Chapter 10
The Littoral Community

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10.1 The Littoral Zoobenthos

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The littoral zone of the lakes is an ecotone that forms an independent compartment comprising all trophic levels (primary producers, consumers, decomposers), a large diversity of ecological niches and food webs (herbivory and detrital), and a great diversity (Roldán and Ramírez 2008). The lake's littoral area presents a high environmental heterogeneity, which leads to a diversity of habitats susceptible to being occupied by a rich and diverse benthic fauna Esteves (1988).

Lake Alchichica embraces a discontinuous stromatolites ring that runs parallel and close to the littoral. This carbonated structure jointly with the gradual decrease of the lake's water level has resulted in different isolation degrees of separation between the littoral and pelagic zones; in this way, there are littoral regions that are in direct contact and interchange with the pelagic zone, while others, in the opposite end, are isolated (see Chap. 8).

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The littoral area of Lake Alchichica characterizes an ample range of environmental and biological characteristics resulting in a wide variety of habitats exposed to high temporal variability associated to fluctuations in the weather conditions, water level, wave energy, and biological activity.

10.1.1 Background Studies

The first study of the littoral benthos of Lake Alchichica revealed 10 chironomid species ranging between four and seven in different littoral areas (Alcocer et al. 1993a). The most important chironomid numerically and in biomass contribution was *Tanypus* (*Apelopia*) sp. Alcocer et al. (1993b) reported 15 taxonomic groups of benthic macroinvertebrates (BMI) in the littoral of Lake Alchichica. Tubificids, hirudinean, amphipods, and chironomids were the most frequent and abundant groups. Macrophytes coverage and salinity played an essential role in explaining the taxonomic richness of BMI in Lake Alchichica.

Subsequently, Alcocer et al. (1998) reported 44 taxa of littoral BMI in Lake Alchichica. Four taxa composed up to 99% of the organisms present: oligochaetes, amphipods, midges, and leeches; the most important species were *Limnodrilus hoffmeisteri*, *Hyalella azteca*, *Tanypus (Apelopia)*, and *Stictochironomus* sp. Once again, aquatic vegetation is the critical variable explaining taxonomic richness. Some studies provide additional information on the biology/ecology of specific taxa.

Hyalella azteca displayed a high density (13,496 ± 20,740 ind/m^2) that remained constant throughout the annual cycle with no significant difference among the littoral zones (Alcocer et al. 2002). The vegetation type and coverage play a significant role in the amphipod dynamics. The population structure of *H. azteca* showed juveniles were numerically dominant (55–64%), followed by females (13–20%), males (10–17%), and ovigerous females (8–14%). The male to female ratio was 1:1.75. Fecundity was positively correlated to female size; the number of eggs carried by the ovigerous females was 4.5 ± 2.8 eggs/female.

Oligochaete species richness of Lake Alchichica (i.e., *Limnodrilus hoffmeisteri* and *Tubifex tubifex*) is among the lowest worldwide. High oligochaete densities and biomasses values (>45,000 ind/m^2 and >2700 mg AFDW/m^2) in the littoral zone of Lake Alchichica associated with surface sediments with high organic matter content. Density and biomass values of oligochaetes did not show significant seasonal differences (Peralta et al. 2002). *Limnocytherina axalapasco* and *Candona alchichica* in the littoral zone reached densities up to 3612 ± 4148 ind/m^2 and 22,812 ± 16,045 ind/m^2, respectively, and biomasses of 9.83 ± 11.6 mg C/m^2 and 366.2 ± 281 mg C/m^2, respectively (Hernández et al. 2010). Finally, *Cletocamptus gomezi* in the littoral zone reached a density of 4106 ± 10,962 ind/m^2 with biomass of 3.66 ± 9.75 mg C/m^2, with no statistical temporal differences in density or biomass (Alcocer et al. 2015).

10.1.2 Structure: Composition and Richness

A total of 53 taxa of benthic organisms (Table 10.1) has been mentioned to inhabit the littoral zone of Lake Alchichica (Acosta et al. 2017; Alcocer et al. 1993a, b, 1998, 2002; Cohuo-Durán et al. 2014; Escobar-Briones and Alcocer 2002; Peralta et al. 2002; Suárez-Morales et al. 2013).

However, a more recent study by Alcocer et al. (2016), considering 11 sampling stations equally distributed along the littoral zone of Lake Alchichica found only 21 macroinvertebrates. The taxonomic richness ranges from 2 to 13 with an average of 9 ± 3 taxa (Fig. 10.1).

The only species present in all localities (100%) is the tubificid worm *Limnodrilus hoffmeisteri*, followed by the amphipod *Hyalella azteca* (90%), the leeches

Table 10.1 Taxonomic list of the benthic invertebrates that inhabit the littoral zone of Lake Alchichica

Crustacea	*Hyalella azteca*	Chironomidae	*Cricotopus (Isocladius) triannulatus*
	Limnocytherina axalapasco		*Psectrocladius*
	Candona alchichica		*Limnophyes*
	Cletocamptus gomezi		*Micropsectra sp. 1*
Oligochaeta	*Limnodrilus hoffmeisteri*		*Micropsectra sp. 2*
	Tubifex tubifex		*Chironomus alchichica*
Hirudinea	*Helobdella stagnalis*		*Tanypus (Apelopia)*
	Glossiphoniidae		*Procladius*
Nematoda	*Neotobrilus*		*Dicrotendipes neomodestus*
	Semitobrilus		*Psectrotanypus*
	Tobrilus		*Apedilum elachistus*
	Hoplolaimus sp. 1		*Chironomus (s. str.)*
	Hoplolaimus sp. 2		*Cryptochironomus sp. fulvus gr.*
	Paracyatholaimus		*Stictochironomus*
	Daptonema		*Paratanytarsus*
	Monhystera		*Labrudinea pilosella*
Mollusca	*Physa*	Trichoptera	*Grensia*
Odonata	*Enallagma praevarum*		*Oecetis*
	Aesxhna dugesi		*Oxyethira*
Hemiptera	*Ambrysus*		*Polycentropus*
	Buenoa	Coleoptera	*Berosus*
	Krizousacorixa tolteca		*Stenus*
Ephemeroptera	*Callibaetis montanus*		*Tropisternus*
Diptera	*Culicoides occidentalis sonorensis*		*Donacia*
	Culex		*Hydroporus*
	Stratiomys		*Lacodytes*
	Ephydra hians		

