Chapter 9
Aquatic Vegetation

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9.1 Hydrophytes. Definition and Delimitation of the Group

Lake Alchichica has been scarcely researched from a floristic point of view. Only two research have recorded some of its aquatic flora (Ramírez-García and Novelo 1984; Ramírez-García and Vázquez-Gutiérrez 1989). Other studies focused on benthic fauna (Alcocer et al. 1998), and macrophytes carbon dynamics (Pérez-Rodríguez et al. 2012) refer to plants' importance Alchichica lacustrine coast. This chapter describes lakeside flora and aquatic vegetation.

Hydrophytes or macrophytes are plants adapted to the aquatic environment to a lesser or greater degree, which grow and reproduce submerged or partially submerged. It is a plant group that includes, in a broad sense, charophytes (Charophyta), mosses and livers (Bryophyta), ferns, and related groups (Pteridophyta) monocotyledons and eudicotyledons (Angiospermae). This work only includes herbaceous angiosperms and follows the concept of hydrophyte that groups three categories based on the degree of dependence and adaptation of the plant to the aquatic environment, according to Lot (2013), Lot et al. (1998, 1999), and Ramos and Novelo (1993) in:

1. Strict aquatic: those that develop their entire life cycle in the water.
2. Subaquatic: those that grow up much of their life cycle in the water and cannot survive for long periods in completely dry spells soils.

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J. Alcocer (ed.), *Lake Alchichica Limnology*,
https://doi.org/10.1007/978-3-030-79096-7_9

3. Tolerant: those that spend much of their life cycle in dry soils but tolerate flooded soils for some time.

In some cases, during the life cycle of hydrophytes, there may be months during the drought, in which the water level is nil, but the soil remains moistured and allows them to complete their life cycle.

Hydrophytes are besides classified by their life forms, according to Lot et al. (1999), Ramos and Novelo (1993), and Ramos et al. (2004) in:

1. Emerging rooted hydrophytes. Plants that are rooted in the substrate with a part of the stem submerged and emerging leaves and reproductive organs.
2. Submerged rooted hydrophytes. Plants rooted in the substrate and maintain fully submerged stem and leaves, and either submerged, emerging, or floating reproductive organs.
3. Rooted hydrophytes of floating leaves. Plants attached to the substrate, with the leaves floating on the water surface and emerging reproductive structures.
4. Free emerging floating hydrophytes. Plants that are not fixed to the substrate with their vegetative and reproductive organs floating on the water surface.
5. Free submerged floating hydrophytes. Plants that are not fixed to the substrate, with their vegetative organs submerged, and only the reproductive organs emerging.

Strict aquatic plants are typical of swamps, streams, lakes, lagoons, reef lagoons, dams, and artificial canals. Most species grow in freshwater and brackish water, but seagrasses are also hydrophytes that grow in reef lagoons. Hydrophytes from freshwater and brackish aquatic environments made up diverse communities and may be associated with bryophytes, ferns, and charophytes.

9.2 Aquatic Flora and Vegetation of Mexico

The aquatic angiosperms in Mexico include 28 monocotyledons families and 38 eudicotyledons families. The three most notable families for their richness are Asteraceae, Poaceae, and Cyperaceae (Lot 2013; Lot et al. 1998). The aquatic vegetation in Mexico develops in all climates, from sea level to inland waters of more than 4000 m of altitude (between 1000 and 2500 m is where it, perhaps, presents its most remarkable richness). The aquatic vegetation concentrates in areas near the sea and where relatively high precipitation matches large areas of poor drainage. According to Rzedowski (2006), aquatic vegetation distributes into several subtypes based on its floristic composition, structure, and distribution as follow:

1. Floating vegetation that grows in slow-moving waters that are either freshwater or moderately brackish where *Lemna* spp. or *Potamogeton* spp. genera inhabit.
2. Submerged vegetation that grows in essentially transparent, freshwater, or slightly brackish waters, where *Potamogeton* spp. and *Ruppia* spp. inhabit. This last genus prefers continental and coastal marine environments.

