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Review

Freshwater Diversity of Zooplankton from Mexico: Historical Review of Some of the Main Groups †

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Abstract: In this review, we include rotifers, copepods, and cladocerans, including other groups not usually deemed as zooplankters: i.e., protists, acari, and large branchiopods. The objectives of this study were to integrate the dispersed literature on the taxonomy and diversity of these freshwater zooplankton groups and to explain (1) how these contributions can be arranged in distinct historical periods and (2) how this knowledge has allowed the detection of exotic and threatened species. We divided the freshwater zooplankton studies in Mexico into three historical periods: the first one comprised the 1840s to the 1940s when foreign researchers carried out most studies during several expeditions. Spanish researchers promoted surveys on different zooplankton taxa at the end of this first period. The second period, from the early 1950s to the end of the 1990s of the XX century, showed a remarkably increased research activity in its last ten years only (that is, during the 1990s to 2000), represented by contributions of a new generation of Mexican zooplanktologists. This period yielded more complete zooplankton listings and detailed morphological descriptions of rotifers, cladocerans, copepods, and large branchiopods. The third period started from the year 2000 to date. During this time, listings and online faunistic baselines based on integrative taxonomy have been the primary trend. An account of exotic zooplankters and conservation issues of several native species are discussed. The results of this review show that the knowledge of the freshwater zooplankton of this country has increased significantly over the last 40 years, with at least 408 first records of species for Mexico. Currently, the knowledge of Mexican freshwater zooplankton is among the most complete in the world. However, it is estimated that only a small fraction of the true diversity has been documented.

Keywords: zooplankton; taxa; regional; microcrustaceans; macrocrustaceans; continental waters; Mexico

1. Introduction

In this revision of the Mexican freshwater zooplankton, we include data on rotifers, copepods, cladocerans, protists, acari, and large branchiopods. Ostracods, chironomids, and fish larvae were excluded.

Protists have been recognized as a group since Haeckel's early system of classification (1866) [1]. They are recognized as polyphyletic, which is used as a functional and operational term. For example, "protozooplankton" is commonly used for predominantly non-filamentous heterotrophic species that belong to the zooplankton, although many species can be mixotrophic [2]. Protists are a crucial link to higher trophic levels in the freshwater plankton food webs, but they also contribute to recycling organic carbon and energy in the microbial loop [3]. They occupy various trophic levels within the plankton community. In addition, their capacity to either live with symbiotic zoochlorellae or sequester chloroplasts makes them the most diverse feeding-behavior planktonic group. This functional protist overlapping explains their occurrence in the same niches, but more observations are necessary to discover their actual richness, which should be higher than the apparent one [4–7]. The protozooplankton is present in most freshwater habitats but has been largely neglected in plankton studies [7]. Morphologically, ciliates, flagellates, and heliozoans are among the main groups of heterotrophic zooplankton protists.

Rotifers are chiefly parthenogenetic zooplankters, mainly represented by females, but the group also comprises benthic or periphytic forms. A complex mandible, the mastax, characterizes them. They are eutelic blastocoelomates with an anterior ciliated corona, their main locomotion structure, for which they are also known as "wheel animals."

Water mites include thousands of acari species that are true permanent residents of many freshwater habitats [8]. They are grouped into eight superfamilies [8,9], three of which include members with adaptations to living in the plankton [10–13]. Furthermore, water mites can prey on other zooplankters [12,14,15]. More than 7,500 water mite species have been described worldwide [9,16,17].

Cladocerans and rotifers have been traditionally considered part of the zooplankton communities, but they include bottom-living or phytal forms. Like rotifers, cladocerans reproduce mainly with a parthenogenetic cycle [18]. Up to 850 cladoceran species are known worldwide [19]. The taxonomic identity of several species recorded in Mexico has been confirmed with molecular tools, but groups of cryptic species have also been recognized [20].