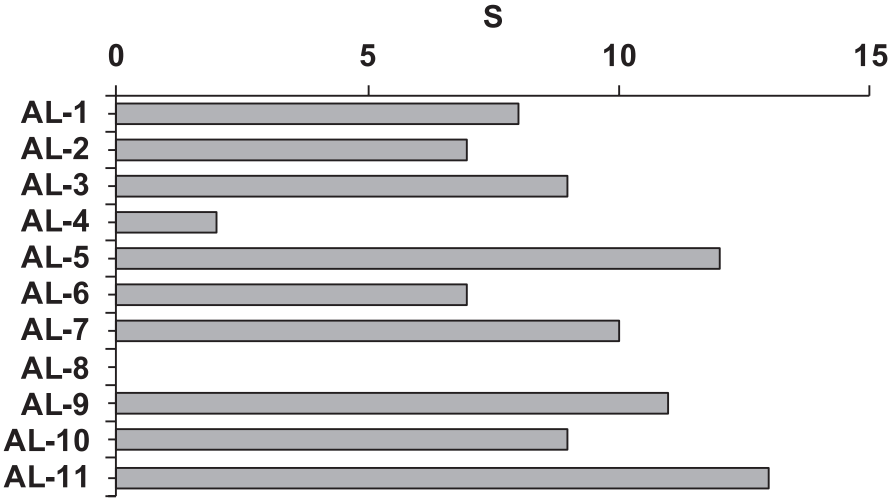

Fig. 10.1 BMI taxonomic richness (S) in the littoral zone of Lake Alchichica. (AL-1 to AL-11 = littoral sampling stations; see Chap. 8, Fig. 8.1)

Helobdella stagnalis, Glossiphoniidae, and the midge *Micropsectra* (80%), and the water boatmen *Krizousacorixa tolteca,* and the midges *Cricotopus (Isocladius) triannulatus* and *Chironomus stigmaterus* (now *Chironomus alchichica*) (60%).

10.1.3 Distribution and Seasonal Variations

The BMI distribution along the littoral zone was heterogeneous, which was not surprising considering the littoral area is environmentally diverse (see Chap. 8). Regarding abundance, the oligochaete *Limnodrilus hoffmeisteri* (43%) and the amphipod *Hyalella azteca* (39%) contributed with the largest percentage (82%) well above the other taxa (Fig. 10.2). *Limnodrilus hoffmeisteri* (0–80%) dominated in 60% of the sampling stations, while *Hyalella azteca* (18–100%) dominated in the other 40%. At located littoral areas, *Micropsectra* and *Tanypus (Apelopia)* (≈5%) reached higher abundances (≈10% and 5%, respectively).

The average density of the MIBs ranged from 7437 ± 5724 ind/m^2 to 70,252 ± 14,407 ind/m^2, with a global mean of 33,536 ± 20,463 ind/m^2. The BMI abundance peak was associated with the diatom and cyanobacteria blooms, most likely providing abundant and fresh food (Pérez-Rodríguez et al. 2013). Sediment texture played a key role in explaining BMI distribution. The diversity of Shannon ranged from 0.002 to 1.69 with an average of 1.26 ± 0.54. Shannon's maximum diversity fluctuated in a range of 0.33 to 3.06 with an average of 2.49 ± 0.84. Finally, Shannon's evenness ranged from 0.002 to 0.73 with an average of 0.46 ± 0.20 (Alcocer et al. 2016).

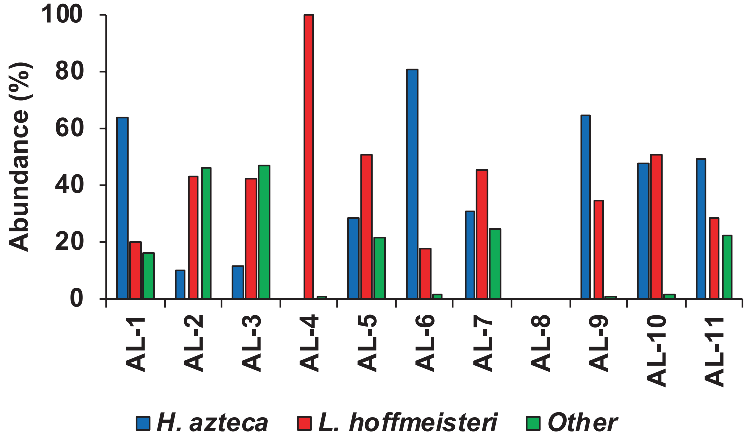

Fig. 10.2 Relative abundance of the dominant BMI in the littoral zone of Lake Alchichica. (AL-1 to AL-11 = littoral sampling stations; see Chap. 8, Fig. 8.1)

Total BMI biomass was 88.5 ± 309.5 mg C/m^2. Temporarily, July displayed the lowest average biomass (37.52 ± 138.71 mg C/m^2), while May the highest average biomass (129.75 ± 450.06 mg C/m^2). Spatially, the biomass among sampling stations ranged from 25.72 ± 104.86 mg C/m^2 to 151.48 ± 484.52 mg C/m^2 (Alcocer et al. 2016; Pérez-Rodríguez et al. 2013).

10.1.4 Function and Trophic Complexity

The community structure of the littoral ecosystem simplifies as littoral-pelagic isolation increases. Although simplification is graphically evident in a decrease in taxonomic richness, diversity, maximum diversity, and equity (but not in density), it is not supported statistically (Alcocer et al. 2016).

