

Chapter 9

Zooplankton Diversity and Their Spatiotemporal Distribution: An Ecological Assessment from a Brackish Coastal Lagoon, Chilika, Odisha



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Abstract Zooplankton constitutes a pivotal component in the pelagic food webs and serves as the major source of fish diet, thereby determining the productivity of coastal fisheries. Therefore, understanding zooplankton diversity and their ecology in coastal lagoon settings is a high priority research area. We examined the spatio-temporal distribution of zooplankton diversity (size >120 μm) in relation to environmental variables in Chilika lagoon. The sampling was conducted on the monthly frequency from July 2012 to June 2016 from 13 locations and identified a total of 186 zooplankton taxa which included 131 as first record from the Chilika lagoon. To date, a total inventory of 263 species of holoplankton represented by 16 diverse categories of organisms, namely, Ciliophora (51), Foraminifera (13), Tubulinea (5), Rotifera (42), Hydrozoa (1), Ctenophora (1), Nematoda (1), Polychaeta (3), Gastropoda (12), Bivalvia (5), Cladocera (13), Copepoda (95), Ostracoda (4), Malacostraca (13), Chaetognatha (2), Chordata (2), and 23 types of meroplankton were identified. Chilika lagoon exhibited a significant variation in salinity (0–35.5) at spatiotemporal scale and consisted of marine, brackish, and freshwater zooplankton along the estuarine salinity gradient. Copepods emerged as one of the most dominant and diverse zooplankton group in terms of species richness, abundance, and widespread distribution. Among the four orders of Copepoda (i.e., Calanoida, Cyclopoida, Harpacticoida, and Poecilostomatoida), Calanoida was the most abundant one. An important component of total zooplankton pool, i.e., microzooplankton (20–200 μm), was also examined in relation to environmental variables. Ciliophora dominated the microzooplankton community followed by copepod

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nauplii and Rotifera, except in the freshwater zone of the lagoon. Foraminifera, cirripede nauplii, gastropod veliger, and bivalve veliger were minor contributors in microzooplankton. Salinity and phytoplankton abundances were the major factors influencing microzooplankton community composition. The present study highlighted the necessity of a long-term systematic monitoring of zooplankton diversity and composition in Chilika lagoon.

Keywords Zooplankton · Copepoda · Salinity · Chilika · Coastal lagoon

1 Background

Coastal lagoons are highly productive and economically important aquatic environment which constitute ~13% of the world's coastline. Coastal lagoons are separated from the adjoining sea by a barrier or communicate with the sea through inlets (mouths) (Perez-Ruzafa et al. 2011). The lagoons are highly dynamic ecosystems due to continuous material influxes (dissolved and particulate) from both marine and terrestrial environments (Mitsch and Gosselink 1993). In global context, the lagoons are stressed by both natural (e.g., extreme climatic events) and anthropogenic pressures (e.g., eutrophication, sewage discharge, and overfishing) (Kumar et al. 2016; Arreola-Lizarraga et al. 2016). These natural and anthropogenic pressures on coastal lagoons along with mixing of water from riverine and marine sources yield a sharp gradient in the physicochemical factors which determine the zooplankton community composition and distribution over the spatiotemporal scales.

Zooplankton modulate carbon flow in the food chain through their trophic interactions with lower as well as higher consumers (Isari et al. 2007). They also act as a recycler and transform particulate organic matter and nutrients into dissolved organic matter (Steinberg and Landry 2017). Generally, in an aquatic ecosystem, the fishery yields are highly dependent on the availability of zooplankton standing stocks. For instance, a high quantum of fishery (e.g., sardines and anchovies) in areas with high zooplankton (e.g., *Calanus sinicus*) production has been reported in Changjiang River estuary (China) (Gao et al. 2011). In general, zooplankton feed on phytoplankton and detritus and put a higher predation pressure on the algal standing stock. For instance, an experimental study from the Zuari and Mandovi estuaries (India) revealed a significant (>60%) grazing of phytoplankton (pico and nano) standing stock by the microzooplankton (Gauns et al. 2015).

Zooplankton are also considered as bioindicator of climate change in lagoonal and marine environments (Molinero et al. 2005). Zooplankton, due to their characteristic life processes, provide an excellent proxy to track changing climatic conditions (Carter et al. 2017). Climate change influences not only zooplankton dynamics but also their phenotype, physiology, and community composition (Dam 2013). For instance, a reduction in the size of ectotherms due to long-term warming is a common prediction on the effect of changing climate on zooplankton (Rice et al. 2015).

The zooplankton communities are quite diverse in their morphology, physiology, reproductive biology, trophic status, mode of life, and responses to different environmental stimuli. In general, zooplankton range from tiny protozoan to gigantic jellyfishes and are divided into several size classes, such as microzooplankton (20–200 μm), mesozooplankton (200 μm –2 mm), macrozooplankton (2–20 mm), and megazooplankton (>20 mm). Some of the microzooplanktonic forms are tintinnids, foraminifers, radiolarians, trochophore larvae of polychaetes, copepod nauplii, gastropod veligers, and barnacle nauplii. Cladocerans, copepods, ostracods, and amphipods are the ideal examples of mesozooplankton. Some examples of macrozooplankton are the pteropods, mysids, chaetognaths, lucifers, dolioloids, and salps. The megazooplankton are only few in numbers and are mostly represented by siphonophores.

In recent past, investigations on zooplankton have targeted the taxonomic diversity, abundances, and environmental drivers in coastal lagoons (Ziadi et al. 2015; Varghese et al. 2018; Gutierrez et al. 2018). Spatiotemporal variations in zooplankton are regulated by multitude of environmental factors such as trophic state, food availability, and predation pressure (Souza et al. 2011; Miron et al. 2014). Among physical forcing, salinity has been recognized as one of the crucial factors in controlling the spatiotemporal distribution of zooplankton (Santangelo et al. 2007; Etile et al. 2009; Antony et al. 2020). Zooplankton also respond to variations in hydrobiological factors such as temperature, pH, transparency, and food availability. For instance, temperature, pH, transparency, and chlorophyll were the primary environmental variables that regulated the zooplankton ecology in Sontecomapan Lagoon (Mexico) (Miron et al. 2014). Further, zooplankton communities also respond to the trophic variations in estuarine ecosystems (Park and Marshall 2000; Gopko and Telesh 2013). For example, higher relative abundances of rotifers (*Keratella* sp.) were indicative of trophic status of Neva Estuary (Finland) (Gopko and Telesh 2013).

Chilika lagoon (hereafter Chilika), a Ramsar site (no. 229), located on the east coast of India is an ideal ecosystem to examine zooplankton communities and their response to contrasting physicochemical regimes. Considering this, several studies have targeted zooplankton to decipher their community composition, variability, and ecological preferences from this lagoon (Devasundaram and Roy 1954; Patnaik 1973; Pattanaik and Sarma 1997; Naik et al. 2008; Mukherjee et al. 2014, 2015, 2018; Rakhesh et al. 2015; Sahu et al. 2016). Most of these studies have either focused on a particular zooplankton group (Mukherjee et al. 2014, 2015) or examined the community composition only up to the order level based on seasonal and monthly surveys (Patnaik 1973; Pattanaik and Sarma 1997; Naik et al. 2008). Importantly, species-level zooplankton community structure with detailed quantitative accounts has been investigated only in few studies (Devasundaram and Roy 1954; Rakhesh et al. 2015; Sahu et al. 2016; Mukherjee et al. 2018). The present chapter deals with long-term spatiotemporal patterns of zooplankton communities and their environmental controlling factors from Chilika based on systemic field surveys. The comprehensive dataset generated with current study was integrated with existing literature to synthesize the present status of the spatiotemporal distribution of the zooplankton from this lagoon.

2 Materials and Methods

2.1 Study Area

Chilika is connected to the northwestern Bay of Bengal (BoB) on the east coast of India ($19^{\circ}28'–19^{\circ}54' N$ and $85^{\circ}06'–85^{\circ}35' E$). Chilika spans over an area of 906 km^2 during summer and 1165 km^2 during monsoon (Srichandan and Rastogi 2020). The lagoon is connected to the BoB through outer channel as well as through Palur Canal at the southern end (Fig. 9.1). The hydrology of Chilika is strongly influenced by the tropical southwest monsoon (July–October). Chilika receives freshwater discharge from 52 rivers and rivulets; however, 19 of them are major contributors (Ganguly et al. 2015). The freshwater influx into the lagoon occurs in the upper reaches of northern sector mainly from the distributaries of Mahanadi delta, while seawater influx mostly occurs through inlets located at the outer channel. Chilika is spatially categorized into four ecological sectors, namely, southern sector (SS), central sector (CS), northern sector (NS), and outer channel (OC), based on the salinity gradient (Srichandan et al. 2015a). Chilika also experiences different salinity regimes in different sectors such as oligohaline (NS: 0.5–5), mesohaline (CS and SS: 5–18), and polyhaline (OC: 18–30) (Muduli and Pattnaik 2020). In addition, extreme weather events such as *Phailin* (October 12, 2013) and *Hudhud* (October

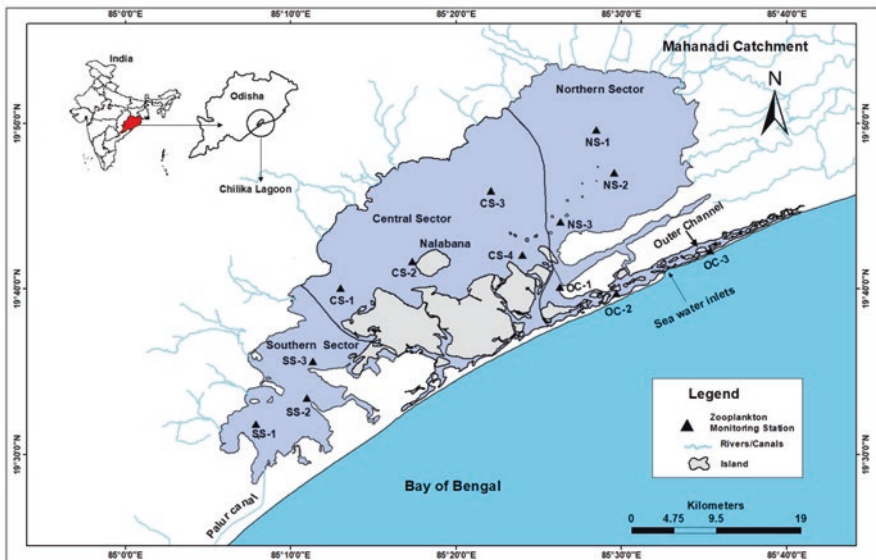


Fig. 9.1 Geographical map of Chilika lagoon showing 13 sampling stations used in zooplankton sampling. Physical boundaries are hypothetical to demonstrate the SS southern sector, CS central sector, NS northern sector, OC outer channel of the lagoon

12, 2014) have been shown to cause variability in nutrient molar ratios and phytoplankton biomass leading to proliferation of blooms (Kumar et al. 2016; Srichandan et al. 2015b).

2.2 *Sampling and Analysis*

2.2.1 *Zooplankton*

Microzooplankton (20–200 μm) were examined from July 2011 to June 2012; thereafter, zooplankton (>120 μm) were examined from July 2012 to June 2016. Thus, the study period for zooplankton included a total of 4 years which were referred as Y-1 (July 2012–June 2013), Y-2 (July 2013–June 2014), Y-3 (July 2014–June 2015), and Y-4 (July 2015–June 2016) throughout this chapter. Field surveys were carried out at a monthly frequency from 13 selected stations across 4 sectors and 3 distinct seasons, i.e., monsoon (July–October), post-monsoon (November–February), and pre-monsoon (March–June).

Microzooplankton were sampled by filtering ~ 100 l of water through 20 μm plankton net (make: KC Denmark; mouth diameter: 25 cm; length: 40 cm) which were subsequently passed through a 200 μm mesh to exclude large size zooplankton. Lugol's iodine solution (final concentration 1%) and formaldehyde (final concentration 2%) were added to the sample for preservation. Samples were concentrated by the gravimetric sedimentation technique. Subsequently, the supernatant was siphoned out leaving 100 ml as the final volume. One milliliter of concentrated sample was transferred to a Sedgewick Rafter counting chamber. The qualitative and quantitative analysis of microzooplankton was carried out using an inverted microscope (make: Olympus; model: IX73) following the standard taxonomic keys of Kofoid and Campbell (1929), Maeda (1986), Altaff (2004), Al-Yamani et al. (2011), and Gao et al. (2016).

