (Gomont) Anagnostidis & Komárek 1988[8,10,11,*,**]
Family	Merismopediaceae
	Aphanocapsa grevillei (Berkeley) Rabenhorst 1865[11,*,**], *Aphanocapsa marina* Hansgirg in Foslie 1890[9,*,**], *Aphanocapsa* sp. C.Nägeli 1849[10,11,*,**], *Aphanocapsa rivularis* (Carmichael) Rabenhorst 1865[8,10,*,**], *Merismopedia convoluta* Brébisson ex Kützing 1849[8,*,**], *Merismopedia punctat*a Meyen 1839[8,9,*,**], *Merismopedia elegans* A.Braun ex Kützing 1849[6,7,11,*,**], *Merismopedia warmingiana* (Lagerheim) Forti 1907[9,*,**], *Merismopedia tenuissima* Lemmermann 1898[4], *Merismopedia glauca* (Ehrenberg) Kützing 1845[6,7,8,9,11,*,**], *Merismopedia* sp. F.J.F.Meyen 1839[10,11,*,**], *Synechocystis aquatilis* Sauvageau 1892[4,6,7,*], *Synechocystis pevalekii* Ercegovic 1925[8,*,**], *Synechocystis* sp. C.Sauvageau 1892[11,*,**]
Family	Pseudanabaenaceae
	Jaaginema pseudogeminatum (G.Schmid) Anagnostidis & Komárek 1988[8,*,**], *Pseudanabaena limnetica* (Lemmermann) Komárek 1974[4,7,9,10,*], *Pseudanabaena minima* (G.S.An) Anagnostidis 2001[9,*,**]
Order	Oscillatoriales
Family	Coleofasciculaceae
	Coleofasciculus chthonoplastes (Thuret ex Gomont) M.Siegesmund, J.R.Johansen & T.Friedl 2008[1]
Family	Coleofasciculaceae
	Geitlerinema claricentrosum (N.L.Gardner) Anagnostidis 1989[8,*,**], *Geitlerinema earlei* (N.L.Gardner) Anagnostidis 1989[9,*,**]
Family	Microcoleaceae
	Arthrospira platensis Gomont 1892[6,7,*,**], *Arthrospira gigantea* (Schmidle) Anagnostidis 1998[8,*,**],*Planktothrix prolifica* (Gomont) Anagnostidis & Komárek 1988[8,11,*,**], *Kamptonema chlorinum* (Kützing ex Gomont) Strunecký, Komárek & J. Smarda 2014[8,10,*,**], *Kamptonema proteus* (Skuja) Strunecký, Komárek & J.Smarda 2014[9,*,**], *Kamptonema laetevirens* (H.M.Crouan & P.L.Crouan ex Gomont) Strunecký, Komárek & J.Smarda 2014[1,2,3,5], *Microcoleus paludosus* Gomont 1892[1], *Porphyrosiphon versicolor* (Gomont) Anagnostidis & Komárek 1988[8,10,11,*,**], *Johanseninema constrictum* (Szafer) Hasler, Dvorák & Poulícková 2014[8,*,**], *Trichodesmium erythraeum* Ehrenberg ex Gomont 1892[2,5,10,11,*], *Trichodesmium* sp. Ehrenberg ex Gomont 1892[7,*,**]
Family	Oscillatoriaceae
	Lyngbya aestuarii Liebman ex Gomont 1892[1,2,3,5,6,7,9,*], *Lyngbya confervoides* C. Agardh ex Gomont 1892[1,5], *Lyngbya majuscula* Harvey ex Gomont 1892[8,10,11,*,**], *Lyngbya anomala* (C.B.Rao) Umezaki & Watanabe 1994[8,*,**], *Lyngbya* sp. C.Agardh ex Gomont 1892[3,10,11,*], *Oscillatoria anguina* Bory ex Gomont 1892[8,*,**], *Oscillatoria chilkensis* Biswas 1932[1,3], *Oscillatoria curviceps* C.Agardh ex Gomont 1892[8,10,11,*,**], *Oscillatoria limosa* C.Agardh ex Gomont 1892[9,*,**], *Oscillatoria perornata* Skuja 1949[8,9,10,*,**], *Oscillatoria princeps* Vaucher ex Gomont 1892[6,7,8,9,10,11,*,**], *Oscillatoria sancta* Kützing ex Gomont 1892[9,*,**], *Oscillatoria simplicissima* Gomont 1892[9,*,**], *Oscillatoria tenuis* C.Agardh ex Gomont 1892[11,*,**], *Oscillatoria* sp. Vaucher ex Gomont 1892[3,10,11,*] *Phormidium corium* Gomont ex Gomont 1892[1,7,*], *Phormidium fragile* Gomont 1893[1,5], *Phormidium submembranaceum* Gomont 1892[1,6,7,*], *Phormidium aerugineo-caeruleum* (Gomont) Anagnostidis & Komárek 1988[1], *Phormidium ambiguum* Gomont 1892[9,*,**], *Phormidium* sp. Kützing ex Gomont 1892[2,10,11,*]
Order	Spirulinales
Family	Spirulinaceae

(continued)

Table 11.3 (continued)

	Spirulina labyrinthiformis Gomont 1892[9,*,**], *Spirulina major* Kützing ex Gomont 1892[9,*,**], *Spirulina subsalsa* Oersted ex Gomont 1892[8,*,**], *Spirulina subtilissima* Kützing ex Gomont 1892[6,9,*,**], *Spirulina* sp. Turpin ex Gomont 1892[10,11,*,**]

[1]Biswas (1932), [2]Patnaik (1973), [3]Patnaik and Sarkar (1976), [4]Raman et al. (1990), [5]Adhikary and Sahu (1992), [6]Rath and Adhikary (2008), [7]Panigrahi et al. (2009), [8]Jha et al. (2009), [9]Mohanty and Adhikary (2013), [10]Srichandan et al. (2015a), [11]Srichandan et al. (2015b)
*Inventorized during survey in post-restoration period (2000–2014)
**New records during survey in post-restoration period (reported for the first time from the lagoon)

11.2.4 Chlorophyta

Chlorophyta are green colored phytoplankton with chlorophyll a and b, xanthophylls, and carotenes as the dominant photosynthetic pigments (Dawson 1966). The Chlorophyta prevails in a wide range of environments ranging from freshwater to estuarine and marine conditions. In general, Chlorophyta occur preferably in freshwater upstream regions of estuaries. For example, in upper reaches of Tapi Estuary (India), dominance of chlorophytic phytoplankton communities such as *Ankistrodesmus falcatus*, *Chlorella vulgaris*, *Scenedesmus quadricauda*, *Spirogyra indica*, *Pediastrum* sp. and *Closterium acerosum* have been observed (George et al. 2012). Chlorophyta population was numerically more abundant in the freshwater region of Chilika lagoon (Srichandan et al. 2015b). Literature also suggests that eutrophic conditions further maximize the diversity and density of Chlorophyta population (Saify et al. 1986).

Devasundaram and Roy (1954) and Patnaik (1973) investigated the entire Chilika lagoon and recorded only one species of Chlorophyta are presented by *Spirogyra* sp. A survey conducted between the year 2000 and 2001 on the phytoplankton communities reported 14 species of Chlorophyta (Rath and Adhikary 2008). Further, Panigrahi et al. (2009) documented 10 species of Chlorophyta. Subsequently, a study on Chilika between 2003 and 2006 reported 114 species of Chlorophyta (Jha et al. 2009). Mohanty and Adhikary (2013) studied the algal diversity of Chilika lagoon extensively in different seasons and reported 14 species of Chlorophyta. A study on Chilika between the year 2011 and 2012 recorded 32 species belonging to 25 genera. The freshwater Chlorophyta *Eudorina* sp. were most abundant in the northern sector of the lagoon (Srichandan et al. 2015a). Another study during the year 2012–2014 has documented a total of 54 species of Chlorophyta (Srichandan et al. 2015b). To date, 178 Chlorophyta species have been reported from the Chilika lagoon (Table 11.4). Among the encountered 178 species, 173 species were all new records and inventorized during post-restoration period.