Detritivores (43.3 ± 23.1%) and herbivorous (40.1 ± 25.7%) BMI dominated numerically over carnivorous (16.6 ± 16.0%) in the littoral zone of Lake Alchichica (Fig. 10.3). Detritivores and herbivores were dominant in 40% of each of the littoral stations, in 10% were co-dominant, while 10% dominated the carnivorous.

According to Pérez-Rodríguez et al. (2013), there are four trophic guilds in the littoral BMI of Lake Alchichica. Herbivorous composed the highest percentage (50%, 155 ± 471.9 mg C/m^2) of the total biomass, while filter feeders constituted the lowest percentage (3%, 39.4 ± 72.1 mg C/m^2); detritivores accounted for 28% of the total biomass (85.8 ± 274.6 mg C/m^2), while predators contributed 19% of the total biomass (47.1 ± 152.9 mg C/m^2). Throughout the year, the biomass of detritivores and predators BMI remained similar, while herbivorous peaked in May, followed by a minimum in July. Filter feeders peak in January and diminished in July. Spatially, all littoral stations were different in their percentual composition of trophic guilds.

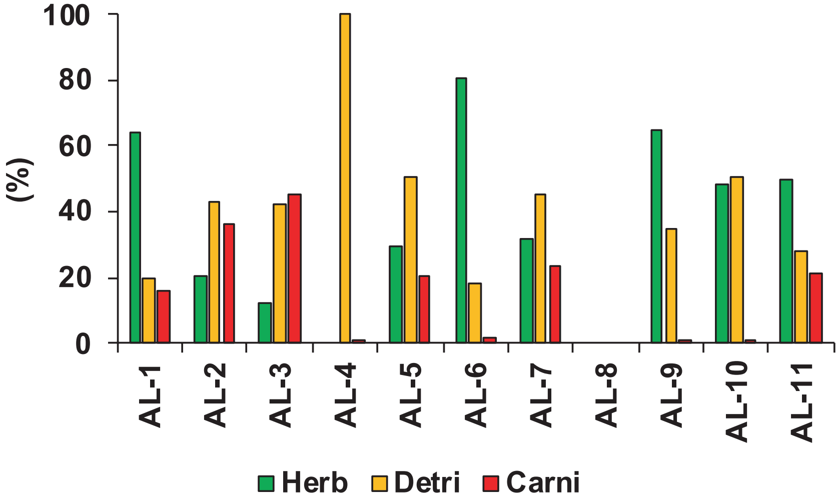

Fig. 10.3 Trophic groups of BMI in the littoral zone of Lake Alchichica. (*Herb* herbivores, *Detri* detritivores, *Carni* carnivores; AL-1 to AL-11 = littoral sampling stations; see Chap. 8, Fig. 8.1)

In general, the stations with the highest vegetation cover presented the highest BMI biomass composed mainly of herbivores. Plant coverage and sedimentary organic matter content were the most critical factors in explaining the MIB biomass and distribution.

There are six Functional Feeding Groups -FFG- in the littoral BMI assemblages of Lake Alchichica (Fig. 10.4). Most of the BMI are collector-gatherers (40.5 ± 25.9%), shredders (35.2 ± 28.0%), and predators-engulfer (14.2 ± 15.7%), while piercers-predators, piercers-herbivorous and scrapers were scarce (<1%).

10.1.5 Cryptic Fauna

The shape of the lake's basin approximates that of a cylinder (see Chap. 6). Nowadays, the lake has a reduced littoral area and a very abrupt slope with calcareous deposits called "tufa" (stromatolites). Tufa forms when carbonate-rich groundwater emerges in an alkaline-sodium lake, precipitating the carbonates in the form of calcite and, to a lesser extent, aragonite; microbial activity promotes carbonate precipitation (see Chap. 22). Tufa deposits that come in the form of a ring on the lake's periphery resemble, by their appearance, coral reefs. More critical, tufa deposits constitute an available habitat for cryptic species.

Stromatolites are solid mounds or cylinders of carbonate deposition that hardly retain sediments preventing benthic organisms from settling. Nonetheless, Escobar-Briones and Alcocer (2002) found and described a new asellid isopod species, *Caecidotea williamsi*, cryptically inhabiting in tufa crevices. *C. williamsi*

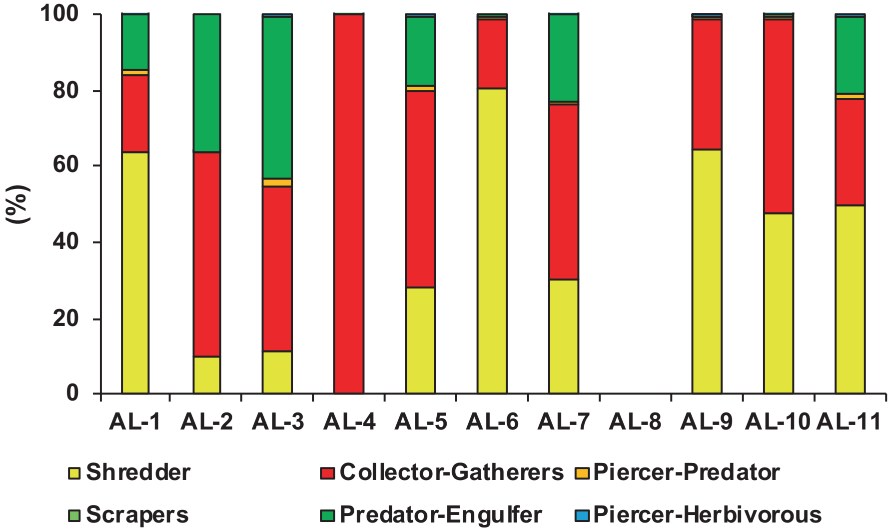

Fig. 10.4 FFG of BMI in the littoral zone of Lake Alchichica. (AL-1 to AL-11 = littoral sampling stations; see Chap. 8, Fig. 8.1)

constitutes the first report of an epigean asellid isopod inhabiting inland saline waters in America. Hernández et al. (2010) found *C. williamsi* shares this habitat with the amphipod *Hyalella azteca*, and two ostracods, *Limnocythere inopinata* (now *Limnocytherina axalapasco*) and *Candona* sp. (now *Candona alchichica*).