Water samples for zooplankton (>120 μm) were collected with a plankton net (make: KC Denmark; mouth diameter: 25 cm; length: 48 cm) which was towed horizontally for 5–10 min. The amount of water passed through the net was quantified using a digital flow meter fitted with the net. Samples were preserved with 5% formaldehyde and subsampled using a plankton splitter (make: KC Denmark). A subsample (45 ml) was withdrawn from each sample, dispensed on the zooplankton counting chamber (dimensions 220 \times 100 mm, inner diameter 76 mm, make: KC Denmark) and enumerated using an inverted microscope (make: Olympus; model: IX73). Zooplankton were identified up to the genus/species level based on standard literature (Kasturirangan 1963; Battish 1992; Conway et al. 2003). For compilation of zooplankton species checklist, classification system and updated scientific names as per WoRMS (World Register of Marine Species, <http://www.marinespecies.org/>) were referred.

2.2.2 Physicochemical Parameters and Phytoplankton Enumeration

At each sampling station, in situ measurement of water temperature, pH, salinity, and turbidity (nephelometric turbidity units (NTU)) was carried out by water quality Sonde (YSI, Model No. 6600, V2) throughout the study period. The detailed procedure for collection and analysis of dissolved oxygen (DO) and dissolved nutrients (nitrate, NO_3^- ; phosphate, PO_4^{3-} ; and silicate, SiO_4^{4-}) is described in Srichandan et al. (2015a).

Phytoplankton samples from each station were collected by filtering ~100 l of water through a plankton net (make: KC Denmark; mesh size: 10 μm ; mouth diameter: 25 cm) and preserved with 2% neutralized formaldehyde and 1% Lugol's iodine solution. The phytoplankton cells were enumerated and identified as described earlier (Srichandan et al. 2015a). Total chlorophyll *a* (Chl *a*) was estimated by filtering 1 l of water through Whatman GF/F filters (pore size: 0.7 μm) using 90% acetone extraction method, and optical density was measured using a UV-Visible Spectrophotometer (Thermo Scientific™ Evolution 201).

2.3 Statistical Analysis

Canonical correspondence analysis (CCA) was applied to identify major environmental drivers of the dominant zooplankton groups. CCA was performed using CANOCO (version 4.5), and CCA biplots were generated based on the statistical significance of the environmental variables evaluated through Monte Carlo permutation (number of permutation: 499). Pearson's correlation coefficient (*r*) between environmental variables and zooplankton groups was computed using SPSS (v. 20).

3 Results and Discussion

3.1 Zooplankton Diversity

Zooplankton communities of the Chilika represented almost all animal phyla either as holoplankton or meroplankton. Zooplankton can be permanent forms (holoplankton) or temporary forms (meroplankton). Holoplankton include different groups such as Ciliophora, Foraminifera, Tubulinea, Rotifera, Hydrozoa, Ctenophora, Nematoda, Polychaeta, Gastropoda, Bivalvia, Cladocera, Copepoda, Ostracoda, Malacostraca, Chaetognatha, and Chordata. On the other hand, meroplankton includes the larvae of certain invertebrates and vertebrates.

Based on past and present studies, so far, a total of 263 species of holoplankton represented by 16 diverse categories of organisms, namely, Ciliophora (51), Foraminifera (13), Tubulinea (5), Rotifera (42), Hydrozoa (1), Ctenophora (1),

Nematoda (1), Polychaeta (3), Gastropoda (12), Bivalvia (5), Cladocera (13), Copepoda (95), Ostracoda (4), Malacostraca (13), Chaetognatha (2), and Chordata (2), and 23 types of meroplankton have been catalogued from Chilika (Table 9.1). The photomicrographs of some newly recorded zooplankton taxa in Chilika are presented in Plate 9.1. Importantly, earlier studies have adopted various different methods for collection, preservation, concentration, and microscopy of zooplankton in Chilika. For instance, some earlier studies have used plankton nets of 74 μm for microzooplankton collection (Mukherjee et al. 2018), while others have used sedimentation technique without plankton net (Sahu et al. 2016). Sampling frequency

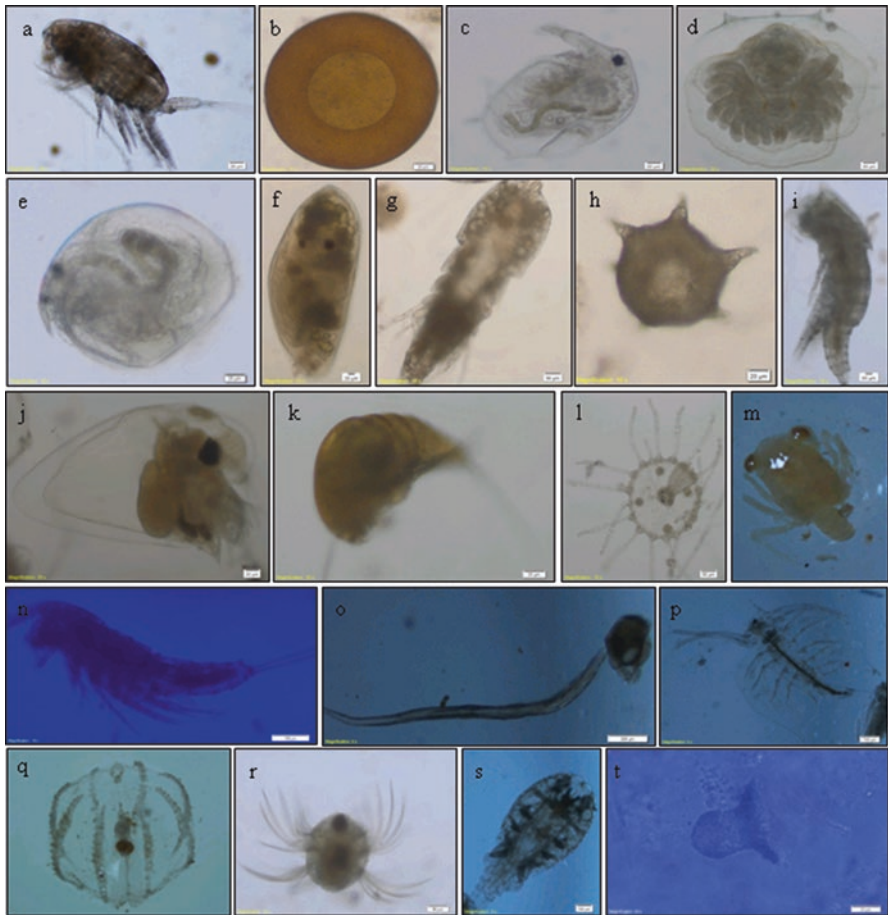


Plate 9.1 Photographs of some newly reported zooplankton taxa (a) *Acrocalanus gibber*; (b) *Arcella discoides*; (c) *Bosminopsis deitersi*; (d) brachiopod larva; (e) *Chydorus* sp.; (f) cirripede cypris larva; (g) *Clytemnestra scutellata*; (h) *Diffugia corona*; (i) *Euterpina acutifrons*; (j) *Pseudevadne tergestina*; (k) *Metis* sp.; (l) *Obelia* sp.; (m) brachyuran megalopa larva; (n) *Microsetella norvegica*; (o) *Oikopleura dioica*; (p) *Penilia avirostris*; (q) *Pleurobrachia pileus*; (r) polychaete larva; (s) *Sapphirina* sp.; (t) *Tintinnopsis mortensenii*

Table 9.1 List of zooplankton taxa from Chilika

Phylum	Ciliophora
Class	Oligotrichea
Subclass	Oligotrichia
Order	Choreotrichida
Family	Tintinnidiidae
	<i>Leprotintinnus nordqvistii</i> (Brandt 1906) Kofoid and Campbell 1929 ^{a-c} , <i>Leprotintinnus simplex</i> Schmidt 1902 ^{a,c}
Family	Codonellidae
	<i>Tintinnopsis beroidea</i> Stein 1867 ^{b-d} , <i>Tintinnopsis cylindrica</i> Daday 1887 ^{a-e} , <i>Tintinnopsis mortensenii</i> Schmidt 1902 ^{b,c,f} , <i>Tintinnopsis tocatinensis</i> Kofoid and Campbell 1929 ^{a-c} , <i>Tintinnopsis tubulosa</i> Levander 1900 ^{a-d} , <i>Tintinnopsis uruguayensis</i> Balech 1948 ^{b-d} , <i>Tintinnopsis bermudensis</i> Brandt 1906 ^{b-d} , <i>Tintinnopsis buetschlii</i> Daday 1887 ^{b-d} , <i>Tintinnopsis tenuis</i> Hada 1932 ^{b,c,f} , <i>Tintinnopsis acuminata</i> Daday 1887 ^{b,c,f} , <i>Tintinnopsis dadayi</i> Kofoid 1905 ^{b,c,f} , <i>Tintinnopsis gracilis</i> Kofoid and Campbell 1929 ^{a-e} , <i>Tintinnopsis sacculus</i> Brandt 1896 ^{b-d} , <i>Tintinnopsis fimbriata</i> Meunier 1919 ^{a,c,e} , <i>Tintinnopsis directa</i> Hada 1932 ^{a,c-e} , <i>Tintinnopsis compressa</i> Daday 1887 ^{a,c} , <i>Tintinnopsis rotundata</i> Kofoid and Campbell 1929 ^{a,c} , <i>Tintinnopsis radix</i> Imhof 1886 ^{a,c-e} , <i>Tintinnopsis nucula</i> Fol 1884 ^{a,c} , <i>Tintinnopsis parvula</i> Jorgensen 1912 ^{a,c,e} , <i>Tintinnopsis spiralis</i> Kofoid and Campbell 1929 ^{a,c,e} , <i>Tintinnopsis filakinensis</i> Al-Yamani et al. 2011 ^{a,c} , <i>Tintinnopsis lohmanni</i> Laackmann 1906 ^{c,d} , <i>Tintinnopsis nana</i> Lohmann 1908 ^{c,d} , <i>Tintinnopsis karajacensis</i> Brandt 1896 ^{a,c,e} , <i>Tintinnopsis</i> sp. Stein 1867 ^{b-c,g} , <i>Codonella</i> sp. Haeckel 1873 ^{c,g}
Family	Tintinnidae
	<i>Dadayiella bulbosa</i> Brandt 1906 ^{a,c} , <i>Eutintinnus fraknoii</i> Daday 1887 ^{a,c} , <i>Eutintinnus</i> <i>apertus</i> Kofoid and Campbell 1929 ^{a,c} , <i>Eutintinnus elongatus</i> Jorgensen 1924 ^{a,c} , <i>Eutintinnus</i> sp. Kofoid and Campbell 1939 ^{c,e} , <i>Amphorellopsis acuta</i> Schmidt 1902 ^{c,d}
Family	Codonellopsidae
	<i>Stenosemella nivalis</i> Meunier 1910 ^{a,c} , <i>Stenosemella ventricosa</i> (Claparede and Lachmann 1858) Jorgensen 1924 ^{a,c} , <i>Stenosemella</i> sp. Jorgensen ^{c,e} , <i>Codonellopsis</i> <i>ostenfeldti</i> (Schmidt 1902) Kofoid and Campbell 1929 ^{a-d}
Family	Ptychocylididae
	<i>Favella philippinensis</i> Roxas 1941 ^{b-d} , <i>Favella brevis</i> Kofoid and Campbell 1929 ^{b,c,f} , <i>Favella adriatica</i> (Imhof 1886) Jorgensen 1924 ^{a,c,e} , <i>Favella campanula</i> (Schmidt 1902) Jorgensen 1924 ^{a,c,e} , <i>Favella ehrenbergii</i> (Claparede and Lachmann 1858) Jorgensen 1924 ^{a,c,e} , <i>Favella</i> sp. Jorgensen 1924 ^{b,c,f}
Family	Metacyclididae
	<i>Metacylis tropica</i> Duran 1957 ^{a,c} , <i>Metacylis jorgensenii</i> Cleve 1902 ^{c,d}
Family	Dictyocystidae
	<i>Dictyocysta seshaiyai</i> Krishnamurthy and Santhanam 1975 ^{b,c,f} , <i>Dictyocysta</i> sp. Ehrenberg 1854 ^{b-d} , <i>Luminella</i> sp. Kofoid and Campbell 1939 ^{b,c,f}
Family	Cyttarocylididae
	<i>Cyttarocylis</i> sp. Fol 1881 ^{c,g}
Phylum	Foraminifera
Class	Polythalamia
Order	Globigerinida
Family	Globigerinidae