3. Subaquatic vegetation with the presence of many herbaceous rooted in shallow water, for example, *Agrostis* sp., *Berula* sp., *Bidens* sp., *Cyperus* sp., *Eleocharis* sp., *Juncus* sp., *Polygonum* sp., and *Ranunculus* sp., Some of which, such as *Cyperus* sp. and *Juncus* sp., have a tolerance to water's high salt content.

9.3 Hydrophyte Flora of Lake Alchichica. Composition and Distribution

For the recognition of the aquatic and subaquatic vegetation of Lake Alchichica, an observation route and botanical collection was carried out on the periphery of the lake, systematically in 12 visits per month (1980–1981) (Ramírez-García and Novelo 1984) and *ad libitum* in three visits in dry and rainy seasons (2015, 2018 and 2020). The specimens are in the Herbario Nacional de México (MEXU), Instituto de Biología, Universidad Nacional Autónoma de México (Figs. 9.1 and 9.2).

The floristic composition of Lake Alchichica comprises six species grouped into five genera and three families, belonging to the Poales and Alismatales orders of the Monocotyledoneae class. The predominant family is Cyperaceae, with three species. In Mexico, more than 25% of the Cyperaceae are hydrophytes, and within the aquatic monocotyledons, they rank the first place in species richness (Diego-Pérez and González-Elizondo 2013; Lot 2013). Followed Juncaceae with two species; its moderate species richness associates to a family represented by fewer species than Cyperaceae; among the aquatic monocotyledons, they occupy the third species richness place in the country (Galván-Villanueva 2001; Galván-Villanueva and

Fig. 9.1 Method of botanical collection. Collecting *Juncus* sp. to the W of Lake Alchichica

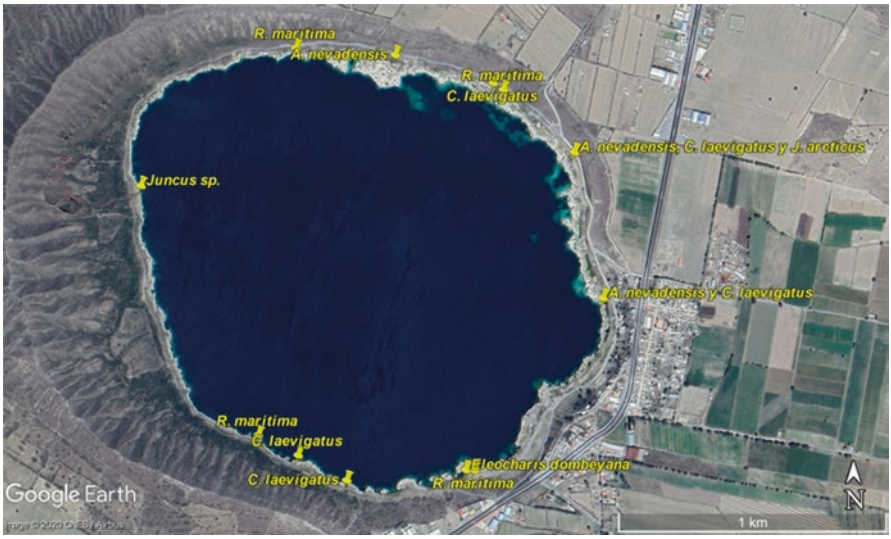

Fig. 9.2 Location of the collection points of the hydrophytes of Lake Alchichica

Table 9.1 Floristic list and life form of the hydrophytes of Lake Alchichica

Type of hydrophyte and life-form	Order / Family / Species	Distribution on the Alchichica littoral	Depth
	Poales		
	Cyperaceae		
	Amphiscirpus nevadensis (S. Wats.) Oteng-Yeb. *	NE. Open and flat areas. Waterlogged sites	0 cm
	Cyperus laevigatus L. *	NE and S. Open and flat areas. Waterlogged sites	0 cm
Subaquatic. Emerging rooted	*Eleocharis dombeyana* Kunth	S. in water cavities	30 cm
	Juncaceae		
	Juncus arcticus Willd *	E. Open and flat areas. Waterlogged sites	0 cm
	Juncus sp.	W. Less open areas. Wet soils	0 cm
	Alismatales		
Strict aquatic.	Ruppiaceae		
Submerged rooted	*Ruppia maritima* L. *	N and SW. In the water body of the lake	300 cm

An asterisk* indicates halophile species

Martínez-Domínguez 2013; Lot 2013). Finally, there is only one species of Ruppiaceae in the lake. There are only two Ruppiaceae species in Mexico, both restricted to saline waters; also, it locates among the aquatic monocotyledons with lower species richness (Lot 2013; Ramírez-García 2013) (Table 9.1).