C. williamsi is a small isopod (1–8 mm) with pigmented eyes. The body is mottled pale and light brown or gray. Many individuals inhabit empty trichopteran cases cemented within the tufa crevices. Its crevicular habitat explains its absence from other benthic habitats in the lake (Alcocer and Escobar-Briones 2007).

10.2 Littoral Heterotrophic Protists

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10.2.1 Introduction

As previously mentioned, the presence of stromatolites in the littoral zone of Lake Alchichica favors the formation of numerous microenvironments, with a wide range of biological and environmental conditions and a great diversity of habitats. In this work, heterotrophic protists diversity associated with the littoral zone was studied in a lake site where the stromatolites' littoral conditions combine with an area more related to open waters. To carry out the study, we use the colonization method of artificial polyurethane foam units (PFU) substrates proposed by Cairns et al. (1969). Cairns et al. (1979) found that the equilibrium in the number of protist species colonizing the PFU is reached around 21 days. In the present study, the substrates stayed in place until 38 days. During this period, the presence of 39 species of heterotrophic protists was observed in Alchichicica.

Protists perform numerous important functions in water bodies: autotrophic flagellates contribute to primary production through their ability to photosynthesize. Heterotrophic nanoflagellates (HNFs) are the primary consumers of bacteria, as are ciliates and small amoebae. Larger ciliates can consume, in addition to bacteria, flagellates, phytoplankton, diatoms, and other ciliates; large amoebae also consume algae, flagellates, ciliates, diatoms, etc. (Fenchel 1987). Protists are usually abundant in the littoral zone of water bodies since there are abundant and different types of food; in addition to diverse ecological niches, such as parts of aquatic plants, biofilms on surfaces (on the rocks and sediment), and filamentous algae. In turn, they are part of the food of larger organisms as rotifers, microcrustaceans (copepods, cladocerans), and macrocrustaceans such as ostracods or *Hyalella* (Monakov 2003).

In 1990, the study of protists from the littoral zone was carried out in Lake Alchichica using the method of polyurethane foam units (PFU) colonization (Cairns et al. 1969). It is a simple method that allows obtaining comparable samples at various sampling sites and at different times, reducing the difficulty in studying the various taxonomic groups and simplifying information on the community's structure (Bamforth 1982; Pratt et al. 1986). Polyurethane foam constitutes a habitat used in different ways by protists: as a refuge, as a fixation site, and as a place for feeding.

The PFUs (three replicates for each sampling date) were placed in the littoral zone, in the outer part of the barrier formed by the stromatolites. The environmental conditions of the littoral are fully described in the Chap. 8. According to Plafkin et al. (1980) the PFU colonization process behaves like a colonization of islands and follows the McArthur-Wilson model.

Since the study was carried out with the water extracted from the PFU, it was not possible to quantify the species' absolute density. The densities are in ind/mL referred to as one milliliter of water volume squeezed from the PFUs. In the present study, the substrates were in place until 38 days.

All the species observed are considered free-living (Table 10.2). In Fig. 10.5, it is evident that Alveolata (Ciliata) and Discoba groups had the highest number of species throughout the colonization process. After them, Stramenopiles and Amebozoa were the groups with the most species. All ciliates' species are found within Alveolata, while species included in the trophic group of HNF (heterotrophic nanoflagellates) belong to the supergroups Discoba, Stramenopiles, and Holozoa.

Bodo caudatus (6159 ± 4494 ind/mL), *Bodo saltans* (1532 ± 982 ind/mL), and *Spumella termo* (1428 ± 1168 ind/mL) were the most abundant species in HNF. *Actinophrys sol* (480 ± 163 ind/mL), *Trichamoeba osseossacus* (471 ± 790 ind/mL) and *Mayorella microeruca* (377 ± 241 ind/mL) dominated the amoeba and

Table 10.2 Taxonomic list of heterotrophic protists species from the littoral zone of Lake Alchichica according to Adl et al. 2019)

Discoba	**Stramenopiles**	**Alveolata**
Vahlkampfia sp**.**	*Actinophrys sol*	Ciliophora
Euglenozoa	*Actinosphaerium eichornii*	*Aspidisca cicada*
Anisonema ovale	*Spumella guttula*	*Chilodonella uncinata*
Petalomonas steinii	*Spumella mínima*	*Cinetochimlum margaritaceum*
Notoselenus apocamptus	*Spumella termo*	*Cothurnia* sp.
Kinetoplastia	*Spumella vivípara*	*Cyclidium citrullus*
Bodo caudatus	**Amoebozoa**	*Cyclidium glaucoma*
Bodo globosus	*Amoeba chaos*	*Enchelys simplex*
Bodo mínima	*Trichamoeba osseossacus*	*Holophrya simplex*
Bodo repens	Evosea	*Litonotus fasciola*
Bodo saltans	*Filamoeba nolandii*	*Mesodinium acarus*
Copromonas subtilis	Discosea	*Oxytricha* sp.
Rhyncomonas nasuta	*Mayorella microeruca*	*Spaherophrya soliformis*
Holozoa	*Vexillifera* sp.	*Stylonychia notophora*
Monosiga ovata	**Rhizaria**	*Trochilia minuta*
	Cercozoa	*Uronema* sp.
	Gymnophrys cometa	