(continued)

Table 9.1 (continued)

	<i>Globigerina bulloides</i> d'Orbigny 1826 ^{b,c,f} , <i>Globigerina</i> sp. d'Orbigny 1826 ^{b,c,f,h}
Class	Globothalamea
Order	Rotaliida
Family	Ammoniidae
	<i>Ammonia</i> sp. Brünnich 1771 ^{b,c,f}
Family	Bolivinitidae
	<i>Bolivina</i> sp. d'Orbigny 1839 ^{b,c,f}
Family	Discorbidae
	<i>Discorbis</i> sp. Lamarck 1804 ^{b,c,f,h}
Family	Nonionidae
	<i>Nonionella</i> sp. Cushman 1926 ^{b,c,f}
Family	Elphidiidae
	<i>Elphidium</i> sp. Montfort 1808 ^{c,i}
Order	Lituolida
Family	Lituolidae
	<i>Flabellamina</i> sp. Cushman 1928 ^{b,f}
Order	Textulariida
Family	Textulariidae
	<i>Textularia</i> sp. DeFrance 1824 ^{b,c,f,j}
Class	Tubothalamea
Order	Miliolida
Family	Spiroloculinidae
	<i>Spiroloculina</i> sp. d'Orbigny 1826 ^{b,c,f,h}
Family	Hauerinidae
	<i>Quinqueloculina</i> sp. d'Orbigny 1826 ^{b,c,f} , <i>Triloculina</i> sp. d'Orbigny 1826 ^{b,c,f,h}
Order	Spirillinida
Family	Ammodiscidae
	<i>Ammodiscus</i> sp. Reuss 1862 ^{b,c,f}
Phylum	Amoebozoa
Class	Tubulinea
Order	Arcellinida
Family	Arcellidae
	<i>Arcella discoides</i> Ehrenberg 1843 ^{b,f,h} , <i>Arcella</i> sp. Ehrenberg 1832 ^{b,f,h}
Family	Centropyxidae
	<i>Centropyxis</i> sp.
Family	Diffugiidae
	<i>Diffugia corona</i> Wallich 1864 ^{b,f,h} , <i>Diffugia</i> sp. Leclerc 1815 ^{b,c,h,i}
Phylum	Rotifera
Class	Eurotatoria
Subclass	Monogononta
Order	Ploima
Family	Brachionidae

(continued)

Table 9.1 (continued)

	<i>Anuraeopsis fissa</i> Gosse 1851 ^{b,c,f} , <i>Anuraeopsis</i> sp. Lauterborn 1900 ^{b,c,f} , <i>Brachionus dichotomus reductus</i> Koste and Shiel 1980 ^{b,f,h} , <i>Brachionus falcatus</i> Zacharias 1898 ^{b,e,h} , <i>Brachionus quadridentatus</i> Hermann 1783 ^{b,h,k} , <i>Brachionus rubens</i> Ehrenberg 1838 ^{b,d,h} , <i>Brachionus</i> sp. Pallas 1766 ^{b-d,g,h,j} , <i>Brachionus angularis angularis</i> Gosse 1851 ^{c,k} , <i>Brachionus plicatilis</i> Muller 1786 ^{c,e,j,k} , <i>Brachionus bidentata</i> Anderson 1889 ^{c,e,k} , <i>Brachionus urceolaris</i> Müller 1773 ^k , <i>Brachionus calyciflorus</i> Pallas 1766 ^k , <i>Kellicottia longispina</i> Kellicott 1879 ^{d,h} , <i>Keratella tropica</i> Apstein 1907 ^{b,h,j,k} , <i>Keratella tecta</i> Gosse 1851 ^{b,c,f} , <i>Keratella</i> sp. Bory de St. Vincent 1822 ^{c,d,g,h,j} , <i>Plationus patulus</i> Müller 1786 ^{b,h,k}
Family	Asplanchnidae
	<i>Asplanchna brightwellii</i> Gosse 1850 ^{b,f,h} , <i>Asplanchna</i> sp. Gosse 1850 ^{b-d,h}
Family	Dicranophoridae
	<i>Dicranophorus</i> sp. Nitzsch 1827 ^{b,f,h}
Family	Lecanidae
	<i>Lecane batillifer</i> Murray 1913 ^{c,h,k} , <i>Lecane crepida</i> Harring 1914 ^{h,k} , <i>Lecane inopinata</i> Harring and Myers 1926 ^{e,k} , <i>Lecane leontina</i> Turner 1892 ^k , <i>Lecane styx</i> Harring and Myers 1926 ^{e,k} , <i>Lecane ungalata</i> Gosse 1887 ^k , <i>Monostyla bulla</i> Gosse 1851 ^{d,e,h,k} , <i>Monostyla luna</i> Muller 1776 ^{c,h,k} , <i>Monostyla</i> sp. Ehrenberg 1930 ^{d,h} , <i>Lecane</i> sp. Nitzsch 1827 ^{b-d,h,j}
Family	Lepadellidae
	<i>Lepadella</i> sp. Bory de St. Vincent 1826 ^{b-d,h,j}
Family	Synchaetidae
	<i>Polyarthra vulgaris</i> Carlin 1943 ^{b,f,h} , <i>Polyarthra</i> sp. Ehrenberg 1834 ^{d,h}
Order	Flosculariaceae
Family	Hexarthridae
	<i>Hexarthra</i> sp. Schmarda 1854 ^{b-c,h,j,k}
Family	Conochilidae
	<i>Conochilus dossuarius</i> Hudson 1885 ^{c,k}
Family	Filiniidae
	<i>Filinia longiseta</i> Ehrenberg 1834 ^{h,k} , <i>Filinia opoliensis</i> Zacharias 1898 ^{h,k} , <i>Filinia</i> sp. Bory de St. Vincent 1824 ^{c,g,h}
Family	Testudinellidae
	<i>Pompholyx sulcata</i> Hudson 1885 ^{h,k} , <i>Testudinella patina</i> Hermann 1783 ^{c,h,j,k} , <i>Testudinella</i> sp. Bory de St. Vincent 1826 ^{c,d,h,j}
Family	Trichocercidae
	<i>Trichocerca</i> sp. Lamarck 1801 ^{c,d,h,j}
Phylum	Cnidaria
Class	Hydrozoa
Subclass	Hydroidolina
Order	Leptothecata
Family	Campanulariidae
	<i>Obelia</i> sp. Peron and Lesueur 1810 ^{b,c,f}
Phylum	Ctenophora
Class	Tentaculata
Order	Cydippida

(continued)

Table 9.1 (continued)

Family	Pleurobrachiidae
	<i>Pleurobrachia pileus</i> O.F. Müller 1776 ^{b,c,f,j}
Phylum	Nematoda
Class	Enoplea
Subclass	Enoplia
Order	Enoplida
Family	Enchelidiidae
	<i>Belbolla</i> sp. Andrassy 1973 ^{b,c,f,j}
Phylum	Annelida
Class	Polychaeta
Subclass	Errantia
Order	Phyllodocida
Family	Nereididae
	<i>Nereis chilkaensis</i> Southern 1921 ^{c,i} , <i>Neanthes glandicincta</i> Southern 1921 ^{c,h,i} , <i>Perinereis marjorii</i> Southern 1921 ^{c,h,i}
Phylum	Mollusca
Class	Gastropoda
Subclass	Heterobranchia
Order	Pteropoda
Family	Creseidae
	<i>Creseis acicula</i> Rang 1828 ^{b,c,f}
Family	Heliconoididae
	<i>Heliconoides inflatus</i> d'Orbigny 1835 ^{b,c,f}
Order	Pylopulmonata
Family	Pyramidellidae
	<i>Quirella humilis</i> Preston 1905 ^{c,i}
Order	Cephalaspidea
Family	Tornatinidae
	<i>Acteocina estriata</i> Preston 1914 ^{c,i}
Subclass	Caenogastropoda
Order	Littorinimorpha
Family	Atlantidae
	<i>Atlanta</i> sp. Lesueur 1817 ^{b,c,f}
Family	Stenothyridae
	<i>Stenothyra</i> sp. Benson 1856 ^{h,i}
Order	Caenogastropoda
Family	Epitoniidae
	<i>Janthina</i> sp. Roding 1798 ^{b,c,f}
Family	Potamididae
	<i>Pirenella cingulata</i> Gmelin 1791 ^{c,i,j}
Family	Litiopidae
	<i>Litiopa copiosa</i> Preston 1915 ^{c,i}
Order	Neogastropoda

(continued)

Table 9.1 (continued)

Family	Nassariidae
	<i>Nassa denegabilis</i> Preston 1914 ^{c,i} , <i>Nassarius orissaensis</i> Preston 1914 ^{c,i} , <i>Tritia burchardi</i> Dunker 1849 ^{c,i}
Class	Bivalvia
Subclass	Autobranchia
Order	Mytilida
Family	Mytilidae
	<i>Modiola undulatus</i> var. <i>crassicosata</i> Preston 1914 ^{c,i}
Order	Veneroida
Family	Veneridae
	<i>Clementia annandalei</i> Preston 1914 ^{c,i} , <i>Meretrix casta</i> Gmelin 1791 ^{c,i} , <i>Marcia opima</i> Gmelin 1791 ^{c,i}
Order	Cardiida
Family	Semelidae
	<i>Theora opalina</i> Hinds 1843 ^{c,i}
Phylum	Arthropoda
Class	Branchiopoda
Subclass	Diplostraca
Order	Onychopoda
Family	Podonidae
	<i>Pseudevadne tergestina</i> Claus 1877 ^{b,c,f} , <i>Evadne nordmanni</i> Loven 1836 ^{b,c,f} , <i>Evadne</i> sp. Loven 1836 ^{c,h-j}
Order	Ctenopoda
Family	Sididae
	<i>Penilia avirostris</i> Dana 1849 ^{b,c,f,h,j} , <i>Diaphanosoma excisum</i> G.O. Sars 1885 ^{b,c,f,h,j} , <i>Diaphanosoma</i> sp. Fischer 1850 ^{b,c,f,h,j}
Order	Anomopoda
Family	Chydoridae
	<i>Chydorus sphaericus</i> O.F. Müller 1776 ^{b,c,f,h,j} , <i>Chydorus</i> sp. Leach 1816 ^{b,c,f,h,j} , <i>Alona</i> sp. Baird 1843 ^{b,c,f,h,j}
Family	Bosminidae
	<i>Bosminopsis deitersi</i> Richard 1895 ^{b,f,h}
Family	Macrothricidae
	<i>Macrothrix</i> sp. Baird 1843 ^{b,f,h}
Family	Moinidae
	<i>Moina micrura</i> Kurz 1875 ^{b,f,h,j} , <i>Moina</i> sp. Baird 1850 ^{b,g,h,j}
Class	Hexanauplia
Subclass	Copepoda
Order	Calanoida
Family	Acartiidae
	<i>Acartia centrura</i> Giesbrecht 1889 ^{b,c,i} , <i>Acartia danae</i> Giesbrecht 1889 ^{b,c,f} , <i>Acartia erythraea</i> Giesbrecht 1889 ^{b,c,f} , <i>Acartia negligens</i> Dana 1849 ^{b,c,f} , <i>Acartia southwelli</i> Sewell 1914 ^{b,c,f} , <i>Acartia spinicauda</i> Giesbrecht 1889 ^{b,c,f} , <i>Acartiella major</i> Sewell 1919 ^{c,i,j,l} , <i>Acartiella minor</i> Sewell 1919 ^{c,i,j} , <i>Acartia chilkaensis</i> Sewell 1919 ^{c,i,l} , <i>Acartia</i> sp. Dana 1846 ^{b,c,g}

(continued)

Table 9.1 (continued)