Environmental features (e.g., altitude, climate, winds, and sediments), and physicochemical variables (salinity, alkalinity, ion composition of water) (Ramírez-García and Novelo 1984), and the morphology of Lake Alchichica influence the hydrophytes development in the lake. The low floristic richness in Lake Alchichica relates to its oligotrophic status (low nutrient and low organic matter production, Alcocer and Oseguera 2019), limiting the growth of species.

The number of species of Lake Alchichica (6) is low compared to that of Lake Texcoco (24), both lakes with similar environmental characteristics and with only four species in common: *E. dombeyana*, *Juncus* sp., *R. maritima*, and *S. pectinata* (Rzedowski 1957; https://datosabiertos.unam.mx/biodiversidad/). Lake Texcoco was considerably larger (100 km^2) (Rzedowski 1957), which allowed many hydrophytes with a complete inventory. Differently, there are fewer species in the smaller Lake Alchichica (2.3 km^2), (Alcocer and Oseguera 2019), and an inventory yet to be completed.

In contrast, the species richness of Lake Alchichica (6) is high compared to that of the other five crater lakes located in the same area to the E of Puebla: Tecuitlapa (7), Aljojuca (6), Quechulac (5), La Preciosa (4), and Atexcac (4) with similar environmental features, of which Lake Alchichica only shares with Lake Atexcac two species in common: *C. laevigatus* and *R. maritima* (Ramírez-García and Novelo 1984). Lake Alchichica is the largest of all, which allows a greater presence of species. The collections made in this study increased its floristic inventory by adding four species to the previous reports by Ramírez-García and Novelo (1984) of two species. A new record of *A. nevadensis* unknown for Puebla state, and the first collections of *E. dombeyana*, *J. arcticus*, and *Juncus* sp.

9.3.1 Cyperaceae

Amphiscirpus nevadensis (S. Wats.) Oteng-Yeb. Subaquatic plant. Emerging rooted. Herbs, perennial, rhizomatous, stems 5–45 cm tall, trigonous, circular or flattened, leaf blades stiff and pointed, sheaths closed, inflorescences terminal, capitate, spikelets 1–8 sessile, scales and flowers spirally arranged in 3 rows or more in the rachilla. Distribution. SW from Canada, the United States of America, Chile, and Argentina. In Mexico has been registered only in the State of Mexico, to the N of Lake Texcoco. Alt. 2250 m. Habitat. Lakes with saline or alkaline soil. Remarks. It is a scarce plant, which due to the drastic modifications suffered by the habitat from where it has been collected in Mexico, should be considered endangered (Diego-Pérez and González-Elizondo 2013; González-Elizondo 2001; González-Elizondo et al. 2008, 2018; Smith 2002).

Fig. 9.3 *Amphiscirpus nevadensis*, to the E of the coastline of Lake Alchichica. (**a**) Emerging rooted plant, (**b**) grows in flooded sandy soils. (Photographs by Elia Matías-Hernández)

In Lake Alchichica, *A. nevadensis* grows in relatively conspicuous populations to the NE of the coast (Fig. 9.2), 3–6 m from the water body, in open and flat areas, near the outcrops of microbialites, in permanent or temporary flooded sandy soils, with other plants such as *C. laevigatus*, with the largest population in the N. Phenology. Flowering and fruiting in spring and summer (Fig. 9.3a, b). Its presence in the site may be explained because it is a hydrophyte adapted to exclusive conditions of saline and alkaline lakes, such as those of Lake Alchichica with salinity 8.5–9 g/L, alkalinity pH 8.8–8.9, and ionic composition of sodium chloride, magnesium salts, carbonates, bicarbonates and borates (Alcocer and Oseguera 2019).