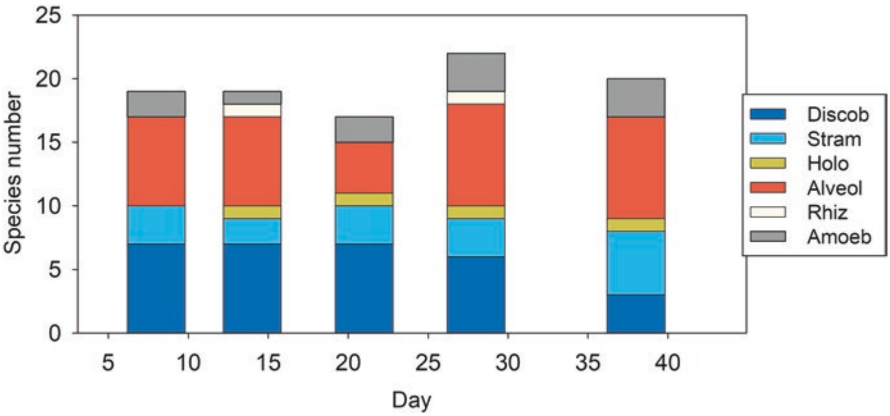

Fig. 10.5 Number of protists species by taxonomic supergroup and sampling day according to Adl et al. (2019)

related groups. In ciliates, *Cyclidium glaucoma* (53 ± 51 ind/mL), *Uronema* sp. (29 ± 31 ind/mL), *Stylonychia notophora* (26 ± 49 ind/mL) and *Trochilia minuta* (21 ± 31 ind/mL).

Theoretically, species number along the colonization process of the PFU must have a positive trend. It did not happen in Lake Alchichica because, at 8 and 14 days, 19 species were observed, but at 21 days, there was a decrease to 17 species. On day 28, an increase to 23 species occurred, and a slight decrease to 20 species on day 38.

10.2.2 Trophic Groups

Figure 10.6 shows the number of species according to their type of feeding (trophic group) throughout the sampling period. Pratt and Cairns (1985) criteria were used for flagellates and amebae, and the ciliates followed the one of Adl et al. (2019). Four trophic groups were found: bacterivores, predators, omnivores, and omnivores-cytrophic. Bacterivores consume bacteria by filtering them from the water; omnivores consume bacteria and other smaller protists, while cytrophic omnivores need to consume other protists to grow, but by consuming them, they also ingest bacteria.

Predators attack their prey, usually other protists or microalgae. From day 8 to 28, bacterivores had the largest number of species, followed by omnivores. However, on day 38, the omnivores equalized the number of bacterivorous.

The composition and dominance of heterotrophic protists in the littoral zone of Lake Alchichica provide valuable information about the biological conditions. The abundance of bacterivorous species indicates the presence of significant amounts of bacteria, which is common in littoral environments due to the fact that there is usually abundant decomposing organic matter (Arndt et al. 2000). This food favors the presence and growth of bacterivorous and detritivorous species of different sizes, among them, the bacterivorous flagellates which are the smallest. In the present study, several genus *Bodo* species, and *Spumella*, small bacterivorous, reached the highest abundances. Other important bacterivores were some small amoebae species such as *Vexillifera* sp. or *F. nolandi*.

The next largest trophic group was the omnivores. This group includes larger amoebae and the vast majority of ciliates. Omnivorous feed on bacteria, but they also

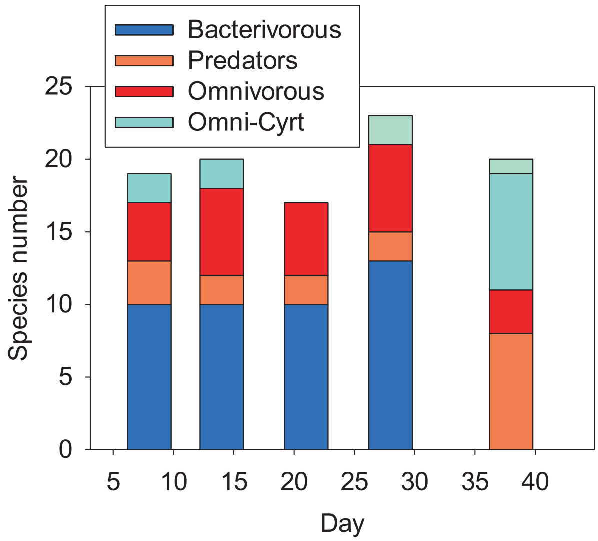

Fig. 10.6 Number of species by trophic group and sampling day in Lake Alchichica

consume other microorganisms such as small cyanobacteria, autotrophic flagellates, HNF, some diatoms, and various other microalgae types. A variant of this group is that of the omnivores-cytrophic, which in order to grow, they must consume protists, commonly flagellated, although they also feed on bacteria (Adl et al. 2019).

Although not very numerous, the predators' group included species from the supergroup Stramenopila (Heliozoa), such as *A. sol* and *A. eichornii*, which are passive predators. In the same case, the ciliated suctor *S. soliformis* is also a passive predator of other ciliates and flagellates. Finally, the ciliate *L. fasciola* is an active predator that detects, attacks, and consumes other ciliate and flagellate species.

The environmental factor that seems to exert the most significant influence on the species richness of the littoral heterotrophic protists of Lake Alchichica is salinity. The lake water has a salinity of 8.5 ± 0.2 g/kg (Vilaclara et al. 1993). At the site where the PFUs were placed, the salinity was 7 ± 0.1 g/kg. This salinity seemed to harm the species richness of protists since in other nearby lakes, with freshwater or considerably less saline, up to 50% more species were observed than in Lake Alchichica (Lugo 1993). Several dominant species in the study, as the HNF *B. saltans* and *R. nasuta,* and the ciliate *C. glaucoma* can occur under both marine and freshwater conditions, but other species have a narrow range of tolerance and salinity may be a limit for their distribution (Arndt et al. 2000; Lynn 2008).