Family	Candaciidae
	<i>Candacia discaudata</i> Scott A. 1909 ^{b,c,f}
Family	Centropagidae
	<i>Centropages furcatus</i> Dana 1849 ^{b,c,f} , <i>Centropages orsinii</i> Giesbrecht 1889 ^{b,c,f} , <i>Centropages tenuiremis</i> Thompson I.C. and Scott A. 1903 ^{b,c,f} , <i>Centropages calaninus</i> Dana 1849 ^{b,c,f} , <i>Centropages</i> sp. Kroyer 1849 ^{b,c,f}
Family	Pontellidae
	<i>Calanopia minor</i> Scott A. 1902 ^{b,c,f} , <i>Calanopia</i> sp. Dana 1852 ^{b,c,f} , <i>Labidocera acuta</i> Dana 1849 ^{b,c,f} , <i>Labidocera pectinata</i> Thompson I.C. and Scott A. 1903 ^{b,c,f} , <i>Labidocera pavo</i> Giesbrecht 1889 ^{b,c,i,l} , <i>Labidocera</i> sp. Lubbock 1853 ^{b,c,g} , <i>Pontella spinipes</i> Giesbrecht 1889 ^{b,c,f} , <i>Pontella danae</i> Giesbrecht 1889 ^{b,c,f} , <i>Pontella securifer</i> Brady 1883 ^{b,c,f}
Family	Temoridae
	<i>Temora discaudata</i> Giesbrecht 1889 ^{b,c,f} , <i>Temora turbinata</i> Dana 1849 ^{b,c,l} , <i>Temora</i> sp. Baird 1850 ^{c,g}
Family	Tortanidae
	<i>Tortanus forcipatus</i> Giesbrecht 1889 ^{b,c,f}
Family	Calanidae
	<i>Mesocalanus tenuicornis</i> Dana 1849 ^{b,c,f} , <i>Canthocalanus pauper</i> Giesbrecht 1888 ^{b,c,f} , <i>Nannocalanus minor</i> Claus 1863 ^{b,c,f}
Family	Paracalanidae
	<i>Acrocalanus gibber</i> Giesbrecht 1888 ^{b,c,f} , <i>Acrocalanus gracilis</i> Giesbrecht 1888 ^{b,c,f} , <i>Acrocalanus longicornis</i> Giesbrecht 1888 ^{b,c,f} , <i>Acrocalanus monachus</i> Giesbrecht 1888 ^{b,c,f} , <i>Acrocalanus</i> sp. Giesbrecht 1888 ^{b,c,f} , <i>Paracalanus aculeatus</i> Giesbrecht 1888 ^{b,c,f} , <i>Paracalanus parvus</i> Claus 1863 ^{b,c,f,j} , <i>Paracalanus crassirostris</i> Dahl F. 1894 ^{c,i} , <i>Paracalanus</i> sp. Boeck 1865 ^{b,c,f} , <i>Bestiolina similis</i> Sewell 1914 ^{c,l}
Family	Eucalanidae
	<i>Eucalanus</i> sp. Dana 1852 ^{b,c,g} , <i>Subeucalanus subcrassus</i> Giesbrecht 1888 ^{b,c,f} , <i>Subeucalanus monachus</i> Giesbrecht 1888 ^{b,c,f} , <i>Subeucalanus</i> sp. Geletin 1976 ^{b,c,f} , <i>Pareucalanus</i> sp. Geletin 1976 ^{b,c,f}
Family	Pseudodiaptomidae
	<i>Pseudodiaptomus annandalei</i> Sewell 1919 ^{b,c,h-j,l} , <i>Pseudodiaptomus aurivilli</i> Cleve 1901 ^{b,c,f,j} , <i>Pseudodiaptomus serricaudatus</i> Scott T. 1894 ^{b,c,f,j} , <i>Pseudodiaptomus binghami</i> Sewell 1912 ^{c,i,j} , <i>Pseudodiaptomus hickmani</i> Sewell 1912 ^{c,h-j} , <i>Pseudodiaptomus</i> sp. Herrick 1884 ^{b,c,g,h,j}
Family	Diaptomidae
	<i>Heliodiaptomus</i> sp. Kiefer 1932 ^{b,f,h} , <i>Diaptomus</i> sp. Westwood 1836 ^{g,h}
Order	Cyclopoida
Family	Oithonidae
	<i>Oithona attenuata</i> Farran 1913 ^{b,c,f,h,j} , <i>Oithona brevicornis</i> Giesbrecht 1891 ^{b,c,i,j} , <i>Oithona setigera</i> Dana 1849 ^{b,c,f} , <i>Oithona similis</i> Claus 1866 ^{b,c,f,h,j} , <i>Oithona nana</i> Giesbrecht 1893 ^{c,h-j} , <i>Oithona hebes</i> Giesbrecht 1891 ^{c,h,j,l} , <i>Oithona</i> sp. Baird 1843 ^{b,c,g,h,j}
Family	Cyclopidae
	<i>Mesocyclops</i> sp. Sars G.O. 1914 ^{b,g,h} , <i>Thermocyclops</i> sp. Kiefer 1927 ^{b,f,h} , <i>Microcyclops</i> sp. Claus 1893 ^{b,g,h} , <i>Cyclops buxtoni</i> Gurney 1921 ^{h,l} , <i>Cyclops</i> sp. Müller O.F. 1785 ^{g,h}
Order	Harpacticoida

(continued)

Table 9.1 (continued)

Family	Miraciidae
	<i>Miracia efferata</i> Dana 1849 ^{b,c,f} , <i>Distioculus minor</i> Scott T. 1894 ^{b,c,f} , <i>Macrosetella gracilis</i> Dana 1846 ^{b,c,f} , <i>Macrosetella oculata</i> Sars G.O. 1916 ^{b,c,f}
Family	Ectinosomatidae
	<i>Microsetella rosea</i> Dana 1847 ^{b,c,f} , <i>Microsetella norvegica</i> Boeck 1865 ^{b,c,f,j}
Family	Peltidiidae
	<i>Clytemnestra scutellata</i> Dana 1847 ^{b,c,f}
Family	Tachidiidae
	<i>Euterpina acutifrons</i> Dana 1847 ^{b,c,f,j}
Family	Longipediidae
	<i>Longipedia weberi</i> Scott A. 1909 ^{b,c,f}
Family	Metidae
	<i>Metis jousseaumei</i> Richard 1892 ^{b,c,f}
Family	Ameiridae
	<i>Nitokra</i> sp. Boeck 1865 ^{g,h,j}
Family	Canuellidae
	<i>Canuella</i> sp. Scott T. and Scott A. 1893 ^{c,g}
Family	Tegastidae
	<i>Parategastes sphaericus</i> Claus 1863 ^{c,i}
Order	Poecilostomatoida
Family	Oncaeidae
	<i>Oncaea conifera</i> Giesbrecht 1891 ^{b,c,f} , <i>Oncaea venusta</i> Philippi 1843 ^{b,c,l}
	<i>Oncaea</i> sp. Philippi 1843 ^{b,c,f}
Family	Sapphirinidae
	<i>Sapphirina</i> sp. Thompson J. 1829 ^{b,c,f}
Family	Corycaeidae
	<i>Onychocorycaeus agilis</i> Dana 1849 ^{b,c,f,j} , <i>Corycaeus andrewsi</i> Farran 1911 ^{b,c,f,j} , <i>Onychocorycaeus catus</i> Dahl F. 1894 ^{b,c,f,j} , <i>Urocorycaeus longistylis</i> Dana 1849 ^{b,c,f} , <i>Corycaeus speciosus</i> Dana 1849 ^{b,c,f,j} , <i>Corycaeus danae</i> Giesbrecht 1891 ^{c,j,l} , <i>Corycaeus</i> sp. Dana 1845 ^{b,c,f,j} , <i>Farranula concinna</i> Dana 1849 ^{b,c,f} , <i>Farranula gibbula</i> Giesbrecht 1891 ^{b,c,f} , <i>Farranula</i> sp. Wilson C.B. 1932 ^{b,c,f}
Family	Bomolochidae
	<i>Bomolochus</i> sp. Nordmann 1832 ^{b,c,f}
Class	Ostracoda
Subclass	Myodocopa
Order	Halocyprida
Family	Halocyprididae
	<i>Discoconchoecia elegans</i> Sars 1866 ^{b,c,f} , <i>Chonchoecia</i> sp. Dana 1849 ^{b,c,f}
Order	Myodocopida
Family	Cypridinidae
	<i>Macrocypridina castanea</i> Brady 1897 ^{b,c,f}
Subclass	Podocopa
Order	Podocopida
Family	Cyprididae

(continued)

Table 9.1 (continued)

	<i>Cypris</i> sp. O.F. Müller 1776 ^{b,f,h}
Class	Malacostraca
Subclass	Eumalacostraca
Order	Mysida
Family	Mysidae
	<i>Mesopodopsis orientalis</i> W. Tattersall 1908 ^{b,c,g,i,j}
	<i>Rhopalophthalmus africanus</i> O. Tattersall 1957 ^{c,i}
Order	Amhipoda
Family	Gammaridae
	<i>Gammarus</i> sp. Fabricius 1775 ^{b,c,f,h,j}
Family	Paracalliopiidae
	<i>Paracalliope fluviatilis</i> (Thompson 1879) sensu Chilton 1920 ^{h-j}
Family	Ampeliscidae
	<i>Ampelisca pusilla</i> G.O. Sars 1891 ^{c,i}
Family	Oedicerotidae
	<i>Periculodes longimanus</i> (Spence Bate and Westwood 1868) ^{c,i}
Order	Decapoda
Family	Luciferidae
	<i>Belzebub hansenii</i> Nobili 1906 ^{b,c,i,j} , <i>Lucifer</i> sp. J.V. Thompson 1829 ^{c,g,j,l}
Order	Isopoda
Family	Ligiidae
	<i>Ligia exotica</i> Roux 1828 ^{c,i,j}
Family	Anthuridae
	<i>Apanthura sandalensis</i> Stebbing 1900 ^{c,i}
Family	Leptanthuridae
	<i>Accalathura borrailei</i> Stebbing 1904 ^{c,i}
Order	Cumacea
Family	Diastylidae
	<i>Paradiastylis culicoides</i> Kemp 1916 ^{c,i,j}
Family	Bodotriidae
	<i>Iphinoe sanguinea</i> Kemp 1916 ^{c,i}
Phylum	Chaetognatha
Class	Sagittoidea
Order	Aphragmophora
Family	Sagittidae
	<i>Flaccisagitta enflata</i> Grassi 1881 ^{b,c,f}
	<i>Sagitta</i> sp. Quoy and Gaimard 1827 ^{b,c,i,l}
Phylum	Chordata
Class	Appendicularia
Order	Copelata
Family	Oikopleuridae
	<i>Oikopleura (Vexillaria) dioica</i> Fol 1872 ^{b,c,f,j} , <i>Oikopleura (Vexillaria)</i> sp. Lohmann 1933 ^{b,c,f,j}

(continued)

Table 9.1 (continued)

Meroplankton	
	Actinula larvae ^{b,l} , alima larvae of <i>Squilla</i> ^{b,l} , bivalve veligers ^{b,d,g,i,l} , brachyuran protozoa larvae ^l , brachyuran zoea larvae ^{b,l} , brachyuran megalopa larvae ^{b,f} , brachiopod larvae ^{b,f} , caridean larvae ^{b,f} , cirripede cypris ^{b,f} , cirripede nauplii ^{b,d} , copepod nauplii ^{b,d,i} , cyphonautes larvae ^{b,f} , fish egg ^{b,g,i} , fish larvae ^{b,g,i,l} , gastropod veligers ^{b,d,g,i} , isopod larvae ^{b,f} , larvae of mysids ^{b,f} , ophiopluteus larvae ^{b,f} , penaeid prawn larvae ^{b,g} , polychaete larvae ^{b,f} , protozoa of <i>Lucifer</i> ^{b,l} , mysis of <i>Lucifer</i> ^l , tunicate larvae ⁱ

^aMukherjee et al. (2015)^bPresent study^cm, marine^dSahu et al. (2016)^eMukherjee et al. (2018)^fNew records from the present study^gPatnaik (1973)^hf, freshwaterⁱDevasundaram and Roy (1954)^jb, brackish^kMukherjee et al. (2014)^lRakhesh et al. (2015)

has a major influence on the species diversity recovered from any survey including proportion of developmental stages present in a sample. Therefore, the data generated in the present study was not directly comparable to earlier studies. Our study documented higher zooplankton diversity due to a systematic monitoring at monthly scale over the period of 5 years which was crucial for recovering the maximum species richness from the Chilika.