Table 11.4 List of Chlorophyta species from Chilika

Phylum	Chlorophyta
Class	Trebouxiophyceae
Order	Chlorellales
Family	Chlorellaceae
	Actinastrum hantzschii Lagerheim 18825,[10,*,**], *Actinastrum* sp. Lagerheim 1882[9,10,*,**], *Dictyosphaerium* sp. Nägeli 1849[9,10,*,**], *Geminella* sp. Turpin 1828[10,*,**]
Family	Oocystaceae
	Crucigeniella irregularis (Wille) P.M.Tsarenko & D.M.John 2002[10,*,**], *Eremosphaera eremosphaeria* (G.M.Smith) R.L.Smith & Bold 1966[7,*,**], *Eremosphaera viridis* De Bary 1858[7,*,**], *Glochiococcus aciculiferus* (Lagerheim) P. C.Silva 1996[7,*,**], *Oocystis* sp. Nägeli ex A.Braun 1855[10,*,**] *Trochiscia aspera* (Reinsch) Hansgirg 1888[7,*,**], *Trochiscia pachyderma* (Reinsch) Hansgirg[7,*,**], *Trochiscia reticularis* (Reinsch) Hansgirg 1888[7,*,**]
Order	Trebouxiales
Family	Botryococcaceae
	Botryococcus braunii Kützing 1849[7,*,**], *Botryococcus* sp. Kützing, 18499,[10,*,**]
Order	Trebouxiophyceae ordo incertae sedis
Family	Trebouxiophyceae incertae sedis
	Crucigenia sp. Morren 1830[10,*,**]
Class	Chlorophyceae
Order	Chlamydomonadales
Family	Actinochloridaceae
	Actinochloris sp. Korschikov 1953[10,*,**]
Family	Palmellopsidaceae
	Asterococcus superbus (Cienkowski) Scherffel 1908[7,*,**], *Asterococcus* sp. Scherffel 1908[10,*,**]
Family	Palmellopsidaceae
	Chlamydocapsa planctonica (West & G.S.West) Fott 1972[7,9,10,*,**]
Family	Chlamydomonadaceae
	Chlamydomonas microsphaera Pascher & Jahoda 1928[7,*,**], *Chlamydomonas sphagnicola* (F.E.Fritsch) F.E.Fritsch & H.Takeda 1916[7,*,**]
Family	Chlorococcaceae
	Chlorococcum infusionum (Schrank) Meneghini 1842[7,*,**]
Family	Hormotilaceae
	Dendrocystis raoi M.O.P.Iyengar 1962[7,*,**]
Family	Volvocaceae
	Eudorina elegans Ehrenberg 1832[5,6,7,9,10,*,**], *Eudorina* sp. Ehrenberg 1832[9,10,*,**], *Pandorina cylindricum* M.O.P.Iyengar 1981[7,*,**], *Pandorina morum* (O.F.Müller) Bory 1824[7,*,**], *Pandorina* sp. Bory 1824[9,10,*,**], *Pleodorina californica* W.R.Shaw 1894[7,*,**], *Pleodorina indica* (Iyengar) H.Nozaki 1989[7,*,**]
Family	Goniaceae
	Gonium compactum M.O.P.Iyengar in M.O.P.Iyengar & Desikachary 1981[7,*,**], *Gonium pectorale* O.F.Müller 1773[7,*,**], *Gonium* sp. O.F.Müller 1773[10,*,**]

(continued)

Table 11.4 (continued)

Family	Haematococcaceae
	Haematococcus sp. Flotow 1844[10,*,**]
Family	Sphaerocystidaceae
	Sphaerocystis schroeteri Chodat 1897[7,10,*,**], *Sphaerocystis* sp. Chodat 1897[9,*,**]
Family	Tetrabaenaceae
	Tetrabaena socialis (Dujardin) H.Nozaki & M.Itoh 1994[7,*,**]
Family	Treubariaceae
	Treubaria sp. C.Bernard 1908[10,*,**]
Order	Sphaeropleales
Family	Selenastraceae
	Ankistrodesmus falcatus (Corda) Ralfs 1848[7,9,*,**], *Ankistrodesmus falcatus var. radiatus* Lemmermann 1908[7,*,**], *Ankistrodesmus* sp. Corda 1838[9,10,*,**], *Kirchneriella lunaris* (Kirchner) Möbius 1894[7,*,**], *Messastrum gracile* (Reinsch) T.S. Garcia 2016[5,10,*,**], *Selenastrum* sp. Reinsch 1867[9,10,*,**], *Monoraphidium* sp. Komárková-Legnerová 1969[4,6,*]
Family	Scenedesmaceae
	Coelastrum astroideum De Notaris 1867[9,10,*,**], *Coelastrum cambricum* W.Archer 1868[5,*,**], *Coelastrum microporum* Nägeli 1855[10,*,**], *Coelastrum* sp. Nägeli 1849[10,*,**], *Desmodesmus protuberans* (F.E.Fritsch & M.F.Rich) E.Hegewald 2000[8,*,**], *Desmodesmus perforatus* (Lemmermann) E.Hegewald 2000[7,*,**], *Desmodesmus opoliensis* (P.G.Richter) E.Hegewald 2000[10,*,**], *Enallax costatus* (Schmidle) Pascher 1943[10,*,**], *Scenedesmus arcuatus* (Lemmermann) Lemmermann 1899[10,*,**], *Scenedesmus falcatus* Chodat 1926[10,*,**], *Scenedesmus calyptratus* Comas 1980[8,*,**], *Scenedesmus quadricauda* (Turpin) Brébisson 1835[5,6,7,10,*,**], *Scenedesmus obtusus* Meyen 1829[10,*,**], *Scenedesmus* sp. Meyen 1829[9,10,*,**], *Tetradesmus bernardii* (G.M.Smith) M.J.Wynne 2016[10,*,**], *Tetradesmus dimorphus* (Turpin) M.J.Wynne 2016[8,*,**], *Tetradesmus lagerheimii* M.J.Wynne & Guiry 2016[5,6,10,*,**], *Tetradesmus obliquus* (Turpin) M.J.Wynne 2016[7,8,9,10,*,**], *Willea apiculata* (Lemmermann) D.M.John, M.J.Wynne & P.M.Tsarenko 2014[7,*,**], *Willea rectangularis* (A.Braun) D.M.John, M.J.Wynne & P.M.Tsarenko 2014[7,*,**], *Westella botryoides* (West) De Wildeman 1897[7,10,*,**]
Family	Characiaceae
	Fernandinella sp. Chodat 1922[10,*,**]
Family	Microsporaceae
	Microspora stagnorum (Kützing) Lagerheim 1887[7,*,**], *Microspora willeana* Lagerheim 1887[8,*,**]
Family	Hydrodictyaceae
	Monactinus simplex (Meyen) Corda 1839[5,7,10,*,**], *Pediastrum duplex* Meyen 1829[5,6,10,*,**], *Pediastrum duplex var. rotundatum* Lucks 1907[7,*,**], *Pediastrum duplex* var. *subgranulatum* Raciborski 1889[5,*,**], *Pediastrum* sp. Meyen 1829[9,10,*,**], *Stauridium tetras* (Ehrenberg) E.Hegewald 2005[5,6,8,10,*,**], *Pseudopediastrum boryanum* (Turpin) E.Hegewald 2005[10,*,**], *Tetraëdron proteiforme* (W.B.Turner) Brunnthaler 1915[7,*,**], *Tetraëdron lobulatum* (Nägeli) Hansgirg 1888[7,*,**], *Tetraedron gracile* (Reinsch) Hansgirg 1889[5,7,*,**], *Tetraëdron trigonum* (Nägeli) Hansgirg 1888[5,7,10,*,**], *Tetraedron trigonum var. minus* (Reinsch) De Toni[7,*,**], *Tetraëdron* sp. Kützing 1845[9,10,*,**]
Family	Schizochlamydaceae
	Planktosphaeria gelatinosa G.M.Smith 1918[7,*,**], *Schizochlamys gelatinosa* A.Braun 1849[7,*,**]