In conclusion, the Lake Alchichica littoral zone's heterotrophic protists have a relevant ecological function as consumers of bacteria and other protists. In turn, they can be consumed by different groups of littoral macroinvertebrates, either directly or indirectly, as components of the organic detritus that constitute several of these invertebrates' food. From the list of littoral fauna groups observed in Lake Alchichica, crustaceans (copepods, ostracods and *Hyalella*), oligochaetes, and nematodes, chironomids could be the protist's predators (Monakov 2003). In this way, littoral heterotrophic protists constitute an energy transfer link from bacteria to a wide variety of macroscopic organisms, which in turn can be the food of fish (Alchichica's silverside), amphibians (Alchichica's axolotl), or even of aquatic birds that live temporarily or permanently in the lake.

10.3 Littoral Diatoms

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10.3.1 Introduction

In Lake Alchichica, as in other environments, both freshwater and marine and saline, diatoms are essential biological components. In the plankton and the littoral zone, there are numerous species of this group. Diatoms are unicellular or filamentous autotrophic organisms, characterized by presenting a cell wall or frustule made of silicon dioxide. The frustule is formed by two valves (epi and hipovalve) that fit together and joined by a series of bands that form the belt or cingulum. The frustule presents perforations of various forms (striae, pores) or spine-like extensions, which, for a long time, were the basis of the group's taxonomy.

Diatoms are of great importance in the silicon cycle in water bodies and soil. They constitute a fundamental food source for numerous groups of organisms, from protists (ciliates and amoebae) to larger organisms, such as cladocerans and copepods. In the littoral zone of water bodies, they can be the principal food of numerous groups of animals, among them those that make up the meiofauna of sediments, mollusks that scrape them from substrates, or even fish, which consume them together with debris or as epiphytes of plants and algae (Monakov 2003).

Benthic littoral diatoms can form mucilaginous layers on the bottom that help stabilize the substrate and reduce erosion (Grant et al. 1986). In littoral environments, diatoms contribute an essential fraction of primary production, which has been underestimated (Cahoon and Safir 2002), and they constitute the majority of the living organic fraction of sediments. Therefore, they can be considered to constitute most detritivores' food (Admiraal et al. 1984).

As described in detail in Chap. 8 (The Littoral environment), in the littoral area of Lake Alchichica, it is possible to find a wide variety of microenvironments. In the deep (12 m) and rocky area of the littoral, there is a significant growth of the filamentous Chlorophyte *Cladophora* sp. Numerous species of epiphytic cyanoprokaryotes and also some diatoms colonized these filaments (Tavera and Komárek 1996).

In the shallow (<1 m) portion of the litoral zone, the submerged aquatic macrophyte *Ruppia maritima* and the Charophyte *Chara canescens* grow in several places, being substrates where benthic -epiphytic- diatoms grow.

10.3.2 Species Richness

The samples were obtained at eight sites along the lake's perimeter (Fig. 10.7) and three different dates: October 2006, March 2007, and September 2007. The substrates sampled were the submerged aquatic plant *R. maritima* and the charophyte *C. canescens*. Also, where possible, rock scraping or plocon samples were collected. Table 10.3 shows the substrates sampled by season and site. In total, the number of samples analyzed was 32.

In each sampling site and date, water temperature, water conductivity, pH, and dissolved oxygen concentration were measured.

Forty diatom species were found in the eight points sampled in the littoral zone. Table 10.4 shows the list of species. The species number increased in each sampling: 27 species in October 2006, 30 in March 2007, and 36 in September 2007.

Ten species were observed with a frequency ≥75% in the samples obtained (n = 32) during the study (Fig. 10.8): *Navicymbula pusilla, Rophalodia gibberula,*

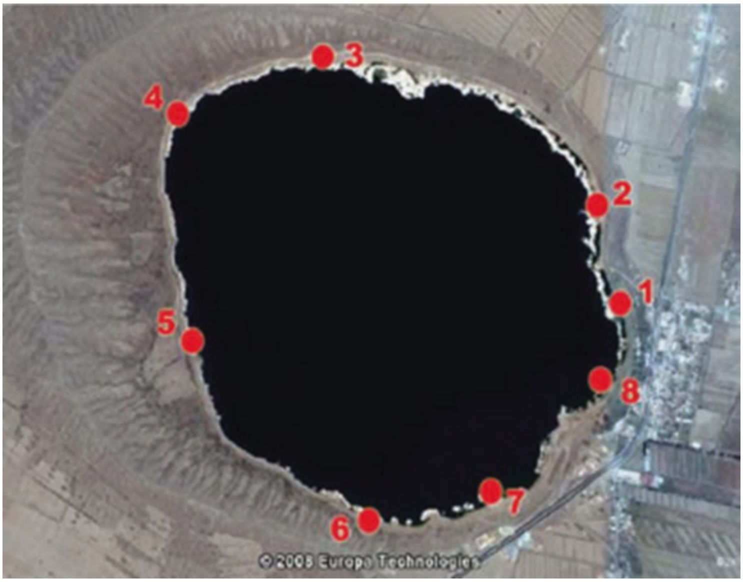

Fig. 10.7 Aerial view of Lake Alchichica showing the sampling site's location

Table 10.3 Substrates sampling for each site and date

Dates/sites	1	2	3	4	5	6	7	8
October 2006	Ep Ru	Ep Cha	El	Pl	Ep Ru El	El Pl	El Pl Ep Ru	El
March 2007	Ep Ru	Ep Cha	El	El	El	Ep Ru Pl	Pl	El
September 2007	Ep Ru	Ep Cha	El	Pl	El	El Pl	Ep Ru Pl	El Ep Ru

Key: Ep: Epiphytic, El: Epilitic, Pl: Plocon, Ru: *Ruppia maritima*, Cha: *Chara canescens*

Gomphoneis olivaceum, Mastogloia smithii, Halamphora veneta, Mastogloia elliptica, *Cocconeis placentula, Surirella striata*, *Anomoeoneis sphaerophora*, and *Navicula cryptocephala*.