3.2 Holoplankton

3.2.1 Ciliophora

The ecological roles of planktonic ciliates (20–200 µm) in the pelagic food web of the aquatic environment are well-recognized. They often represent an essential component of the microzooplankton population in several coastal lagoons (Godhantaraman and Uye 2003; Sahu et al. 2016). They also act as a trophic intermediate from lower trophic level (e.g., pico- and nanoplankton) to higher trophic level (e.g., meso- and macro-carnivores) (Corliss 2002). Furthermore, ciliates are important phytoplankton grazers, nutrient re-mineralizers, and regenerators in coastal systems. In addition, ciliates have been used as bioindicator in evaluating biotic stress and pollution (Xu et al. 2014). Generally, environmental variables such as salinity, temperature, nutrient, food availability, and grazing activities determine the composition, abundance, and distribution of ciliates (Nche-Fambo et al. 2016; Rakshit et al. 2017; Basuri et al. 2020).

There are few studies which have reported planktonic Ciliophora in Chilika (Patnaik 1973; Mukherjee et al. 2015, 2018; Sahu et al. 2016). Ciliophora investigation started with the study of Patnaik (1973) which documented three marine species (i.e., *Codonella* sp., *Tintinnopsis* sp., *Cyrtarocylis* sp.) (Table 9.1). Mukherjee et al. (2015) studied the diversity and distribution of Ciliophora and documented 27 species belonging to 8 genera and 5 families. Subsequently, Sahu et al. (2016) carried out a survey on the microzooplankton and provided a detailed taxonomic account of Ciliophora. They have reported 19 species of Ciliophora of which genus *Tintinnopsis* was the major one and consisted of 14 species. Recently, Mukherjee et al. (2018) carried out an investigation on microplankton dynamics with interactive effect of environmental parameters and recorded 15 species. The present study reported a total of 22 species belonging to 5 families, of which, 8 species (*Tintinnopsis mortensenii*, *Tintinnopsis tenuis*, *Tintinnopsis acuminata*, *Tintinnopsis dadayi*, *Favella brevis*, *Favella* sp., *Dictyocysta seshaiyai*, *Luminella* sp.) serve as first reports from the lagoon. Thus, so far 51 species of Ciliophora have been recorded from the lagoon. The predominance of *Tintinnopsis* in the present study could be attributed to their more flexible adaptive strategies (Reynolds 1997). Other adaptive mechanisms which could contribute to the survival of *Tintinnopsis* in estuarine ecosystems could be the production of resting cysts which usually sink down and rest in the sediments (Krinsic 1987). Once the environmental conditions become conducive, excystment and reproduction occur rapidly leading to the proliferation of *Tintinnopsis*.

3.2.2 Foraminifera

Foraminifera (heterotrophic protists) are unicellular organisms with shells or tests. In general, their shells are composed of organic compounds, sand grains, and crystalline calcites. Foraminifera have been used extensively as an effective proxy for evaluation of environmental perturbations in lagoon ecosystems such as Santa Gilla lagoon (Cagliari, Italy) (Frontalini et al. 2009). The distribution and diversity of foraminifers is usually controlled by environmental parameters, especially salinity, DO, sediment texture, and organic carbon across different marine environments (Murray 2006).

In Chilika, among the two forms (planktonic and benthic) of Foraminifera, benthic foraminifers have been studied extensively (Sen and Bhadury 2016; Gupta et al. 2019). However, the study of Devasundaram and Roy (1954) was the first report of benthic Foraminifera in zooplankton and documented *Elphidium* sp. as a sole member of the community. In the present study, ten benthic (*Ammonia* sp., *Bolivina* sp., *Discorbis* sp., *Nonionella* sp., *Flabellamina* sp., *Textularia* sp., *Spiroloculina* sp., *Quinqueloculina* sp., *Triloculina* sp., *Ammodiscus* sp.) and two planktonic (*Globigerina bulloides*, *Globigerina* sp.) foraminifers have been identified (Table 9.1). The observation of marine planktonic foraminifers in the present study could be due to tidal influx from BoB into the lagoon (Barik et al. 2019).

3.2.3 Tubulinea

Tubulinea (Amoebozoa) commonly termed as testate amoebae are unicellular protists that are partially enclosed in a simple test (shell). They have a wide distribution in estuaries, lakes, rivers, and wetlands as planktonic or benthic forms (Felipe Machado Velho et al. 2000; Qin et al. 2013). Testate amoebae species respond quickly to changes in environmental conditions due to their short generation time.

In context to Indian estuarine ecosystems, there are only few studies which reported Tubulinea in the zooplankton communities (Saraswathi and Sumithra 2016; Kumari et al. 2017). In Chilika, this particular group is understudied, and a single species of Tubulinea represented by *Diffflugia* sp. has been reported earlier (Devasundaram and Roy 1954). The present study documented a total of five species of Tubulinea, of which four (*Arcella discoides*, *Arcella* sp., *Centropyxis* sp., *Diffflugia corona*) were the first records from Chilika (Table 9.1). Of these, *Diffflugia* and *Arcella* are known as indicators of water pollution (Kumari et al. 2017).

3.2.4 Rotifera

Rotifera are the microscopic metazoans (~50–2000 µm) commonly known as “wheel animalcules.” Rotifera possess several characteristic features such as an apical field, a muscular pharynx, and a syncytial body wall. Rotifera may be truly planktonic, benthic, or periphytic. Rotifera are found in a broad salinity regime ranging from freshwater to estuarine and marine. However, they are mostly abundant in the freshwater environment with limited occurrences in the marine environment (Sharma and Naik 1996). Rotifera are abundant in aquatic ecosystems due to their rapid reproductive rates among the metazoans (Herzig 1983). Rotifera are herbivores and efficiently feed on algae, bacteria, and flagellates. Rotifera also act as bioindicator in the ecotoxicological studies, eutrophy, and pollution monitoring (Edmondson and Litt 1982; Abdel-Aziz et al. 2011). The distribution and composition of Rotifera depend on the variability of salinity, temperature, turbidity, and chlorophyll (Azemar et al. 2010; Ezz et al. 2014).

Patnaik (1973) initially documented three genera of Rotifera (*Brachionus*, *Filinia*, and *Keratella*) from Chilika (Table 9.1). Their study revealed that rotifers were largely abundant in the NS and CS zones. Later, Mukherjee et al. (2014) investigated Rotifera (distribution, abundance, and diversity) and documented 23 species during 2012–2013. Mukherjee et al. (2014) have also demonstrated that environmental variables such as salinity, transparency, silicate, and total hardness were the important drivers controlling the Rotifera distribution in the lagoon. Sahu et al. (2016) listed 13 species of Rotifera, of which, six species (*Polyarthra* sp., *Trichocerca* sp., *Brachionus rubens*, *Kellicottia longispina*, *Asplanchna* sp., *Lepadella* sp.) were new records. A survey conducted between 2012 and 2015 on the microplankton dynamics reported ten species of Rotifera (Mukherjee et al. 2018). Their study also showed that distribution of *Brachionus bidentata*, *Lecane batilifer*, *Monostyla bulla*, and *Monostyla luna* was controlled by nitrate and

transparency, while salinity played a crucial role in regulating the distribution of *Lecane styrax*. The distribution of *Hexarthra* sp., *Lecane inopinata*, *Filinia* sp., and *Brachionus falcatus* was controlled by the variation of free CO₂. Our study reported a total of 17 Rotifera species of which 7 species (*Anuraeopsis fissa*, *Anuraeopsis* sp., *Brachionus dichotomus reductus*, *Keratella tecta*, *Asplanchna brightwellii*, *Dicranophorus* sp., *Polyarthra vulgaris*) were the first records from Chilika (Table 9.1). *Brachionus* and *Keratella* are α - β mesosaprobic genera and are indicative of moderate to high organic pollution in estuarine ecosystems (Sladeczek 1983; Tackx et al. 2004). Further, *Brachionus* sp. has been reported as an indicator of sulfide pollution in the Kadinamkulam estuary, Kerala (India) (Nandan and Azis 1994).

3.2.5 Hydrozoa

Hydrozoa exist as either single or colonial form in different life stages such as polypoid, medusoid, or both. In Chilika, only one species (*Obelia* sp.) has been recorded for the first time by our study which highlighted the need for a comprehensive monitoring to examine the planktonic hydrozoan diversity.

3.2.6 Ctenophora

Ctenophora, commonly known as comb jellies or sea walnut, are composed of soft, fragile, and gelatinous body. Further, bioluminescence is a common feature in most species of ctenophores. They are characterized by rows of cilia arrays, which are utilized for mobility (Pang and Martindale 2008). In general, ctenophores are carnivorous and predate on a diverse zooplankton such as copepods, amphipods, annelids, appendicularians, fish eggs, and larvae.

The qualitative and quantitative study of the ctenophores is challenging mainly because of their fragile body (Mianzan 1999). Specific nondestructive sampling methods are highly recommended. Consequently, ctenophores remain understudied worldwide including Chilika. Our study has reported a single species represented by *Pleurobrachia pileus* from the lagoon (Table 9.1, Plate 9.1). Ctenophores are understudied with respect to their detailed understanding on community composition, physiology, faunal interaction, metabolism, and their environmental drivers and need further investigation from the Chilika.

3.2.7 Nematoda

Nematoda are found either as free-living, or embedded in bottom sediments, or associated as parasites to a variety of biota. In general, they are occasionally observed in plankton samples. Further, zooplankton such as medusae, copepods, amphipods, and chaetognaths predate on immature nematodes. They exhibit

elongated, transparent, bilaterally symmetrical body structures and lack cilia or flagella. Our study recorded only a single Nematoda species represented by *Belbolla* sp. in plankton samples.

3.2.8 Annelida

Annelida is a broad phylum of segmented worms that are characterized by a body cavity or coelom. They possess setae or chaetae for locomotion. Annelida is subdivided into Oligochaeta and Polychaeta. Polychaeta are often found in planktonic communities, and only three tychoplanktonic polychaetes, viz., *Nereis chilkaensis*, *Neanthes glandicineta*, and *Perinereis marjorii*, have been reported from Chilika (Devasundaram and Roy 1954) (Table 9.1).

3.2.9 Gastropoda

Gastropoda is the largest class of molluscs that encompasses both planktonic and the benthic forms. Only few studies have reported Gastropoda from Chilika, and so far eight tychoplanktonic species have been documented (Devasundaram and Roy 1954). Our study has reported a total of four truly planktonic Gastropoda, viz., *Creseis acicula*, *Heliconoides inflatus*, *Atlanta* sp., and *Janthina* sp., as new records from the lagoon (Table 9.1).

3.2.10 Bivalvia

Bivalvia, the second largest molluscan class, is commonly known as Lamellibranchia or Pelecypoda. Majority of Bivalvia are benthic, either attached to hard structures or buried in the substratum. Devasundaram and Roy (1954) have reported five species of tychoplanktonic bivalves represented by three families such as Mytilidae (*Modiola undulatus* var. *crassicostata*), Veneridae (*Clementia annandalei*, *Meretrix casta*, *Marcia opima*), and Semelidae (*Theora opalina*) from Chilika (Table 9.1).

3.2.11 Cladocera

Cladocerans (water fleas) are small crustaceans and are recognized by a large compound eye. They belong to the class Branchiopoda and occur exclusively in freshwater, although some taxa can also tolerate higher salinity. The survival of cladocerans in estuarine ecosystems depends on their adaptation to the rapid changes in environmental factors (Haridevan et al. 2015). Most of the cladocerans are herbivorous. Conversely, cladocerans also act as food source for copepods, mysids, small fish, and larval and juvenile stages of larger fishes. Cladocerans exhibit both parthenogenetic and gamogenetic reproduction during favorable and unfavorable

environmental conditions, respectively (Egloff et al. 1997; Rivier 1998; Achuthankutty et al. 2000). Spatiotemporal variation in Cladocera is mostly controlled by salinity dynamics of the ecosystems. For example, salinity controlled the distribution, population structure, size, and grazing rates of cladocerans in Cochin backwaters (India) (Achuthankutty et al. 2000; Haridevan et al. 2015).