(continued)

Table 11.4 (continued)

Order	Chaetophorales
Family	Chaetophoraceae
	Draparnaldia sp. Bory 1808[9,*,**]
Order	Oedogoniales
Family	Oedogoniaceae
	Oedogonium nanum Wittrock ex Hirn 1900[7,*,**], *Oedogonium* sp. Link ex Hirn 1900[3,6,9,10,*]
Class	Ulvophyceae
Order	Ulotrichales
Family	Ulotrichaceae
	Ulothrix aequalis Kützing 1845[7,*,**], *Ulothrix rorida* Thuret 1850[9,*,**], *Ulothrix tenerrima* (Kützing) Kützing 1843[7,*,**], *Ulothrix zonata* (F.Weber & Mohr) Kützing 1833[7,*,**], *Ulothrix* sp. Kützing 1833[9,*,**]
Class	Conjugatophyceae (Zygnematophyceae)
Order	Desmidiales
Family	Closteriaceae
	Closterium acerosum var. *elongatum* Brébisson 1856[7,*,**], *Closterium gracile var. tenue* (Lemmermann) West & West 1902[7,*,**], *Closterium acutum* Brébisson 1848[7,*,**], *Closterium lunula* Ehrenberg & Hemprich ex Ralfs 1848[7,9,*,**], *Closterium strigosum* Brébisson 1856[7,*,**], *Closterium macilentum* Brébisson 1856[7,*,**], *Closterium pygmaeum* Gutwinski 1890[7,*,**], *Closterium venus* Kützing ex Ralfs 1848[8,*,**] *Closterium* sp. Nitzsch ex Ralfs 1848[4,6,9,10,*]
Family	Desmidiaceae
	Cosmarium awadhense B.N.Prasad & R.K.Mehrotra 1977[8,*,**], *Cosmarium calcareum* Wittrock 1872[7,*,**], *Cosmarium costatum* Nordstedt 1875[7,*,**], *Cosmarium crenatum* Ralfs ex Ralfs 1848[7,*,**], *Cosmarium decoratum* West & G.S.West 1895[8,*,**], *Cosmarium geminatum* P.Lundell 1871[7,*,**], *Cosmarium impressulum* Elfving 1881[5,*,**], *Cosmarium indentatum* Grönblad 1920[7,*,**], *Cosmarium lundellii* Delponte 1877[8,*,**], *Cosmarium miscellum* Skuja 1964[8,*,**], *Cosmarium moniliforme* Ralfs 1848[7,*,**], *Cosmarium novae-semliae* Wille 1879[7,*,**], *Cosmarium pachydermum* var. *aethiopicum* (West & G.S.West) West & G.S.West 1905[7,*,**], *Cosmarium papilliferum* Schmidle[7,*,**], *Cosmarium pachydermum* var. *incrassatum* Scott & Grönblad 1957[7,*,**], *Cosmarium pachydermum* P.Lundell 1871[7,9,*,**], *Cosmarium phaseolus* Brébisson ex Ralfs 1848[7,*,**], *Cosmarium punctulatum* Brébisson 1856[8,*,**], *Cosmarium subspeciosum* Nordstedt 1875[7,*,**], *Cosmarium quadrifarium* f. *hexastichum* (P.Lundell) Nordstedt 1889[7,*,**], *Cosmarium quadrifarium* P.Lundell 1871[7,*,**], *Cosmarium ungerianum* (Nägeli) De Bary 1858[7,*,**], *Cosmarium* sp. Corda ex Ralfs 1848[4,9,10,*], *Desmidium swartzii* C.Agardh ex Ralfs 1848[7,*,**], *Euastrum dubium* Nägeli 1849[8,*,**], *Euastrum oblongum* Ralfs 1848[7,*,**], *Euastrum* sp. Ehrenberg ex Ralfs 1848[10,*,**], *Desmidium* sp. C.Agardh ex Ralfs 1848[6,9,*,**], *Micrasterias papillifera* Brébisson ex Ralfs 1848[7,*,**], *Micrasterias* sp. C.Agardh ex Ralfs 1848[9,10,*,**], *Spinocosmarium quadridens* (H.C.Wood) Prescott & A.M.Scott 1942[7,*,**], *Spondylosium* sp. Brébisson ex Kützing 1849[9,10,*,**], *Staurastrum alchora* West & West[7,*,**], *Staurastrum anatinum* Cooke & Wills 1881[7,9,*,**], *Staurastrum bicornatum* Johnson[7,*,**], *Staurastrum bieneanum* Rabenhorst 1862[7,*,**], *Staurastrum boreale* West & G.S.West 1905[7,*,**], *Staurastrum brevispinum var. inerme* Wille[7,*,**], *Staurastrum cingulum* (West & G.S.West) G.M.Smith 1922[7,*,**], *Staurastrum crenulatum* (Nägeli) Delponte 1877[7,*,**], *Staurastrum curviceps* Scott. & Groenblad[7,*,**], *Staurastrum cyclacanthem* West & West[7,*,**], *Staurastrum dilatatum* Ehrenberg ex Ralfs 1848[7,*,**], Staurastrum dilatatum var. productum Scott & Groenblad[7,*,**], *Staurastrum elongated forma* chilikensis[7,*,**], *Staurastrum floriferum* West & G.S.West 1896[7,*,**], *Staurastrum manfeldtii var. pseudosebaldi* (Wille) Coesel

(continued)

Table 11.4 (continued)

	& Meesters 2013[7,*,**], *Staurastrum leptacanthum* Nordstedt 1869[7,*,**], *Staurastrum margaritaceum* Meneghini ex Ralfs 1848[7,*,**], *Staurastrum quadrangular* (Breb.) Ralfs[7,*,**], *Staurastrum ophiura* var. *horridum* A.M.Scott[7,*,**], *Staurastrum polymorphum* Brébisson 1848[7,*,**], *Staurastrum setigerum* Cleve 1864[7,*,**], *Staurastrum proboscideum* (Brébisson) W.Archer 1861[7,*,**], *Staurastrum pseudosebaldi var. compactum* A.M.Scott & Grönblad 1957[7,*,**], *Staurastrum pseudosuecicum* Prescott & A.M.Scott[7,*,**], *Staurastrum punctulatum* Brébisson 1848[7,*,**], *Staurastrum turgescens* De Notaris 1867[7,*,**], *Staurastrum sexcostatum* Brébisson ex Ralfs 1848[7,*,**], *Staurastrum* sp. Meyen ex Ralfs 1848[7,9,10,*,**], *Staurodesmus lobatus* (Børgesen) Bourrelly 1966[7,*,**], *Staurodesmus convergens* (Ehrenberg ex Ralfs) S.Lillieroth 1950[7,*,**], *Staurodesmus* sp. Teiling 1948[7,9,*,**] *Xanthidium armatum* Brébisson ex Ralfs 1848[7,*,**], *Xanthidium pseudobengalicum* R. L.Grönblad[7,*,**], *Xanthidium* sp. Ehrenberg ex Ralfs 1848[7,*,**]
Family	Gonatozygaceae
	Genicularia kinhani (Archer) Rabenhorst[7,*,**], *Genicularia spirotaenia* (De Bary) De Bary 1858[7,*,**], *Genicularia* sp. De Bary 1858[9,*,**]
Order	Zygnematales
Family	Zygnemataceae
	Mougeotia sp. C.Agardh 1824[9,10,*,**], *Spirogyra hyalina* Cleve 1868[7,*,**], *Spirogyra puncticulata* C.C.Jao 1934[7,*,**], *Spirogyra subsalsa* Kützing 1845[7,*,**], *Spirogyra* sp. Link 1820[1,2,3,4,5,6,7,8,9,10,*] *Zygnema* sp. C.Agardh 1817[10,*,**], *Tamnogametum mayyanadense* Erady & Rajappan 1959[7,*,**]
Class	Coleochaetophyceae
Order	Coleochaetales
Family	Coleochaetaceae
	Coleochaete orbicularis Pringsheim 1860[7,*,**]