The environmental heterogeneity of the coast explains the discontinuous spatial distribution of this species, which allows their growth in the NE, on the side of the crater where a gentle slope is found, an extensive coast, fine sand waterflooded sites, and the absence of waves due to the distance of the water body and the barrier of microbialites. In contrast to SW, where it does not grow due to the absence of coastline and because there are thick sediments, waves, and less presence of microbialites. This species perhaps inhabited a wider area of the lake in the past, as Alcocer and Oseguera (2019) and Silva-Aguilera and Escolero (2019) indicate that the lake had a large coastal area that was disappearing as the level of its waters descended, by natural and human factors. *A. nevadensis* today faces adverse scenarios caused by water decrease, loss of the coast, and pollution since in the place where it grows has been found garbage in the soil and water.

Importance. The collection of *A. nevadensis* at Lake Alchichica represents a new record of Mexico's flora. Due to its intrinsic importance, its exclusive presence in two saline and alkaline lakes in the country, and the continuous desiccation and contamination of Lake Alchichica, it is urgent to decide and guarantee the conservation status of the species and the lake as its natural habitat. *A. nevadensis* is a species not yet registered in any protection category in Mexico. Therefore, this information is the basis for its future evaluation and inclusion in the Norma Oficial Mexicana NOM-059-SEMARNAT-2010 in the endangered category and to protect the lake as an aquatic ecosystem *sui generis* at risk.

Cyperus laevigatus L. Subaquatic plant. Emerging rooted. Herbs, perennial, rhizomatous, stems 3–30(70) cm tall, compressed, trigonous to circular, leaf blades short or absent, sheaths closed, inflorescences lateral, capitate, spikelets 1–16 sessile, scales and flowers parallel arranged in 2 rows in the rachilla. Distribution. Pantropical. In America, E of the United States to South America. In Mexico, it grows in almost all the states. Alt. 0–2500 m. Habitat. Saline or alkaline water bodies, flooded halophilic grasslands, ditches, streams, and urban wastewater channels. Remarks. An introduced plant (Diego-Pérez and González-Elizondo 2013; González-Elizondo 2001; González-Elizondo et al. 2018; Tucker et al. 2002).

At Lake Alchichica, *C. laevigatus* inhabits relatively abundant populations on the coast, mainly to the NE and S (Fig. 9.2), 0.5–6 m from the water body, in open and flat areas, around and above the microbialites. In sandy soils that are either flooded or not, where cattle constantly graze it. Phenology. Flowering and fruiting in spring and summer (Ramírez-García and Novelo 1984; obs. pers.) (Fig. 9.4). This plant has the most considerable presence and spatial distribution of the recorded hydrophytes because it is a very common sedge adapted to saline and alkaline soils. The fact that it is an introduced plant indicates that it colonized this lake at some point in the past, perhaps carried by birds. Locally may be important as fodder.

Eleocharis dombeyana Kunth. Herbs, perennial, rhizomatous sometimes subcespitose, stems 4–60 cm tall and up to 1 mm wide, leaf blades absent, sheaths closed, inflorescences terminal in a spikelet single. Distribution. South America, Central America. In Mexico, it is present in Mexico City and 15 states. Alt. 1200–3500 m. Habitat. The shore of streams and water deposits, moist grasslands,

Fig. 9.4 *Cyperus laevigatus*, to the E of the coastline of Lake Alchichica, in waterlogged sites

Fig. 9.5 *Eleocharis dombeyana*, to the S of the coastline of Lake Alchichica, in a cavity with water

disturbed areas, *Abies* forests, pine forests, and oak woods (Diego-Pérez 2012; González-Elizondo 1994, 2001; González-Elizondo et al. 2018).

In Alchichica, *E. dombeyana* scarcely grows in a site to the S of the coast (Fig. 9.2), 1–4 m from the water body, in a cavity with water, of irregular shape, size approximately 80 cm by 100 cm, and depth 30 cm, perhaps fed by groundwater and

rain, since this plant has not yet been recorded in saline sites. Phenology. Flowering and fruiting in summer. Although the literature does not refer to it as hydrophyte, in this study, it is considered subaquatic, emerging rooted, as it is found with these characteristics (Fig. 9.5). Its habitat is the lake's southern portion, the least alkaline (Silva-Aguilera and Escolero 2019). The existence of more springs to the SE of the lake in the past (Silva-Aguilera and Escolero 2019) suggests that it had a greater presence and southern distribution in less alkaline water deposits of Alchichica. Since it is present in a single place, it could disappear due to the constant loss of springs.