The species with a frequency percentage value <10% were *Cocconeis placentula* var. *euglypta*, *Anomoeoneis costata* (both 9.4%) and *Caloneis westii* (3.1%). Most of the species (23 spp.) occurred in the three samplings. In contrast, eight species were found in a single sample: *Hyppodonta* sp. (28.1%) and *Gyrosigma acuminatum* (15.6%) in October 2006. *Anomoeoneis costata* (9.4%) in March 2007. *Cyclotella menenghiniana* (31.2%), *Nitzchia gracilis* (18.8%), *Epithemia sorex*

Table 10.4 Diatom species list from the littoral zone of Lake Alchichica

Achnanthes sp.
Amphora libyca Ehrenberg, 1841
Amphora pediculus (Kützing) Grunow, 1875
*Anomoeoneis costata (*Kützing) Hustedt, *1959*
Anomoeoneis sphaerophora Pfitzer, 1871
Caloneis westii (W. Smith) Hendey, 1964
*Campylodiscus clypeus (*Ehrenberg) Ehrenberg ex Kützing, 1844
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow, *1884*
Cocconeis placentula var. *lineata* (Ehrenberg) Van Heurck, 1885
Craticula sp.
Cyclotella menenghiniana Kützing, 1844
Cy*mbella cistula* (Ehrenberg) O. Kirchner, 1878
Cymbella mexicana (Ehrenberg) Cleve, 1894
Denticula sp.
Diploneis pseudovalis Hustedt, 1930
Entomoneis alata (Ehrenberg) Ehrenberg, 1845
Epithemia argus (Ehrenberg) Kützing, 1844
Epithemia sorex Kützing, 1844
Epithemia turgida (Ehrenberg) Kützing, *1844*
Gomphoneis olivaceum (Hornemann) Ehrenberg 1838
Gomphonema clavatum Ehrenberg, 1832
Gyrosigma acuminatum (Kützing) Rabenhorst, 1853
*Halamphora veneta (*Kützing) Levkov 2009
Hippodonta sp.
Mastogloia elliptica (C. Agardh) Cleve, 1893
Mastogloia smithii Thwaites ex W. Smith, 1856
Navicula cryptocephala Kützing, 1844
Navicula radiosa Kützing, 1844
Navicymbula pusilla (Grunow) Krammer, 2003
Nitzschia communis Rabenhorst, 1860
Nitzschia frustulum (Kützing) Grunow, 1880
Nitzschia gracilis Hantzsch, 1860
Nitzschia vitrea Hantzsch ex Rabenhorst, 1862
Pinnularia brebissonii (Kützing) Rabenhorst, 1864
Pinnularia sp.
Pseudostaurosira brevistriata (Grunow) D.M.Williams & Round, 1988
Rhopalodia gibberula (Ehrenberg) O. Müller, 1895
Stauroneis sp.
Surirella ovalis Brébisson, 1838
Surirella striatula Turpin, 1828

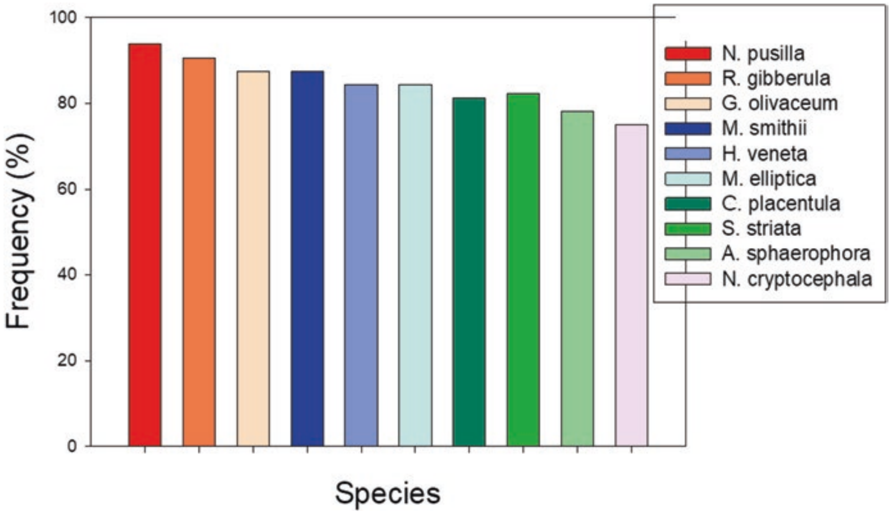

Fig. 10.8 Frequency (%) of the common littoral diatom species in Lake Alchichica

(15.6%), *Cocconeis placentula* var. *euglypta* (9.4%) and *Caloneis westii* (3.1%) in September 2007.

Regarding their spatial distribution, only *G. olivaceum* and N. *pusilla* appeared in the eight sampling sites in October 2006. In March 2007, more species were observed in all the sites: *G. olivaceum* and *N. pusilla*, also *M. elliptica*, *E. alata*, *N. cryptocephala*, *C. placentula* var. *lineata*, *Nitzchia frustulum* and *Epithemia argus*. In September 2007, only three species were present in all sites: *E. argus*, *Rhopalodia gibberula* and *M. smithii*.

Most of the species recorded in the study can live in wide ranges of salinity values, from freshwater environments to marine water. *A. lybica*, *A. sphaerophora*, *C. clypeus*, *E. alata*, *M. smithii*, and *N. communis* have only been found in saline environments. *H. veneta*, *G. olivaceum*, *Hippodonta* sp., *D. pseudovalis* and *R. gibberula* were species with high values of percentage of frequency (Frequency >75%). These are species that develop preferentially in saline environments, being rare in strictly freshwater environments (Hartley 1996; Krammer 2003; Novelo et al. 2007).

The majority of the species found belong to the group of pennate diatoms. *Cyclotella menenghiniana*, a central diatom, was observed in various littoral sites (Frequency 31.2%) only in September 2007. On several occasions, two other species of central diatoms were found in the littoral samples: *Cyclotella alchichicana* and *C. choctawhatcheeana*, which were not included in this study, since they are organisms that arrived from the pelagic zone, where they are common components of phytoplankton (see the chapter on phytoplankton), and their habitat is not the littoral zone.