[1]Devasundaram and Roy (1954), [2]Patnaik (1973), [3]Patnaik and Sarkar (1976), [4]Raman et al. (1990), [5]Rath and Adhikary (2008), [6]Panigrahi et al. (2009), [7]Jha et al. (2009), [8]Mohanty and Adhikary (2013), [9]Srichandan et al. (2015a), [10]Srichandan et al. (2015b)
*Inventorized during survey in post-restoration period (2000–2014)
**New records during survey in post-restoration period (reported for the first time from the lagoon)

11.2.5 *Euglenophyta*

The Euglenophyta is a group of unicellular flagellates found in freshwater and marine environments. The class is distinguished by solitary unicells (only one colonial genus exists) with two anteriorly inserted flagella of which one is emergent, condensed chromosomes throughout the cell cycle, a paraxial rod associated with one or both flagella, a proteinaceous pellicle composed of individual strips each of which is lined by microtubules, and a beta-1, 3 glucan storage product known as paramylum. The diversity of Euglenophyceae members in aquatic environment can be attributed to high nutrient loading from various point and non-point sources indicating organic pollution in a water body (Kumar and Hosmani 2006; Laskar and Gupta 2009). In general, Euglenophyta are known to be dominant in freshwater regimes (preferably in upper reaches) of estuarine ecosystems in comparison to middle and lower reaches. For example, members of euglenophytic phytoplankton were observed to be dominated in upper reaches of Tapi estuary (India) (George et al. 2012). Similarly, a higher abundance of Euglenophyta has been observed in the freshwater zone i.e. northern sector of the Chilika lagoon (Srichandan et al. 2015a).

In Chilika lagoon, Euglenophyta was recorded for the first time by Jha et al. (2009) and documented 53 Euglenophyta species. Subsequently, a study on Euglenophyta diversity was carried out by Mohanty and Adhikary (2013) during 2010–2011.They encountered six species (*Lepocinclis acus*, *Euglena agilis*, *Euglenaria caudata*, *Lepocinclis playfairiana*, *Trachelomonas abrupta*, and *Trachelomonas hispida*) and found that their occurrence in northern and central sectors have attributed to increased eutrophication associated with anthropogenic discharge by human habitation around Chilika lagoon. Subsequently, Srichandan et al. (2015a) investigated phytoplankton community structure including Euglenophyta from the entire Chilika lagoon and added 4 more species to the existing Euglenophyta species list. This study has also revealed that Euglenophyta formed the most dominant group in the northern sector (freshwater zone) of the lagoon. The author has opined that this group occurs preferably in the nutrient-rich freshwater zone and serves as bio-indicator of organic pollution. Recently, a survey conducted between 2012 and 2014 have added 30 more species to the list (Srichandan et al. 2015b). Thus, the total number of Euglenophyta has increased to 92 species which were all inventorized new records during the post-restoration period (Table 11.5). It was also noticed that tropical cyclone *Phailin* which struck the lagoon on 12th October 2013 profoundly affected the Euglenophyta community composition in Chilika lagoon. After *Phailin*, the recovery of freshwater euglenophytes (e.g., *Strombomonas acuminata*, *Trachelomonas* sp.) was observed for the first time from the southern sector of the lagoon. In addition, the freshwater euglenophytes such as *Phacus circumflexus*, *Strombomonas acuminata*, *Trachelomonas granulata*, *Trachelomonas lefevrei*, *Trachelomonas manginii*, and *Lepocinclis acus* were recorded for the first time from the outer channel.

11.2.6 Chrysophyta

Chrysophyta (Golden-brown algae) are a group of marine pigmented heterokonts (Daugbjerg and Henriksen 2001) with a cosmopolitan distribution. They can be a major component in coastal and estuarine waters (e.g. Jochem and Babenerd 1989; Gómez and Gorsky 2003). They are generally autotrophs (Rigual-Hernández et al. 2010) while as opined out by Martini (1977) they have mixotrophic behavior. Further, Chrysophyta have been used as indicators of productivity (Takahashi et al. 2009), atmospheric and water mass variations (Onodera and Takahashi 2005). Chrysophyta are strongly influenced by environmental parameters, particularly by temperature and salinity (Henriksen et al. 1993). In Chilika lagoon, Chrysophyta were more numerous in brackish water salinity regime (Srichandan et al. 2015b).

In Chilika lagoon, only five taxa of Chrysophyta have been reported for the first time by Srichandan et al. (Srichandan et al. 2015a, b) and among them, three taxa

Table 11.5 List of Euglenophyta species from Chilika

Phylum	Euglenophyta (=Phylum Euglenozoa)
Class	Euglenophyceae
Order	Eutreptiales
Family	Astasiaceae
	Astasia klebsii Lemmermann 1910[1,3,4,*,**]
Order	Euglenophyceae incertae sedis
Family	Colaciaceae
	Colacium sp. Ehrenberg, 1834[4,*,**]
Order	Euglenales
Family	Euglenaceae
	Euglena acus var. *rigida* E.Hübner, 1886[1,*,**], *Euglena agilis* H.J.Carter 1856[2,*,**], *Euglena cantabrica* E.G.Pringsheim 1956[4,*,**], *Euglena chlamydomonas*[4,*,**], *Euglena deses* Ehrenberg 1834[4,*,**], *Euglena elastica* Prescott 1944[1,3,4,*,**],*Euglena schmitzii* Gojdics 1953[1,3,4,*,**], *Euglena elongata* W.Schewiakoff 1892[4,*,**], *Euglena gaumei* Allorge & Lefèvre 1931[1,*,**], *Euglena geniculata* F.Schmitz 1884[4,*,**], *Euglena granulata* (G.A.Klebs) F.Schmitz 18841[4,*,**], *Euglena repulsans* J.Schiller 1952[4,*,**], *Euglena sanguinea* Ehrenberg 1832[1,3,4,*,**], *Euglena sociabilis* P.A. Dangeard, 1902[3,4,*,**], *Euglena texta* (Dujardin) Hübner 1886[4,*,**], *Euglena van-goori* Deflandre 1928[1,*,**], *Euglena variabilis* G.A.Klebs 1883[1,3,4,*,**], *Euglena viridis* (O.F. Müller) Ehrenberg 1830[1,4,*,**], *Euglena wangii* S.P.Chu 1946[1,3,4,*,**], *Euglena* sp. Ehrenberg 1830[3,4,*,**], *Euglenaformis proxima* (Dangeard) M.S.Bennett & Triemer 2014[1,*,**], *Euglenaria anabaena* (Mainx) Karnkowska & E.W.Linton 2010[1,*,**], *Euglenaria clavata* (Skuja) Karnkowska & E.W.Linton 2010[1,4,*,**], *Euglenaria caudata* (E.F.W.Hubner) A.Karnowska-Ishikawa, E.Linton & J.Kwiatowski 2010[2,4,*,**], *Euglenopsis vorax* G.A.Klebs 1892[1,3,4,*,**], *Monomorphina nordstedtii* (Lemmermann) T.G.Popova 1955[1,*,**], *Monomorphina pyrum* (Ehrenberg) Mereschkowsky 1877[4,*,**], *Strombomonas acuminata* (Schmarda) Deflandre 1930[4,*,**], *Strombomonas eurystoma* (F.Stein) T.G.Popova 1966[4,*,**], *Strombomonas giardiana* (Playfair) Deflandre 1930[1,4,*,**], S*trombomonas tambowika* (Svirenko) Deflandre 1930[4,*,**], *Strombomonas* sp. Deflandre 1930[4,*,**], *Trachelomonas abrupta* Svirenko [Swirenko] 1914[2,*,**], *Trachelomonas bulla* F.Stein 1878[1,4,*,**], *Trachelomonas armata* (Ehrenberg) F.Stein 1878[4,*,**], *Trachelomonas crebae var. brevicollaris* prescott[1,*,**], *Trachelomonas cylindrica* Ehrenberg 1834[4,*,**], *Trachelomonas granulata* Svirenko 1914[4,*,**], *Trachelomonas hispida* (Perty) F.Stein 1878[2,3,4,*,**], *Trachelomonas hispida* var. *crenulatocollis* (Maskell) Lemmermann 1910[1,*,**], *Trachelomonas lefevrei*[4,*,**], *Trachelomonas manginii* Deflandre 1926[4,*,**], *Trachelomonas oblonga* Lemmermann 1899[4,*,**], *Trachelomonas planctonica* Svirenko 1914[4,*,**], *Trachelomonas similis* A.C.Stokes 1890[4,*,**], *Trachelomonas* sp. Ehrenberg 1835[3,4,*,**]
Family	Phacaceae
	Lepocinclis acus (O.F.Müller) B. Marin & Melkonian, 2003[1,2,3,4,*,**], *Lepocinclis acuta* Prescott 1938[1,3,4,*,**], *Lepocinclis caudata* (A.M. da Cunha) Pascher 1927[4,*,**], *Lepocinclis fusiformis* (H.J.Carter) Lemmermann 1901[1,4,*,**], *Lepocinclis fusiformis* var. *major* F.E.Fritsch & Rich 1930[1,*,**], *Lepocinclis ovum* (Ehrenberg) Lemmermann 1901[4,*,**], *Lepocinclis oxyuris* (Schmarda) B.Marin & Melkonian 2003[1,3,4,*,**], *Lepocinclis oxyuris var. minor* (Skvortzov) D.A.Kapustin 2011[1,*,**], *Lepocinclis playfairiana* (Deflandre) Deflandre 1932[1,2,3,4,*,**], *Lepocinclis repulsans*[4,*,**], *Lepocinclis sphagnophila* Lemmermann 1904[1,4,*,**], *Lepocinclis spirogyroides* B. Marin & Melkonian 2003[1,*,**], *Lepocinclis steinii* Lemmermann 1901[4,*,**],