9.3.2 Juncaceae

Juncus arcticus Willd. Subaquatic plant. Emerging rooted. Herbs, perennial, cespitose, stems 3–125 cm tall, circular or compressed, leaf blades absent or present according to variety, sheaths open, inflorescences pseudolateral in panicle lax or dense. Distribution. Circumboreal, W from Alaska to South America. In Mexico, it is found in Mexico City and 16 states. Habitat. Edge of canals, lakes, lagoons, streams, flood soils, and generally brackish plains in xerophytic scrub and grassland communities. Alt. 675–3900 m. Remarks. In Mexico, there are three varieties (Galván-Villanueva 2001; Galván-Villanueva and Martínez-Domínguez 2013).

At Alchichica, *J. arcticus* scarcely inhabits the E of the coast (Fig. 9.2), 3–6 m from the water body, in open and flat areas, close to the microbialites and a small population of *A. nevadensis*, in saturated sandy soils, with other grasses. Phenology. Flowering and fruiting in summer. This plant's limited spatial distribution indicates a wide coastline habitat and near waterlogged sandy sites. Also, as Galvan-Villanueva (2001) indicates, these juncaceous usually occupy small areas. Perhaps, in the past, it inhabited a broader coastline than the existing one today.

Juncus sp. The genus consists of herbs, perennial, cespitose, stems slender, leaf blades basal, sheaths open, inflorescences terminal or pseudolateral in panicles, cymes or heads. Distribution. Cosmopolite, mainly in the N hemisphere, in Mexico, there are 35 species, 18 of which are aquatic (Galván-Villanueva and Martínez-Domínguez 2013).

In Lake Alchichica, *Juncus* sp. grows in a single site at the W of the coast (Fig. 9.2), 0.5–2 m from the water body, behind the microbialites, in damp, moderately uneven soils, with other grasses. Its distribution towards the western portion of the lake indicates an ecological preference towards an almost absent littoral zone, with higher energy, surrounded by terrestrial vegetation, and a more temperate microhabitat than in the east, which favors the limited and reduced presence of this juncaceous (Fig. 9.6).

Fig. 9.6 *Juncus* sp., to the W of the coastline of Lake Alchichica, in wet soils, behind the microbialites

9.3.3 Ruppiaceae

Ruppia maritima L. Strict aquatic. Submerged rooted. Herbs, perennial, stems simple or highly branched towards the top, 0.3–0.8 mm in diameter, whitish, leaves generally alternated, inflorescences with two flowers, rarely 1, peduncles up to 12 cm long. Distribution. Cosmopolite. In Mexico, it is registered in Mexico City and 13 states. Habitat. Crater lakes, bays, estuaries, and coastal lagoons of brackish or alkaline water. Alt. 0–2400 m. Remarks. Its common name in Puebla is *lama* (Novelo and Lot 2001; Ramírez-García 2013).

In Alchichica, *R. maritima* appeared to the N and SW (Fig. 9.2), forming a discontinuous strip up to 20 m wide, occupying small inlets and *microbialites*, and is more abundant between 1 and 3 m deep. The sediments where it grows are abundant in sand 80.5% (average), low in organic matter 4.7%, have nutrients with 0.25% nitrogen and assimilable phosphorus with 0.23 ppm, and neutral pH 7.3. It is a dominant euryhaline hydrophyte on the shallow littoral, adapted to high salinity, alkalinity, and water transparency of Lake Alchichica (Ramírez-García and Novelo 1984).

R. maritima inhabited a larger portion of the littoral zone as testified by previous collection sites (Ramírez-García and Novelo 1984), which nowadays are already dry. This constitutes additional evidence of the decline in the water level of the lake and the loss of the littoral zone.