Devasundaram and Roy (1954) and Patnaik (1973) have reported one species each, namely, *Evadne* sp. and *Moina* sp., from Cladocera group. Our study has reported a total of 12 species (*Pseudevadne tergestina*, *Evadne nordmanni*, *Penilia avirostris*, *Diaphanosoma excisum*, *Diaphanosoma* sp., *Chydorus sphaericus*, *Chydorus* sp., *Alona* sp., *Bosminopsis deitersi*, *Macrothrix* sp., *Moina micrura*, *Moina* sp.) belonging to 3 orders (Onychopoda, Ctenopoda, and Anomopoda) (Table 9.1). Thus, Chilika remains an understudied system with respect to the cladoceran ecology despite their crucial role in fish diets.

3.2.12 Copepoda

Copepods (phylum, Arthropoda; class, Hexanauplia; subclass, Copepoda) are small crustaceans that are highly diverse and biologically important zooplankton group in all aquatic ecosystems. Copepoda is composed of a total ten orders of which Calanoida, Cyclopoida, Harpacticoida, and Poecilostomatoida are dominant ones. To date, ~12,000 copepod species have been identified (Bron et al. 2011). Copepods live either as free-living (pelagic or benthic) or parasitic lifestyle. Copepoda community structure is regulated by both abiotic and biotic environmental variables in estuarine and lagoon ecosystems (Dalal and Goswami 2001; Antony et al. 2020).

To date, 95 Copepoda taxa have been recorded from Chilika that include 55 Calanoida, 12 Cyclopoida, 13 Harpacticoida, and 15 Poecilostomatoida (Table 9.1). Devasundaram and Roy (1954) investigated copepod between 1950 and 1951 at few stations (Balugaon, Kalupadaghat, Rambha, Satpara, and Arkhakuda) and documented 12 species of copepods. Later, a survey during 2004–2005 on mesozooplankton focused on small-sized copepods' dynamics and recorded ten taxa (Rakesh et al. 2015). In contrast to previous studies, the diversity of species obtained in our survey was relatively higher. Copepoda population in our study was comprised of 80 species representing marine, brackish, and freshwater forms. These assemblages were categorized into four orders: Calanoida (47 species), Cyclopoida (8 species), Harpacticoida (10 species), and Poecilostomatoida (15 species). The dominance of Calanoida could be related to their continuous breeding, rapid larval development, and adaptation to a wide range of environmental conditions (Ramaiah and Nair 1997).

3.2.13 Ostracoda

Ecologically, ostracods can be considered as both zooplankton and benthos. Ostracoda are small crustaceans that are easily distinguished by bivalve carapace. Planktonic ostracods are opportunistic feeders and primarily feed on detritus.

They are also considered as potential indicators of climate change (Lord et al. 2012). Our study has reported a total of four taxa of Ostracoda as new records from the lagoon (Table 9.1). Among the reported species, *Discoconchoecia elegans*, *Chonchoecia* sp., and *Macrocypridina castanea* were representative of marine forms, while *Cypris* sp. was representative of freshwater forms. However, distributional and ecological studies on ostracods have not been conducted so far from Chilika.

3.2.14 Malacostraca

Malacostraca is the largest class within the phylum arthropod that has characteristics of four body regions, i.e., head, pereon, pleon, and urosome. Based on the available literature as well as our study, a total of 13 Malacostraca taxa belonging to 5 orders (Mysida, Amphipoda, Decapoda, Isopoda, Cumacea) have been reported from Chilika. Devasundaram and Roy (1954) have recorded ten tychoplanktonic/benthic Malacostraca and one planktonic Malacostraca. Later, Patnaik (1973) and Rakhesh et al. (2015) have documented two and one Malacostraca species, respectively. Our study has reported three species (*Gammarus* sp., *Belzebub hanseni*, and *Mesopodopsis orientalis*) of Malacostraca (Table 9.1).

3.2.15 Chaetognatha

Chaetognaths (also known as arrow worm) have a tubular elongated transparent body and are commonly present in marine, estuarine, and coastal lagoon habitats. Most of the chaetognaths are pelagic but few benthic species also exist. They are active predators and capture their prey with rigid hooks (Casanova 1999). In Chilika, only two species of Chaetognatha have been reported (Table 9.1). Devasundaram and Roy (1954) and Rakhesh et al. (2015) have reported the occurrence of only one species represented by *Sagitta* sp. The present study has reported two species, namely, *Flaccisagitta enflata* and *Sagitta* sp., from the lagoon.

3.2.16 Chordata

Planktonic chordates are represented mostly by two main classes, namely, Thaliacea and Appendicularia. Thaliacea include three main groups: dolioloids, salps, and pyrosomes. Appendicularia (also known as Larvacea) include three groups: Oikopleuridae (the most studied appendicularians), Fritillariidae, and Kowalewskiiidae. In Chilika, earlier studies have not reported planktonic chordates. Our study has reported two species represented by *Oikopleura dioica* and *Oikopleura* sp. as new records from the lagoon (Table 9.1).

3.3 *Meroplankton*

Meroplankton (or temporary plankton) are mainly composed of the larval stages of benthic, littoral, and nektonic organisms and are crucial for the recruitment of new individuals in the benthic community (Mileikovsky 1971). These larvae are classified as long-life planktotrophic (their duration in the plankton phase can vary from 1 week to 3 months), short-life planktotrophic (vary from 1 week or less), and lecithotrophic (a large yolk providing energy until metamorphosis) (Thorson 1946; Grahame and Branch 1985). In addition, these larvae might be either feeding or nonfeeding. They also serve as a necessary feedstuff for larger zooplankton and fishes (Maksimenkov 1982; Pennington et al. 1986). Meroplankton has been observed as a substantial part of the zooplankton community in many coastal lagoons (Miron et al. 2014; Ziadi et al. 2015). The abiotic factors and food availability have been shown to determine the distribution of meroplankton in the lagoon ecosystems (Santangelo et al. 2007; Ziadi et al. 2015). For instance, higher abundances of meroplankton associated with increased salinity have been reported in Imboassica Lagoon (southeastern Brazil) (Santangelo et al. 2007). In another study, peak abundances of barnacle larvae were found associated with higher phytoplankton density in Ghar El Melh Lagoon (northern Tunisia) (Ziadi et al. 2015).

Devasundaram and Roy (1954) documented six types of meroplankton (i.e., copepod nauplii, bivalve veligers, gastropod veligers, tunicate larvae, fish egg, fish larvae). Later Patnaik (1973) documented five types of meroplankton, among which penaeid prawn larvae were included in existing meroplankton list of Chilika. Rakhesh et al. (2015) reported seven types of meroplankton, of which five forms (protozoa of *Lucifer*, mysis of *Lucifer*, brachyuran protozoa, brachyuran zoea, alima larvae) were new reports. Sahu et al. (2016) recorded two molluscan larvae, i.e., bivalve veliger and gastropod veliger. However, our study has reported a total of 20 types of larval plankton, among which 9 forms were new records. To date, 23 types of meroplankton have been recorded in Chilika (Table 9.1).

3.4 *Microzooplankton Abundances and Community Composition*

The abundances of microzooplankton were significantly higher during monsoon (average 755 ind. l^{-1}) compared to post-monsoon (average 250 ind. l^{-1}) and pre-monsoon (average 347 ind. l^{-1}) (Fig. 9.2). At a spatial scale, the highest and lowest abundances were encountered from SS (average 614 ind. l^{-1}) and NS (average 147 ind. l^{-1}), respectively. This was consistent with earlier studies which have reported maximum microzooplankton abundances during monsoon, whereas minimum abundances were noted from freshwater NS region (Sahu et al. 2016). In general, microzooplankton standing stock is determined by salinity and phytoplankton biomass (Godhantaraman 2001; Jyothibabu et al. 2006). In the present study, higher

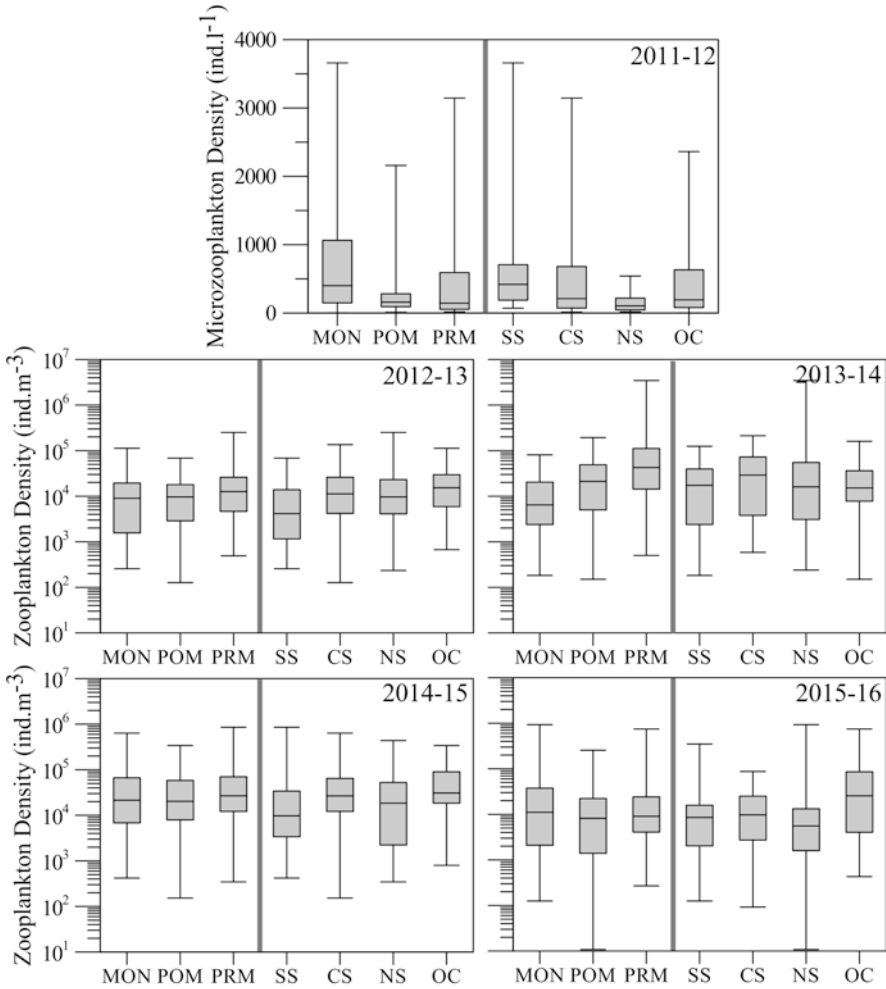


Fig. 9.2 Seasonal (*MON* monsoon, *POM* post-monsoon, *PRM* pre-monsoon) and spatial variability in microzooplankton and zooplankton density during study period. The central bar represents the median. The box represents interval between the 25% and 75% percentiles. The whisker indicates the range

abundances of microzooplankton during monsoon could be due to higher phytoplankton biomass. It has been shown that microzooplankton could consume about 43% of total phytoplankton biomass per day in Cochin backwaters (India) (Jyothisbabu et al. 2006). Therefore, one of the explanations for greater microzooplankton abundances during the monsoon period might be the availability of higher phytoplankton biomass (Srichandan et al. 2015a).

The microzooplankton community was composed of Ciliophora, Foraminifera, Rotifera, copepod nauplii, cirripede nauplii, gastropod veliger, and bivalve veliger.