(continued)

Table 11.5 (continued)

	Lepocinclis teres (F.Schmitz) Francé 1897[4,*,**], *Lepocinclis tripteris* (Dujardin) B. Marin & Melkonian 2003[1,*,**], *Lepocinclis* sp. Perty 1849[4,*,**], *Phacus anacoelus* A. C.Stokes 1885[1,*,**], *Phacus anacoelus* var. *undulata* Skvotzov 1928[1,*,**], *Phacus ankylonoton* Pochmann 1942[1,*,**], *Phacus bergi* Prescott 1944[1,4,*,**], *Phacus caudatus* Hübner 1886[1,4,*,**], *Phacus chloroplastes var. incisa* Prescott[1,*,**], *Phacus chloroplastes* Prescott 1944[1,*,**], *Phacus circumflexus* Pochmann 1942[4,*,**], *Phacus curvicauda* Svirenko 1915[1,*,**], *Phacus helikoides* Pochmann 1942[1,*,**], *Phacus lemmermannii* Svirenko 1915[1,*,**], *Phacus longicauda* (Ehrenberg) Dujardin 1841[1,3,4,*,**], *Phacus limnophilus* (Lemmermann) E.W.Linton & A.Karnkowska-Ishikawa, 2010[4,*,**], *Phacus monilatus* (Stokes) Lemmerman 1901[4,*,**], *Phacus orbicularis var. caudatus* Skvortzow[1,*,**], *Phacus orbicularis* K.Hübner 1886[1,3,4,*,**], *Phacus raciborskii* Drezepolski 1925[1,*,**], *Phacus pleuronectes* (O.F.Müller) Nitzsch ex Dujardin 1841[1,*,**], *Phacus pseudoswirewkoi* Prescott 1944[1,*,**], *Phacus segretii var. ovatum* Prescott[1,*,**], *Phacus segretii* Allorge & Lefèvre 1925[1,*,**], *Phacus spiralis* Allegre & T.L. Jahn 1943[4,*,**], *Phacus spirogyra var. maxima* Prescott[1,*,**], *Phacus suecicus* Lemmermann 1910[1,*,**], *Phacus swirenkoi* Skvortzov 1928[1,4,*,**], *Phacus tortus* (Lemmermann) Skvortzov 1928[1,*,**], *Phacus triqueter* (Ehrenberg) Perty 1852[1,*,**], *Phacus* sp. Dujardin 1841[3,4,*,**]

[1]Jha et al. (2009), [2]Mohanty and Adhikary (2013), [3]Srichandan et al. (2015a), [4]Srichandan et al. (2015b)
*Inventorized during survey in post-restoration period (2000–2014)
**New records during survey in post-restoration period (reported for the first time from the lagoon)

Table 11.6 List of Chrysophyta species from Chilika

Phylum	Ochrophyta
Class	Dictyochophyceae
Order	Dictyochales
Family	Dictyochaceae
	Dictyocha fibula Ehrenberg 1839[1,*,**], *Dictyocha* sp. Ehrenberg 1837[1,2,*,**], *Octactis octonaria* (Ehrenberg) Hovasse 1946[2,*,**]
Class	Chrysophyceae
Order	Chromulinales
Family	Dinobryaceae
	Dinobryon sertularia Ehrenberg 1834[1,*,**]
Family	Chromulinaceae
	Uroglena sp. Ehrenberg 1834[1,*,**]

[1]Srichandan et al. (2015a), [2]Srichandan et al. (2015b)
*Inventorized during survey in post-restoration period (2000–2014)
**New records during survey in post-restoration period (reported for the first time from the lagoon)

(*Dictyocha fibula*, *Dictyocha* sp., and *Octactis octonaria*) were representative of marine water environment (Table 11.6). However, this particular group of phytoplankton is largely understudied with respect to diversity and distribution in Chilika lagoon and possible application in long-term lagoonal environmental monitoring. The present work suggests more comprehensive study on the Chrysophyta taxa in Chilika lagoon in future.

Table 11.7 List of Xanthophyta species from Chilika

Phylum	Xanthophyta (=Ochrophyta)
Class	Xanthophyceae
Order	Mischococcales
Family	Gloeobotrydaceae
	Gloeobotrys limneticus (G.M.Smith) Pascher 1938[2,*,**]
Order	Tribonematales
Family	Tribonemataceae
	Tribonema bombycinum (C.Agardh) Derbès & Solier in Castagne 1851[1,2,*]
Order	Mischococcales
Family	Ophiocytiaceae
	Ophiocytium variable Bohl.[2,*,**]

[1]Adhikary and Sahu (1992), [2]Jha et al. (2009)
*Inventorized during survey in post-restoration period (2000–2014)
**New records during survey in post-restoration period (reported for the first time from the lagoon)

11.2.7 Xanthophyta

Xanthophyta are generally known as yellow green algae. These are non-motile, unicellular or colonial eukaryotic algae exhibits unique pigmentation which gives a yellow or fresh green appearance. This group of photosynthetic algae primarily occurs in freshwater, although a substantially found in marine environments. Literature suggests that mostly yellow green algae incline to be ecologically limited to small water bodies (Sahoo and Kumar 2015). This class characteristically possesses chlorophyll-a, β carotene and xanthophylls. The diversity of Xanthophyta in aquatic environment is large, but their biology, ecology, and biogeography are known for only a few of the more common taxa.

In Chilika lagoon, only three taxa (*Gloeobotrys limneticus*, *Tribonema bombycinum*, and *Ophiocytium variable*) of Xanthophyta have been reported (Adhikary and Sahu 1992; Jha et al. 2009) (Table 11.7). These species have been observed in freshwater zone i.e. northern sector and brackish water zone i.e. central sector. However, Xanthophyta is mostly understudied in Chilika lagoon. Further to clarify these data gaps and uncertainties, careful efforts, longer monthly studies, and the use of modern taxonomic keys are need to be implemented in phytoplankton monitoring programs. All the three species reported from Chilika were inventorized during post-restoration period.