Importance. *R. maritima* has great ecological importance in Lake Alchichica because it constitutes the habitat of diverse aquatic fauna, such as the copepod *Cletocamptus gomezi*, the aquatic insect *Krizousacorixa tolteca*, and the

atherinopsid fish *Poblana alchichica*. The last two species are microendemic. Also, *P. alchichica* is a threatened species and critically endangered (Alcocer et al. 2015; Arce-Uribe et al. 2019; Barrera-Moreno et al. 2019; Kato et al. 2019). The local conservation of *R. maritima* acquires relevance since affecting its presence will impact this ecosystem's shelter habitat and the littoral food webs.

Another species recorded in Lake Alchichica, based on the literature, is *Stuckenia pectinata* (L.) Börner (formerly *Potamogeton pectinatus* L.) (www.tropicos.org). According to Ramírez-García and Novelo (1984), there are two specimens deposited in the Herbarium of the Missouri Botanical Garden (MO) and the Herbarium of the Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional (ENCB) respectively. It is a strict aquatic hydrophyte of the family Potamogetonaceae; in Mexico, this species inhabits lakes, irrigation channels, rivers, ponds, and swamps of fresh or saline water, clean or contaminated. Alt. 0–2700 m (Martínez 2013; Novelo and Lot 2001). Perhaps this plant inhabited the lake in the past but disappeared by sparse populations and affected habitat.

9.4 Subaquatic and Submerged Vegetation of Lake Alchichica

The composition and life forms of the species indicate two types of plant communities:

1. Subaquatic vegetation stands out for bringing together five emerging rooted hydrophytes: *A. nevadensis*, *C. laevigatus*, *E. dombeyana*, *J. articus*, and *Juncus* sp. These are perennial herbs with heights of approximately 45–60 cm. They are grass and tufts in flood or wet areas near the *microbialites* and water cavities. *C. laevigatus* is the most abundant and widespread species. *C. laevigatus* and *E. dombeyana* suggest Alchichica is a disturbed lake since these plants are found in affected sites.
2. Submerged vegetation, represented by submerged rooted hydrophyte *R. maritima*, perennial grass that inhabits the water body, in medium extension.

Subaquatic and submerged vegetation is concentrated towards the NE portion of the lake, where the wider littoral zone allows the growth of emerging rooted hydrophyte communities over a larger area than in the W, where the littoral zone is absent with no vegetation. Alcocer et al. (1998) mention that the main factor controlling the species richness, density, and biomass of the benthic macrofauna in Lake Alchichica is aquatic vegetation by increasing the habitat heterogeneity providing food and protection against predators. The annual production of hydrophyte biomass in Lake Alchichica averaged 303 gDW/m^2/y. It includes *R. maritima* and *C. laevigatus* (Ramírez-García and Vázquez-Gutiérrez 1989). On the other hand, Pérez-Rodríguez et al. (2012) reported an annual average of macrophyte total carbon (LOI) of 2.54 ± 3.64 g C m^{-2} ranging from 0.29 ± 0.5 g C m^{-2} y 1.26 ± 2.21 g C m^{-2}. in July and 3.84 ± 4.12 g C m^{-2} in November.

9.5 Importance and Conservation

Aquatic and subaquatic plants are essential because they are the primary producers in the foodweb, oxygenate the aquatic and terrestrial environment, nourish and stabilize sediments, and provide habitat, shelter, and food to aquatic fauna. More than half of the species recorded in this study *(A. nevadensis*, *E. dombeyana*, *Juncus* sp. and *R. maritima*) could disappear locally in the immediate future due to its scarcity and habitat loss caused by the water level declining of the lake. This water reduction seems to be caused by natural (climates that significantly favor evaporation above precipitation and the scarce groundwater inlet) and human factors (groundwater exploitation and pollution), as mentioned by Alcocer y Oseguera (2019).

This study describes some of the aquatic flora of the site. However, there is still the necessity to explore the place to have a complete floristic inventory. Families like Poaceae and Asteraceae are very likely to be present but have not yet been collected and studied. Therefore, it is imminent to document, evaluate, and protect the biota of the site. We consider that it is a priority to study aquatic plant communities' growth dynamics to estimate the vegetation's current state.

Acknowledgements EMH thanks Fernando Matías-Hernández and Alfredo Saynes-Vásquez for their valuable support in the field, without which this study would not have been possible, and by the detailed review of the manuscript. We also thank Dr. Javier Alcocer for his kind invitation to collaborate in this book and for his comments that enriched this chapter.

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