Ciliophora (annual average 63%) were the most abundant microzooplankton, followed by copepod nauplii (30%), Rotifera (4%), and others (3%). Similar dominance of Ciliophora among different groups of microzooplankton has been reported from many Indian estuarine ecosystems (Rakshit et al. 2014; Sooria et al. 2015). A large seasonal variation in Ciliophora (i.e., tintinnid) abundances was observed with higher abundance (average 520 ind. l⁻¹) during monsoon followed by pre-monsoon (average 226 ind. l⁻¹) and post-monsoon (average 123 ind. l⁻¹) seasons (Fig. 9.3). The abundances of Ciliophora observed during the present study were fairly high or low in comparison to the earlier studies from other Indian estuarine ecosystems including Chilika. For instance, earlier studies have reported 48–55 ind. l⁻¹ from Chilika (Sahu et al. 2016), 1–17 ind. l⁻¹ from Bahuda estuary (Mishra and Panigrahy 1999), 409–3817 ind. l⁻¹ from Cochin backwaters (Jyothibabu et al. 2006), 2–420 ind. l⁻¹ from Parangipettai estuarine and mangrove waters (Godhantaraman 2002), and 52–1995 ind. l⁻¹ from Hooghly estuary (Rakshit et al. 2014, 2017; Rakshit and Sarkar 2016). In general, higher Ciliophora abundance during pre-monsoon season is a common feature in Indian estuarine ecosystems (Godhantaraman 2002; Madhu et al. 2007; Anjusha et al. 2018). In contrast, the maximum abundances of Ciliophora found in Chilika during monsoon could be due to the elevated water temperature and phytoplankton biomass (Srichandan et al. 2015a). Literature suggests that abundance, distribution, and ecology of Ciliophora are primarily governed by food availability (bottom-up control) and predator abundances (top-down control), competitor abundances (e.g., rotifers), temperature, and salinity (Godhantaraman 2002; Biswas et al. 2013; Gauns et al. 2015). Thus, the influence of phytoplankton and

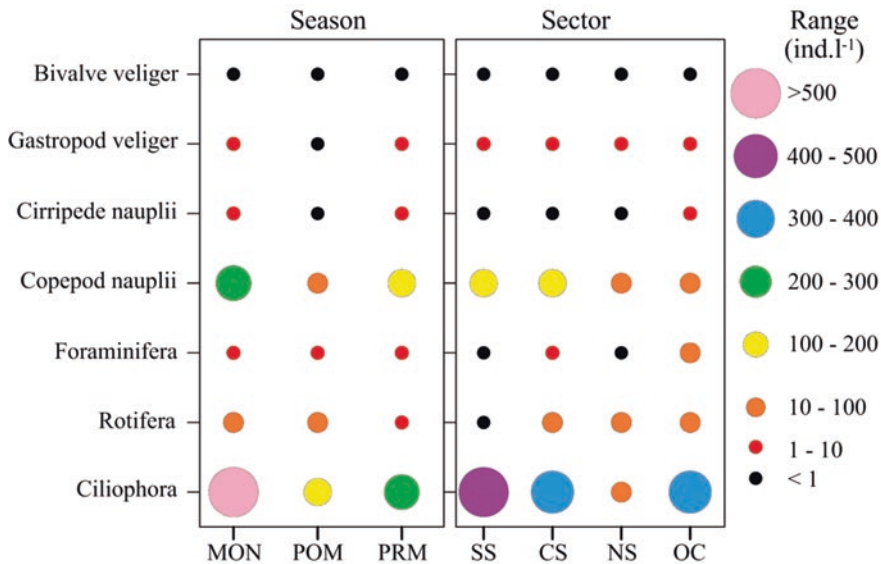


Fig. 9.3 Bubble plot showing seasonal and sectoral variability in microzooplankton communities

temperature in controlling the Ciliophora distribution during the monsoon season seems to be more crucial than other environmental variables.

The distribution of copepod nauplii closely followed the same trend as of Ciliophora with their highest and lowest abundances during monsoon (average 207 ind. l^{-1}) and post-monsoon (average 93 ind. l^{-1}), respectively (Fig. 9.3). Spatially, the highest copepod nauplii abundances were observed in CS (average 198 ind. l^{-1}) followed by SS (average 177 ind. l^{-1}), OC (average 88 ind. l^{-1}), and NS (average 64 ind. l^{-1}). The reason for the large contribution of copepod nauplii to the total microzooplankton might be due to the presence of older stage copepods (copepodites and adults) in higher abundances (maximum up to 571 ind. l^{-1}) in Chilika. Similar large proportion of copepod nauplii in total microzooplankton population has been observed in a brackish water lagoon of Japan (Godhantaraman and Uye 2003).

Rotifera responds quickly to the favorable environmental conditions by parthenogenetic reproduction. In contrast, population size of Rotifera often decline immediately under adverse environmental conditions (Sanders 1987). In Chilika, contribution of Rotifera was lesser in comparison to Ciliophora and copepod nauplii. Rotifera population exhibited a wide range of seasonal fluctuation from 2 (pre-monsoon) to 30 (monsoon) ind. l^{-1} (Fig. 9.3). A clear spatial pattern was also evident in the distribution of Rotifera. The highest abundance of Rotifera was found in the low saline upper reaches (NS) of Chilika, whereas they were completely absent in SS which has higher stable salinity regime. Similar dominance of Rotifera has been recorded in the upper estuarine region (oligohaline to limnetic conditions) of Cochin backwaters (India) (Anjusha et al. 2018). In OC of Chilika, a sharp drop in the salinity occurs during the monsoon months of September and October when there is unidirectional flow of water from lagoon to sea. The drop in salinity of OC could have allowed the appearance of rotifers community in monsoon, although this sector is in close proximity to the BoB. In CS, rotifers appeared particularly at station CS3 which experienced lower salinity during monsoon (salinity 5.8) and post-monsoon (salinity 5). Other microzooplankton such as Foraminifera, cirripede nauplii, gastropod veliger, and bivalve veliger showed a minor contribution at spatiotemporal scales in the lagoon.

3.5 Zooplankton Abundances and Community Composition

A significant variability in zooplankton density between different sectors, seasons, and years was evident in this study. The zooplankton abundances were substantially higher during Y-2 (65×10^3 ind. m^{-3}) followed by Y-3 (62×10^3 ind. m^{-3}), Y-4 (38×10^3 ind. m^{-3}), and Y-1 (19×10^3 ind. m^{-3}). The annual variability in zooplankton abundances followed unimodal seasonal pattern with peak abundances during pre-monsoon except during Y-4 (Fig. 9.2). This was in corroboration with other studies from Indian estuaries, which have observed maximum zooplankton density during pre-monsoon (Madhu et al. 2007; Bhattacharya et al. 2015). The reason for the higher zooplankton abundances during pre-monsoon could be attributed to

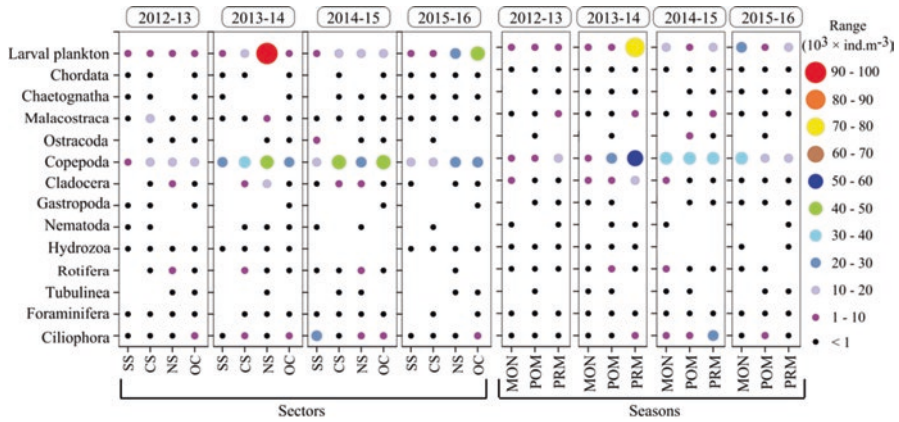


Fig. 9.4 Bubble plot showing seasonal and sectoral variability in zooplankton communities during study years

increased salinity supporting intrusion of marine zooplankton into the lagoon (Madhu et al. 2007). In addition, increased salinity during pre-monsoon could result recruitment of zooplankton population in the lagoon due to rapid multiplication (Venkataramana et al. 2017). The reason for the lower abundances of zooplankton during monsoon might be due to unidirectional flow of water from lagoon to sea resulting concurrent flushing of zooplankton. Similar lower zooplankton abundances during monsoon due to high flushing rate have been observed from Cochin backwaters (India) (Madhupratap 1987; Sooria et al. 2015).

Zooplankton communities in Chilika were distributed into 15 diverse categories, namely, Ciliophora, Foraminifera, Rotifera, Tubulinea, Hydrozoa, Ctenophora, Gastropoda, Cladocera, Copepoda, Ostracoda, Malacostraca, Chaetognatha, Chordata, Nematoda, and planktonic larvae. Copepoda constituted the most dominant zooplankton group irrespective of seasons, sectors, and study year which was in accordance with other coastal lagoons (Naik et al. 2008; Etile et al. 2009; Miron et al. 2014; Rakhesh et al. 2015; Ziadi et al. 2015; Antony et al. 2020). For instance, 81% of copepods' contribution to total zooplankton has been noted in Grand-Lahou lagoon (West Africa) (Etile et al. 2009). In general, increase in salinity is believed to be an important factor for raising the copepod abundances during pre-monsoon season (Vineetha et al. 2015). Copepoda abundances during Y-1 and Y-2 had similar seasonal patterns with higher abundances during pre-monsoon (Fig. 9.4). During Y-3, copepod abundances showed different pattern with much higher abundances during post-monsoon (average $36 \times 10^3 \text{ ind. m}^{-3}$) than pre-monsoon (average $33 \times 10^3 \text{ ind. m}^{-3}$) and monsoon (average $34 \times 10^3 \text{ ind. m}^{-3}$). However, during Y-4, copepod abundances during the monsoon (average $32 \times 10^3 \text{ ind. m}^{-3}$) were prominently higher than post-monsoon (average $12 \times 10^3 \text{ ind. m}^{-3}$) and pre-monsoon (average $13 \times 10^3 \text{ ind. m}^{-3}$). These contrasting response of copepods could be attributed to an increase in salinity (average 13.6) due to relatively lower rainfall during

monsoon of Y-4 (710 mm) compared to other years (Y-1, 855 mm; Y-2, 1533 mm; Y-3, 1340 mm).

Planktonic larvae were the second most abundant group in zooplankton communities. The meroplankton were mostly dominated by copepod nauplii, gastropod veliger, and bivalve veliger. This type of preponderance of larval plankton, especially gastropod veliger and bivalve veliger, suggested a pivotal role of meroplankton in the coupling of benthic–pelagic food webs. The abundance of meroplankton was comparatively higher during pre-monsoon which was in agreement with a study from Cochin estuary (India) (Vineetha et al. 2015). At spatial scale, meroplankton was higher in NS during Y-1 and Y-2 while in OC during Y-3 and Y-4 (Fig. 9.4).

Other zooplankton groups such as Cladocera, Ciliophora, Malacostraca, and Rotifera were also present in higher numbers in the lagoon. The annual variability in Cladocera and Rotifera followed a unimodal pattern with peak abundances during monsoon except for Y-2 (Fig. 9.4). In Y-2, maximum abundances of Cladocera and Rotifera were noticed during pre-monsoon and post-monsoon seasons, respectively. The reason for this unusual condition could be attributed to the reduction in salinity in the aftermath of cyclone *Phailin* (October 2013). The low salinity values recorded in CS (salinity 9; station CS4; February 2014) and NS (salinity 1; station NS1; March 2014) favored the development of a large number of oligohaline Rotifera and Cladocera. Furthermore, due to heavy rainfall and land runoff during *Phailin*, a copious amount of freshwater entered into Chilika which reduced the salinity of the lagoon, drastically (Srichandan et al. 2015b). Eventually, Cyanophyta became the most abundant group in CS as well as NS throughout Y-2, which may have favored the growth of Cladocera and Rotifera (Mukherjee et al. 2018). The freshwater brings large organic matter including bacterial load, which may serve as a good source of food for cladocerans (Venkataramana et al. 2017). Spatially, higher abundances of Rotifera and Cladocera were registered in NS and CS, while they were almost absent in SS over the study period (Fig. 9.4). Distribution of Malacostraca showed unimodality with peak abundances during pre-monsoon except for Y-4. Spatially, Malacostraca were comparatively higher in CS and NS as compared to SS and OC over the study period (Fig. 9.4).