11.3 Spatio-Temporal Distribution of Phytoplankton

Seasonal and spatial variability in phytoplankton communities of Chilika lagoon has been broadly described by Srichandan et al. (2015a, b) over an annual and inter-annual scale (Table 11.8). The survey conducted between 2011 and 2012, reported

Table 11.8 Spatio-temporal variations in some dominant species of phytoplankton recorded from Chilika lagoon

Season/ sector	Phytoplankton taxa 2011–2012 (Srichandan et al. 2015a)	2012–2013 (Srichandan et al. 2015b)	2013–2014 (Srichandan et al. 2015b)
Southern sector			
Monsoon	*Dictyocha* sp., *Thalassiothrix longissima*, *Gymnodinium* sp.	*Prorocentrum micans*, *Prorocentrum cordatum*, *Diploneis weissflogii*	*Diploneis* sp., *Alexandrium* sp., *Dictyocha* sp.
Post-monsoon	*Pleurosigma normanii*, *Pleurosigma* sp., *Gymnodinium* sp.	*Dictyocha* sp., *Diploneis weissflogii*, *Ceratium fusus*	*Gonyaulax* sp., *Alexandrium* sp., *Prorocentrum cordatum*
Pre-monsoon	*Dictyocha* sp., *Synedra* sp., *Synedra ulna*	*Dictyocha* sp., *Synedra* sp., *Pleurosigma* sp.	*Gloeocapsa alpina*, *Gonyaulax* sp., *Alexandrium* sp.
Central sector			
Monsoon	*Pleurosigma normanii*, *Dictyocha* sp., *Protoperidinium* sp.	*Prorocentrum micans*, *Protoperidinium oceanicum*, *Protoperidinium* sp.	*Cylindrospermum* sp., *Phormidium* sp., *Dictyocha* sp.
Post-monsoon	Anabaena sp., *Pleurosigma* sp., *Pleurosigma normanii*	*Dictyocha* sp., *Anabaena* sp., *Cocconeis placentula*	*Phormidium* sp., *Anabaena* sp., *Diploneis* sp.
Pre-monsoon	*Prorocentrum cordatum*, Synedra sp., *Diploneis elliptica*	*Synedra* sp., *Navicula* sp., *Nitzschia* sp.	*Phormidium* sp., *Alexandrium* sp., *Gonyaulax* sp.
Northern sector			
Monsoon	*Anabaena* sp., *Eudorina* sp., *Mougeotia* sp.	*Euglena* sp., *Actinastrum* sp., *Trachelomonas* sp.	*Trachelomonas* sp., *Phormidium* sp., *Anabaena* sp.
Post-monsoon	*Trachelomonas* sp., *Oscillatoria* sp., *Aphanocapsa* sp.	*Anabaena* sp., *Trachelomonas* sp., *Trachelomonas lefevrei*	*Cylindrospermum* sp., *Anabaena* sp., *Strombomonas tambowika*
Pre-monsoon	*Cylindrospermum* sp., *Aphanocapsa* sp., *Anabaena flos-aquae*	*Cylindrospermum* sp., *Anabaena* sp., *Trachelomonas* sp.	*Cylindrospermum* sp., *Gomphosphaeria* sp., *Anabaena* sp.
Outer Channel			
Monsoon	*Nitzschia* sp., Pleurosigma sp., *Aphanizomenon* sp.	*Thalassionema nitzschioides*, *Navicula transitrans*, *Pleurosigma normanii*	*Phormidium* sp., *Cylindrospermum* sp., *Alexandrium* sp.
Post-monsoon	*Chaetoceros* sp., *Surirella* sp., *Pleurosigma normanii*	*Surirella* sp., *Thalassiosira* sp., *Coscinodiscus* sp.	*Gyrosigma fasciola*, *Amphiprora* sp., *Spirogyra* sp.
Pre-monsoon	*Thalassiosira subtili*, *Pseudonitzschia pungens*, *Pleurosigma* sp.	*Nitzschia* sp., *Surirella* sp., *Amphora* sp.	*Pseudonitzschia* sp., *Alexandrium* sp., *Cyclotella* sp.

that Bacillariophyta such as *Nitzschia* sp., *Chaetoceros* sp., and *Thalassiosira subtilis* were ubiquitous during monsoon, post-monsoon and pre-monsoon, respectively in outer channel of the lagoon (Srichandan et al. 2015a). In contrast, Chrysophyta (*Dictyocha* sp.) dominated the phytoplankton communities during monsoon and pre-monsoon in southern sector. However, Bacillariophyta (*Pleurosigma normanii*) was predominant during post-monsoon. High abundance of freshwater Cyanophyta (*Anabaena* sp., *Cylindrospermum* sp.) and Euglenophyta (*Trachelomonas* sp.) was recorded in the northern sector of the lagoon. Central sector was dominated by species of Bacillariophyta (*Pleurosigma normanii*), Cyanophyta (*Anabaena* sp.) and Dinophyta (*Prorocentrum cordatum*) during monsoon, post-monsoon, and pre-monsoon seasons, respectively.

Subsequently, the survey conducted between 2012 and 2013 have shown that the phytoplankton communities in the central sector of the lagoon were dominated by *Prorocentrum micans*, *Dictyocha* sp. and *Synedra* sp. during monsoon, post-monsoon and pre-monsoon, respectively (Srichandan et al. 2015b). In the northern sector, the species such as *Euglena* sp., *Trachelomonas* sp. and *Actinastrum* sp. thrived well during monsoon period while *Anabaena* sp. and *Trachelomonas* sp. dominated during post-monsoon and pre-monsoon seasons. In the southern sector, *Prorocentrum micans* was predominant during monsoon while *Dictyocha* sp. during both post-monsoon and pre-monsoon seasons. However, phytoplankton flora of outer channel was mainly represented by *Thalassionema nitzschioides* in monsoon, *Surirella* sp. in post-monsoon and *Nitzschia* sp. in pre-monsoon.

Another survey undertaken during the period 2013–2014 have shown that in the central sector, freshwater Cyanophyta, i.e. *Phormidium* sp. was mostly represented in post-monsoon and pre-monsoon period while *Cylindrospermum* sp. was largely represented during monsoon (Srichandan et al. 2015b). In the northern sector, *Cylindrospermum* sp. was the significant species during post-monsoon and pre-monsoon period while *Trachelomonas* sp. was more abundant during monsoon season. In outer channel, the most abundant species encountered during monsoon, post-monsoon and pre-monsoon were *Phormidium* sp., *Gyrosigma fasciola*, and *Pseudonitzschia* sp. respectively. In southern sector, epipelic Bacillariophyta (*Diploneis* sp.) dominated during monsoon period where as toxic Dinophyta (*Gonyaulax* sp.) and Cyanophyta (*Gloeocapsa alpina*) dominated during post-monsoon and pre-monsoon season, respectively.

In addition to the general spatio-temporal trends with respect to physico-chemical forcing the phytoplankton community of the lagoon well responded to the extreme climatic events such as tropical cyclone *Phailin* (Srichandan et al. 2015b). An increase in freshwater Cyanophyta *Cylindrospermum* sp., have been observed in central sector and outer channel of Chilika lagoon during post-*Phailin* period. Further, it was also suggested that the enhanced growth of *Cylindrospermum* sp. was attributed to the sediment-resuspension along with physical upward movement. Tropical cyclone *Phailin* had a significant impact on the phytoplankton community composition of southern sector of the lagoon. Toxic dinophytes (e.g. *Alexandrium* sp., *Gonyaulax* sp., *Prorocentrum cordatum*) have been observed in considerably higher number during post-*Phailin* period.

11.4 Phytoplankton Population Density

Typically, in an estuarine ecosystem, phytoplankton abundance is highest during dry season (pre-monsoon) while lowest abundance is recorded during wet (monsoon) season (Perumal et al. 2009; Prabhahar et al. 2011). The pre-monsoon season is usually characterized with increase in salinity, enhanced temperature, sufficient solar irradiance and stable environmental conditions (Saravanakumar et al. 2008). In contrast, heavy rainfall, cloudy sky, river/terrestrial run-off, induced high turbidity limit the light availability in water column and reduce salinity causes reduction in phytoplankton density during monsoon (Perumal et al. 2009). Although in Chilika lagoon several studies deciphered the time scale phytoplankton community structure. However, a well marked spatial and temporal variations in phytoplankton population density has been reported by Srichandan et al. (2015a, b) (Fig. 11.2). In Chilika lagoon, overwhelming dominance of a benthic Bacillariophyta i.e. *Pleurosigma normanii* was observed during monsoon season (Srichandan et al. 2015a). It was suggested that disturbance of benthic habitat by wind and water current was the main factor for the occurrence of large number of this benthic pennate phytoplankton in the surface water. Other factors could be use of mechanized boat for fishing and dredging operations which also cause re-suspension of bottom sediments in water column.