Most species did not show a preference for some substrate since they grew on *R. maritima*, *C. canescens*, as epilithic, or as part of the plocon. Some exceptions were

C.westii, only observed as epilithic, or *G. acuminatum*, which was only epiphytic; *A. costata*, *E. sorex* and *P. brevissonii* were not observed in the plocon samples.

The environmental conditions measured correspond to those generally observed in the littoral zone and are described fully in Chap. 8. The temperature varied between 16 and 25 °C, the dissolved oxygen between 5 and 13 mg/L, and the pH was basic to strongly basic (8–12 units). During the study, the conductivity range was between 8 (E5 October 2006) and 13 mS/cm (E1, E2, E6, and E7 March 2007). The highest values were associated with decreased water level and salts' concentration in several sampled ponds.

Lake water's electrical conductivity ranges between 12 and 13 mS/cm (Vilaclara et al. 1993). However, due to groundwater entry at various points in the littoral zone, the conductivity may be lower.

10.3.3 Temporal, Spatial, and by Substrate Variation

In Fig. 10.9, the analyzed samples' grouping is observed by time of year, site, and sample type, using the Jaccard index as a similarity value and the UPGMA grouping method. Two groups were evident. The first of them (red box) includes the majority (9) of the sites and substrates from the October 2006 sampling (sampling 1), indicating that the composition of sites 1, 2, 3, 4, and 5 were similar, as well as the epilithic samples from sites 6 and 8 and the epiphytic from site 7. At site 4, which is penultimate to join the group, only a plocon sample was taken (similarity slightly less than 0.5).

In the second group (blue box), the samples from all the sites from the March 2007 sample joined first (sample 2) and then a group of 8 sites from sample 3 (September 2007). Plocon samples from sites 3 and 4 of the third sample are very similar (>0.85) and joined first with the epiphytic sample from station 7, and then with the epilithic sample from site 6, they are then joined with those of the group formed by the pair of plocon samples from sample 2.

Less similar samples, which later joined the previous group, were epilithic from sites 3 and 8 and epiphytic from sites 2, 8, and 5 of the third sample. Most different samples were from sampling date 1: the epilithic and the plocon from site 7, and the plocon from site 6, the latter being the least similar to all the rest. The analysis showed that the most remarkable similarities were temporary. The samples were grouped mainly according to the sampling dates, without the type of substrate from which they were obtained associating them. In some cases, the different substrates of the same site were similar, but in others, they were very different; for example, the epiphytic sample from site 7 of sample 1 had low similarity to the epiphytic and plocon samples from the same site.

The species richness of littoral diatoms of Lake Alchichica, considered a hyposaline lake, was greater than that of the hypersaline Mono lake (Nevada, USA), which only had 30 species (Herbst and Blinn 1998), but less than other hypersaline water bodies such as La Amarga lagoon in Argentina (53 spp.), or the Central Park lake, Turkey, with 126 spp. When Lake Alchichica is compared with freshwater bodies,

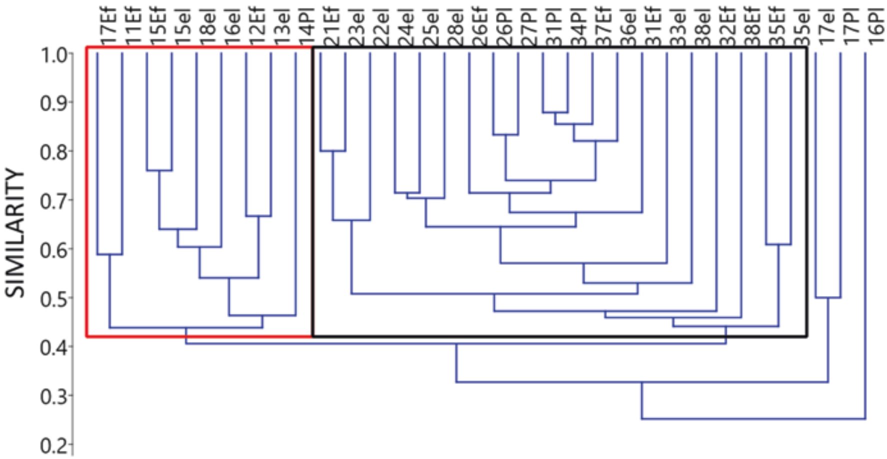

Fig. 10.9 Cluster analysis of Lake Alchichica's diatom species (presence-absence data). Key: First number: sampling number (1–3); second number: sampling site (1–8). Substrates: *Ep* epiphytic, *el* epilithic, *Pl* plocon. Most of the epiphytic samples were from *R. maritima*. Only the epiphytic samples from site 2 are from *C. canescens* (12Ef and 32Ef)

the number of Lake Alchichica diatom species is considerably lower (e.g., Lake Nagpur, India, 92 spp.; Marjal Oliva-Pego, Spain. 51 spp.) (Maidana and Romero 1995; Kaoru et al. 1997; Sarode and Kamat 1980; Cantoral-Uriza and Sanjurjo 2008).

The species richness of littoral diatoms of Lake Alchichica was moderate, with a predominance of species capable of resisting a wide salinity range. However, species with preferentially saline or marine conditions were also present. Except for exceptional cases, no specificity of diatoms was observed for any substrate since most of them were observed indistinctly in several of them. Temporal variation had the most significant influence since the critical factor for grouping the samples was the sampling date. Some of the plocon samples became the ones with the most remarkable difference in species composition. The diatoms of Lake Alchichica seem to be of great importance from the littoral food webs' point of view. They are indeed a very significant food for most of the different groups of macroinvertebrates that inhabit it. Together with the planktonic diatom species, they indeed have a very relevant function within the lake's silicon cycle.

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