3.6 Hydrography and Phytoplankton

Chilika is characterized by a large seasonal and spatial variability in physicochemical factors attributed to the reversing tropical monsoon (southwest monsoon and northeast monsoon). Over the study period, a clear seasonal pattern of rainfall was observed, with the highest during southwest monsoon. Salinity was lowest during monsoon and highest during pre-monsoon over the study period. Annual mean salinity in Y-4 (16) was significantly higher than in Y-1 (13), Y-2 (10), and Y-3 (9). The pH remained mostly alkaline (annual average 7.8–8.4) which could be due to extensive buffering capacity of seawater causing the change of pH within a very

narrow limit (Srichandan et al. 2015a). The overall observed DO showed marked variation ranging from 3.87 to 14.0 mg l⁻¹. The overall NO₃⁻, PO₄³⁻, and SiO₄⁴⁻ concentrations were recorded in the range of 0.0–35.2, 0.01–4.0, and 0.0–258.9 μmol l⁻¹, respectively. A distinct spatiotemporal heterogeneity in distribution of nutrients was observed over the study period. The overall trend in distribution of NO₃⁻ showed higher values during pre-monsoon, which could be ascribed to the higher residence time during pre-monsoon (325 days) than monsoon (56 days) (Muduli et al. 2013). SiO₄⁴⁻ was highest during monsoon, which was linked to the increased river influx containing soil and silt particles (Srichandan et al. 2015a). Over the study period, phytoplankton density varied in between 54 and 464,160 cells l⁻¹ with significant spatiotemporal variations. In this study, seven phytoplankton classes, Bacillariophyta, Chlorophyta, Euglenophyta, Dinophyta, Cyanophyta, Chrysophyta, and Haptophyta, were identified.

3.7 Environmental Drivers of Microzooplankton and Zooplankton Communities

CCA biplots showed that salinity was the key driver controlling the microzooplankton components especially Rotifera. A negative correlation was observed between the freshwater zooplankton group Rotifera and salinity ($r = -0.330$, p -value <0.01) which was consistent with several estuarine ecosystems including Chilika (Park and Marshall 2000; Anjusha et al. 2018; Mukherjee et al. 2018). The abundances of Ciliophora and Dinophyta were positively correlated ($r = 0.322$, p -value <0.01) which was in accordance with a study from Hooghly River estuary (India) (Rakshit et al. 2014) (Fig. 9.5). In addition, Ciliophora exhibited a negative correlation with NO₃⁻, PO₄³⁻, and SiO₄⁴⁻. Apart from environmental variables, Ciliophora also showed a negative correlation with Rotifera which corroborated with earlier reports from Rhode River estuary of Chesapeake Bay (Dolan and Gallegos 1992). The negative relationship could be due to competition between Ciliophora and Rotifera for their preferred foods such as bacterioplankton (Buikema et al. 1978).

CCA further showed the influence of environmental variables on the zooplankton community composition. Salinity showed a positive correlation with Copepoda which agreed with other studies from estuarine systems (Miron et al. 2014; Bhattacharya et al. 2015; Vineetha et al. 2015). Generally, any monodiet of Bacillariophyta or Dinophyta is nutritionally inadequate for the growth and reproduction of copepods (Jones and Flynn 2005). CCA showed that Copepoda were mostly associated with both Bacillariophyta and Dinophyta which often are considered the most abundant food for copepods (Liu et al. 2010) (Fig. 9.5). Further, Dinophyta are important food material for copepods due to their higher volume-specific organic content (Kleppel 1993). It has been shown that copepods on a Dinophyta diet increase their egg production and survival rates (Shin et al. 2003; Sushchik et al. 2004).

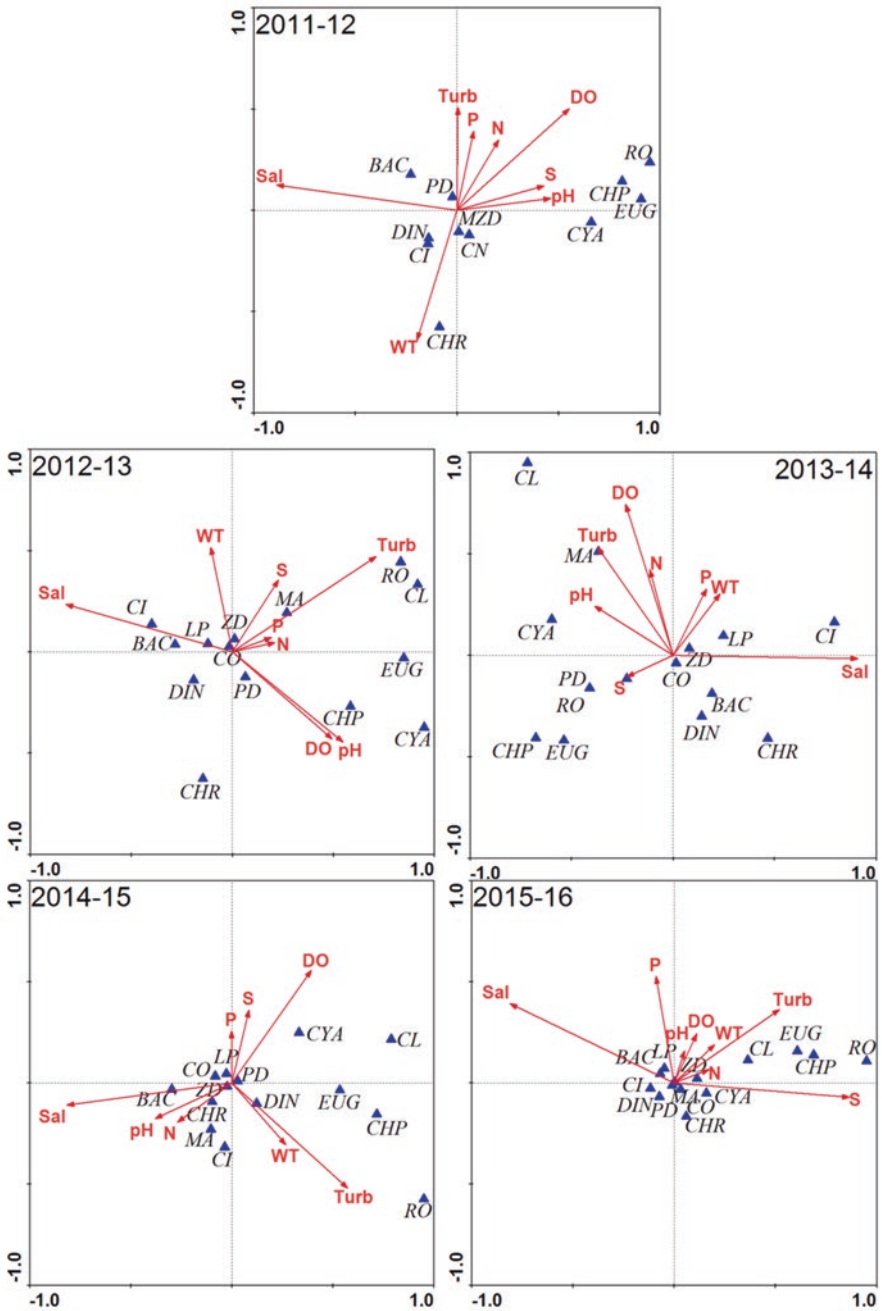


Fig. 9.5 CCA biplots of biological (dominant microzooplankton, zooplankton, and phytoplankton groups) and environmental variables. *WT* water temperature, *DO* dissolved oxygen, *Sal* salinity, *Turb* turbidity, *N* nitrate, *P* phosphate, *S* silicate, *PD* phytoplankton density, *MZD* microzooplankton density, *ZD* zooplankton density, *CI* Ciliophora, *RO* Rotifera, *CN* copepod nauplii, *CL* Cladocera, *CO* Copepoda, *MA* Malacostraca, *LP* larval plankton, *BAC* Bacillariophyta, *DIN* Dinophyta, *CYA* Cyanophyta, *CHP* Chlorophyta, *EUG* Euglenophyta, *CHR* Chrysophyta

In Chilika, multiple environmental variables influenced the distribution and abundances of rotifers. For instance, CCA plot showed a significant positive correlation of rotifers with turbidity, NO_3^- , PO_4^{3-} , and SiO_4^{4-} during Y-1. However, during Y-2 (*Phailin* cyclone year), SiO_4^{4-} , phytoplankton abundances, Chlorophyta, and Euglenophyta showed a positive correlation with rotifers (Fig. 9.5). In addition, salinity was negatively correlated with rotifers during Y-2. During Y-3 (*Hudhud* cyclone year), both correlation matrix and CCA analyses showed that water temperature, turbidity, and Chlorophyta were the key drivers of rotifers distribution. During Y-4, rotifers were positively correlated with several biotic (Chlorophyta, Euglenophyta) and abiotic (water temperature, turbidity, dissolved oxygen, pH, NO_3^-) factors. These abiotic and biotic factors have been shown to control the rotifer community structures in many estuarine ecosystems (Gopakumar and Jayaprakash 2003; Azemar et al. 2010; Varghese and Krishnan 2011; Garcia and Bonel 2014; Wei and Xu 2014; Mukherjee et al. 2018). For example, salinity, SiO_4^{4-} , and phytoplankton biomass were the main controlling factors of the rotifer community in Schelde estuary (Belgium) (Azemar et al. 2010). In another study, turbidity and PO_4^{3-} were the main factors determining the rotifers communities in Cochin backwaters (India) (Varghese and Krishnan 2011). Literature also suggests that rotifers are adapted to thrive under high turbidity as the adverse consequences of competition and predation are partly reduced due to low visibility (Thorp and Mantovani 2005).

In Chilika, cladocerans showed a positive relationship with turbidity in most of the study years which could be attributed to their sensitivity to visual predation (Pangle and Peacor 2009). Both CCA and correlation matrix showed a significant positive correlation of cladocerans with Cyanophyta during Y-2 and Y-3, whereas during Y-4 it was positively correlated with Euglenophyta (Fig. 9.5). The positive relationship between Cladocera and Euglenophyta suggested that the latter could be a good food source for Cladocera (Kawecka and Eloranta 1994). It has been shown that cladocerans graze on colonial or filamentous Cyanophyta (Ka et al. 2012; Tonno et al. 2016). CCA also showed a negative correlation between Cladocera abundance and salinity during Y-2 and Y-3 signifying prevalence of limnophilic forms. Malacostraca were observed in close association with turbidity which was consistent with a study from Gironde estuary (France) (David et al. 2005).

4 Conclusion

The present study is the first compilation on the diversity, composition, and distribution of zooplankton communities from Chilika. To date, 263 species of holoplankton (51 Ciliophora, 13 Foraminifera, 5 Tubulinea, 42 Rotifera, 1 Hydrozoa, 1 Ctenophora, 1 Nematoda, 3 Polychaeta, 12 Gastropoda, 5 Bivalvia, 13 Cladocera, 95 Copepoda, 4 Ostracoda, 13 Malacostraca, 2 Chaetognatha, 2 Chordata) and 23 types of meroplankton have been documented. The present study documented a total of 186 zooplankton taxa, of which 131 were first records from the lagoon. A

strong spatial–seasonal variation was evidenced in the zooplankton community which was attributed to the variability in biotic and abiotic variables. A clear seasonal cycle with pre-monsoon maxima was observed in zooplankton abundances over the study period. Copepoda, the most diverse and dominant zooplankton taxon, was represented by calanoids, cyclopoids, harpacticoids, and poecilostomatoids. Other zooplankton groups such as Rotifera, Ciliophora, Cladocera, Malacostraca, and larval plankton also showed higher abundances at spatiotemporal scales. Biotic–abiotic interactions revealed through CCA showed the combined effects of environmental variables and availability of sufficient phytoplankton diet such as Bacillariophyta and Dinophyta as a major factor controlling the composition of Copepoda. CCA also revealed that biotic (Chlorophyta, Euglenophyta) and abiotic variables (water temperature, salinity, turbidity, dissolved oxygen, pH, NO_3^- , SiO_4^{4-}) were the key factors responsible for controlling the distribution of Rotifera. Salinity and availability of food sources played an important role in controlling the abundances, distribution, and diversity of cladocerans. Turbidity played a significant role in controlling the abundance of Malacostraca. This study provided detailed information on the microzooplankton community of Chilika which enhanced our understanding regarding their crucial role in this lagoon. Generally, species diversity and composition is the most recognized facet, but attempts are also essential, specifically with respect to the medusae including jellyfish that are understudied in Chilika. In addition, fine-scale (diurnal and tidal) monitoring is also important to gain deeper insights on the zooplankton ecology. Further, studies on identifying indicator zooplankton taxa may help in discerning the effect of climate change on hydrobiological regimes of the lagoon.

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