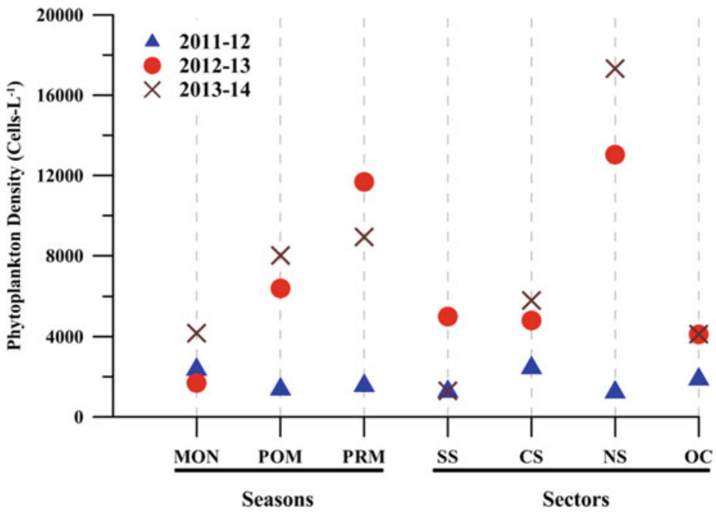

Fig. 11.2 Phytoplankton population density at spatio-temporal scale. *NS* Northern Sector, *CS* Central Sector, *SS* Southern Sector, *OC* Outer Channel, *MON* monsoon, *POM* post-monsoon, *PRM* pre-monsoon

11.5 Spatial and Seasonal Variation in Phytoplankton Abundance

Srichandan et al. (Srichandan et al. 2015a, b) have reported a clear spatial variation in phytoplankton density with respect to four ecological sectors of the Chilika lagoon (Fig. 11.3). Euglenophyta dominated the phytoplankton communities at lower salinity zone (i.e. northern sector), while Bacillariophyta were ubiquitous throughout the higher salinity zones (i.e., southern, central and outer channel) (Srichandan et al. 2015a). When tropical cyclone *Phialin* hit the lagoon in October 2013, it caused a drastic reduction in salinity (avg. 1.9 ppt) resulting proliferation of Cyanophyta in central sector besides northern sector (Srichandan et al. 2015b).

A marked temporal variation in phytoplankton density with respect to seasons has also been described by Srichandan et al. (Srichandan et al. 2015a, b) (Fig. 11.4). Seasonal changes in freshwater influx during monsoon appeared to be a controlling factor in determining the phytoplankton species composition and their abundances. The survey conducted between year 2011 and 2012 have shown that Bacillariophyta were the most dominant group in the lagoon irrespective of the season albeit with

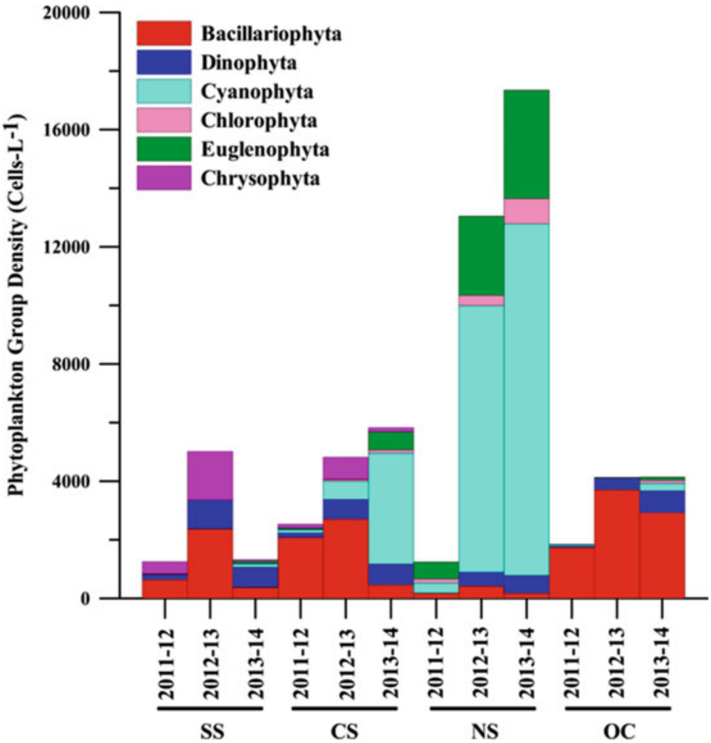

Fig. 11.3 Phytoplankton community composition of Chilika lagoon at spatial scale. *SS* Southern Sector, *CS* Central Sector, *NS* Northern Sector, *OC* Outer Channel

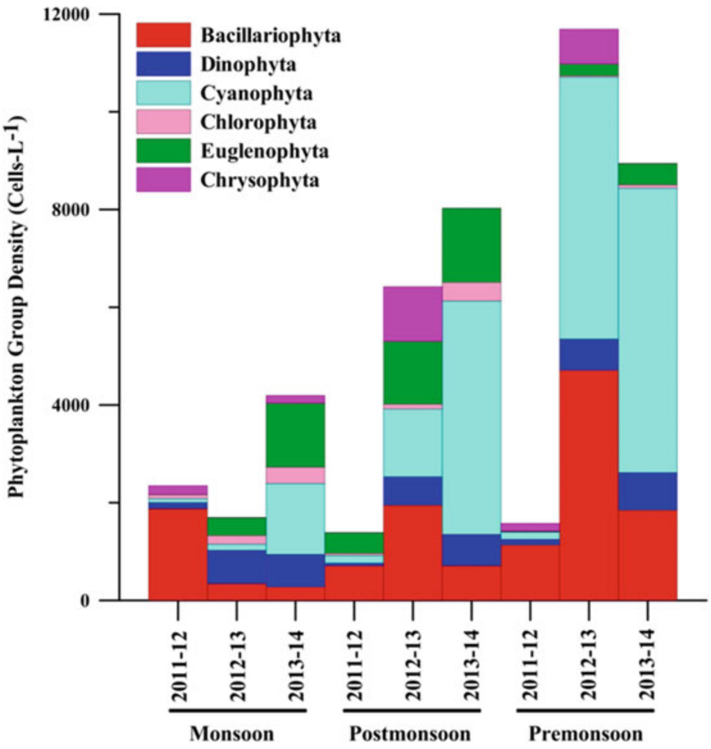

Fig. 11.4 Phytoplankton community composition of Chilika lagoon at temporal scale

varying cell densities (Srichandan et al. 2015a). Bacillariophyta were more abundant in monsoon season with mean cell density of 1879 cells L^{-1}, which subsequently decreased to 710 cells L^{-1} in post-monsoon season and further increased to 1134 cells L^{-1} in pre-monsoon season.

11.6 Phytoplankton and Environmental Variables

Phytoplankton communities in a lagoon are largely determined by a series of environmental parameters such as temperature, light, pH, salinity, dissolved oxygen, wind force, and tidal rhythm. In many estuaries, salinity has been considered as a key environmental variable for controlling the distribution and phytoplankton community composition. For example, in Schelde estuary in Belgium and Netherlands (Lionard et al. 2005), Suwannee River estuary in Florida (Quinlan and Phlips 2007), Bach Dang estuary in Vietnam (Rochelle-Newall et al. 2011), Pearl River Estuary in South China (Zhang et al. 2014) and Passos River estuary in Northeast Brazil (Aquino et al. 2015) salinity determined the spatial and temporal distribution of phytoplankton. In Chilika lagoon, salinity played a crucial role by governing the abundance and distribution of phytoplankton (Patnaik 1973; Patnaik and Sarkar 1976; Panigrahi et al. 2009; Srichandan et al. 2015a, b). Patnaik (1973) have determined that appearance and disappearance of freshwater, brackishwater and marine forms of phytoplankton mostly depended on the salinity conditions of the lagoon. Further, Raman et al. (1990) and Srichandan et al. (2015a) have determined that salinity was the predominant factor in controlling the distribution of phytoplankton in the Chilika lagoon. For instance, Srichandan et al. (2015a) have observed Dinophyta and Chrysophyta as the dominant phytoplankton groups in southern sector due to stable salinity regime. In outer channel, marine phytoplankton forms were prevalent due to higher salinity regime because of direct connectivity to the Bay of Bengal. Due to high freshwater discharge from rivers, northern sector was mostly represented by freshwater phytoplankton forms. Further, due to inter-mixing of freshwater and seawater, central sector was represented by both freshwater and marine phytoplankton taxa.

Depending upon the salinity preference and according to the biotic categories in the ecological classification, the phytoplankton communities have been classified into 3 different groups; oligohaline (0–5 ppt), mesohaline (5–18 ppt), and polyhaline (>18 ppt) (Marshall 1993). The dominant phytoplankton species *Amphiprora* sp., *Amphora* sp., *Cocconeis placentula*, *Coscinodiscus* sp., *Cyclotella* sp., *Diploneis* sp., *Diploneis weissflogii*, *Navicula transitans*, *Navicula* sp., *Nitzschia* sp., *Pleurosigma normanii*, *Pleurosigma* sp., *Surirella* sp., *Synedra* sp., *Alexandrium* sp., *Gonyaulax* sp., *Prorocentrum micans*, *Prorocentrum cordatum*, *Protoperidinium* sp., *Anabaena* sp., *Cylindrospermum* sp., *Phormidium* sp., *Spirogyra* sp., *Euglena* sp., *Trachelomonas* sp., and *Dictyocha* sp. had a wide salinity preference ranging from oligohaline, mesohaline and polyhaline in Chilika lagoon (Srichandan et al. 2015b). Few species such as *Gomphosphaeria* sp., *Actinastrum* sp., *Trachelomonas lefevrei*, and *Strombomonas tambowika* were found only at oligohaline regions while *Thalassiosira* sp. was restricted only to polyhaline regions. Some species (*Pseudonitzschia* sp., *Thalassionema nitzschioides*, *Tripos fusus*, and *Protoperidinium oceanicum*) were observed both at mesohaline and polyhaline regions but were entirely absent in oligohaline regions. Species viz. *Gyrosigma fasciola*, *Gloeocapsa alpina* were distributed only in the oligohaline and mesohaline regions of the Chilika lagoon.

Nitrate and phosphate has been considered limiting nutrient to algal growth (Mukhopadhyay et al. 2006; Gle et al. 2008). Chu et al. (2014) observed in a highly turbid estuary of Southeast Asia that inorganic nutrient concentrations and their respective ratios were found to be principal factors that structured phytoplankton diversity and influenced the emergence of potentially toxic species. In Chilika lagoon, maximum nitrate and phosphate concentrations were recorded during pre-monsoon season. It was also suggested that higher nitrogenous nutrient concentration during pre-monsoon could be related to higher residence time of the water in the lagoon during the low-flow period (pre-monsoon) (Srichandan et al. 2015b).

Besides seasonal variability, nitrate and phosphate concentrations also show distinct spatial variability. For instance, freshwater head of tropical estuaries such as Tagus (Portugal) and Bach Dang (Vietnam) estuaries are greatly influenced by direct riverine inputs which reflect higher nutrient loading (Brogueira et al. 2007; Chu et al. 2014). Similarly, Srichandan et al. (2015b) have observed that freshwater zone (i.e. northern sector) of the lagoon displayed the higher amount of nitrate and phosphate due to riverine inputs compared to other three sectors of the lagoon. In Chilika lagoon it has been shown that nitrate ($r = -0.295$, $p < 0.05$) and phosphate ($r = -0.284$, $p < 0.05$) has great influence on phytoplankton communities especially on the Dinophyta abundance and diversity (Srichandan et al. 2015b). Similar to nitrate and phosphate concentrations, marked spatio-temporal variation in silicate concentration has also been observed in estuarine ecosystems. For instance, persistently higher silicate concentration was reported in monsoon season in Zuari estuary (India), (Patil and Anil 2011). Similarly in Chilika lagoon, maximum silicate concentration has been observed during monsoon (Srichandan et al. 2015a, b). It was suggested that decreased silicate concentration in pre-monsoon could be due to the utilization of silicate by a large number of Bacillariophyta for the synthesis of their shells. This was evident from a strong negative correlation between chlorophyll (Chl-*a)* and silicate during pre-monsoon ($r = -0.331$, $p < 0.05$). The source of silicate in lagoon is mainly the heavy inflow of freshwater from riverine distributaries and land drainage of catchment area.

Turbidity has been frequently cited as a key factor controlling the distribution, abundance and diversity of phytoplankton in estuaries. For instance, in Dhamra River Estuary (India) and Na Thap River Estuary (Thailand), distributions and compositions of phytoplankton have been reported to have relationship with changes in turbidity (Palleyi et al. 2011; Lueangthuwapranit et al. 2011). In Chilika lagoon, several studies have mentioned turbidity as the major controlling factor of primary producer (Patnaik 1973; Srichandan et al. 2015a, b). It was also observed that passage of tropical cyclone *Phailin* increased the turbidity (221.4 NTU (nephelometric turbidity units)) via influx of exogenous material of terrestrial origin and restricted the development of phytoplankton bloom after *Phailin*. In addition, satellite remote sensing imagery has also revealed that the phytoplankton biomass did not change much due to high turbidity prevailing in the lagoon after *Phailin* (Srichandan et al. 2015b). Furthermore, many studies have shown that phytoplankton community structure is highly correlated with pH. For example, a positive correlation between Cyanophyta abundance and pH has been noted in the estuarine region of southeastern coast of Tamilnadu, India (Ramanathan et al. 2013). Similarly, a strong positive correlation between Cyanophyta abundance and pH ($r = 0.450$, $p < 0.01$) has been observed in Chilika lagoon (Srichandan et al. 2015b). Thus phytoplankton flora of Chilika lagoon is susceptible to change under the influence of mainly salinity, light availability, pH, and nutrients resulting heterogeneity in species composition, and population size of phytoplankton.

11.7 Future Directions

Compared to understanding on the microplankton (20–200 μm), there are significant knowledge gaps regarding the species composition of picoplankton and nanoplankton in Chilika lagoon. Detailed literature search indicated that the genetic diversity of picophytoplankton community of Chilika lagoon is completely unexplored and warrants a thorough investigation using high-throughput DNA sequencing. In fact, the molecular genetic diversity of picophytoplankton, as such, from any of Indian coastal ecosystems remains poorly understood. This necessitates the application of high-throughput DNA sequencing in the area of phytoplankton ecology to understand the diversity and distribution of smaller size phytoplankton. Further, intense monitoring is necessary to study the dynamics of phytoplankton population with respect to tidal and diurnal variation in Chilika lagoon. Further, climate change is recognized as a major threat to the survival of species and integrity of ecosystems world wide. In Chilika lagoon, rise in water temperatures by 0.39 °C in a decade have already been observed (Pandey 2015). Changes in the size-structure of phytoplankton communities in response to warming are now being documented across a range of ecosystem types and spatial scales. Therefore, further intensive studies on phytoplankton dynamics in Chilika lagoon in the context of climate change assumes greater importance. Apart from response to varying temperature, phytoplankton plays an important role in cloud formation by producing dimethyle sulfide which acts as cloud condensation nuclei. Hence, role of lagoon phytoplankton in such aspects need to be investigated. Since the lagoon is prone to anthropogenic pollution and deterioration of water quality, possibilities and scope of phytoremediation strategies should be explored. As the lagoon supports livelihood of millions of fisher folk who depend on the capture fisheries, the feeding habit of planktivore fishes should be explored for possible implementation of production enhancement strategies.

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