The large branchiopods, i.e., fairy and brine shrimps of the order Anostraca, tadpole shrimps of the order Notostraca, and clam shrimps of the orders Cychlestherida, Laevicaudata, and Spinicaudata, live mostly in ephemeral freshwater bodies with extreme physical and chemical conditions. The Anostraca is represented in Mexico by species of four families [21] (Supplementary Table S1). The brine shrimp *Artemia* is limited to brine water habitats (TDS > 35 g L). The Notostraca is represented by two genera: *Triops* and *Lepidurus* [22]. The clam shrimp order Cyclestherida is represented in Mexico by the Cyclestheriidae, the Laevicaudata by the Lynceidae, and the Spinicaudata by the Cyzicidae, Leptestheriidae, and Limnadiidae [23] (Supplementary Table S1). They have not been considered true zooplankters.

The free-living planktonic Copepoda is represented by three orders in Mexico: Calanoida, Cyclopoida, and Harpacticoida; the latter, largely benthic, is represented by 21 species in this country [24] (Supplementary Table S1), but their diversity is probably underestimated. Among the cyclopoids, 19 genera of the highly diverse and widespread family Cyclopidae have been recorded; also, four families of the order Calanoida are known to occur in Mexico: Diaptomidae, Centropagidae, Temoridae, and Pseudodiaptomidae.

A single member of each of the chiefly euryhaline families Centropagidae, Temoridae, and Pseudodiaptomidae has been recorded in Mexico (Supplementary Table S1) [18,25,26].

The family Diaptomidae is the most diverse in Mexico, with members of eight genera [27–29] (Supplementary Table S1). Many freshwater calanoid copepods appear to have limited distributional patterns in the Neotropical region [30,31]. The two Mexican regions with the most records and potential endemisms of Cladocera and Copepoda are the Neovolcanic Axis of the central-eastern region and the Yucatan Peninsula [30,32].

The objectives of this review are to integrate the dispersed literature on the taxonomy and diversity of these freshwater zooplankton groups in Mexico and to explain (1) how these contributions can be arranged into distinct historical periods and (2) how this knowledge has allowed a general estimation of the national biodiversity of the freshwater zooplankton and the detection of exotic and threatened species to support the conservation of this largely ignored community. The results of the review show that the knowledge of the freshwater zooplankton of this country has increased significantly over the last 40 years, with at least 408 first records of zooplankton species for Mexico.

2. Methods

We surveyed all published papers on the taxonomy of Mexican epicontinental zooplankton, including visits to institutional libraries (i.e., the Royal Belgian Institute of Natural Sciences, University of Ghent, National Autonomous University of Mexico, and the National Polytechnic Institute, Mexico), theses, and project reports performed in Mexico. We also performed multiple searches of specialized literature, including keywords for each group from different academic databases, including Web of Knowledge, SCOPUS, and Google Scholar, among others. All consultations were made until 30 November 2022 and included searches as "Calanoid", "Freshwater", and "Mexic*" not "New Mexico", for example, for calanoid copepods.

3. Results

Following the comprehensive analysis of the available specialized literature, we divided the zooplankton studies in Mexico into three historical periods: the first comprised the XIX century to the 1940s decade in the XX century, the second period was from the early 1950s to the end of the 1990s of the XX century, the third period started from the year 2000 to date. The rise in publications coverage and the increased number of species reported (Figures 1–5) are markers of the progress in discovering the Mexican zooplankton biodiversity. In the following paragraphs, we provide details of each phase. Additionally, in the Supplementary Table S1, we include the number of species for each group and further bibliographic information regarding them.

3.1. Phase 1: Early Studies Dominated by Foreign Researchers (Second Half of XIX Century to 1940s of XX Century)

In this phase, foreign scientists or scientific expeditions worked in Mexico; for example, the studies of Pearse et al. 1936 in the Yucatan Peninsula [33]. All of them intended to discover the diversity of different groups. Subsequently, the arrival of the Spanish zoologists E. Rioja and B. Osorio Tafall promoted new studies on zooplankton crustaceans also on protists and rotifers.

3.1.1. Protists

Formal studies on planktonic protists started in this phase with works by Bravo-Hollis [34] in Central Mexico [35]. In that same period, Sámano and Sokoloff [36], Ancona et al. (see 39), and Osorio-Tafall [37,38] also contributed to the knowledge of this group [39].

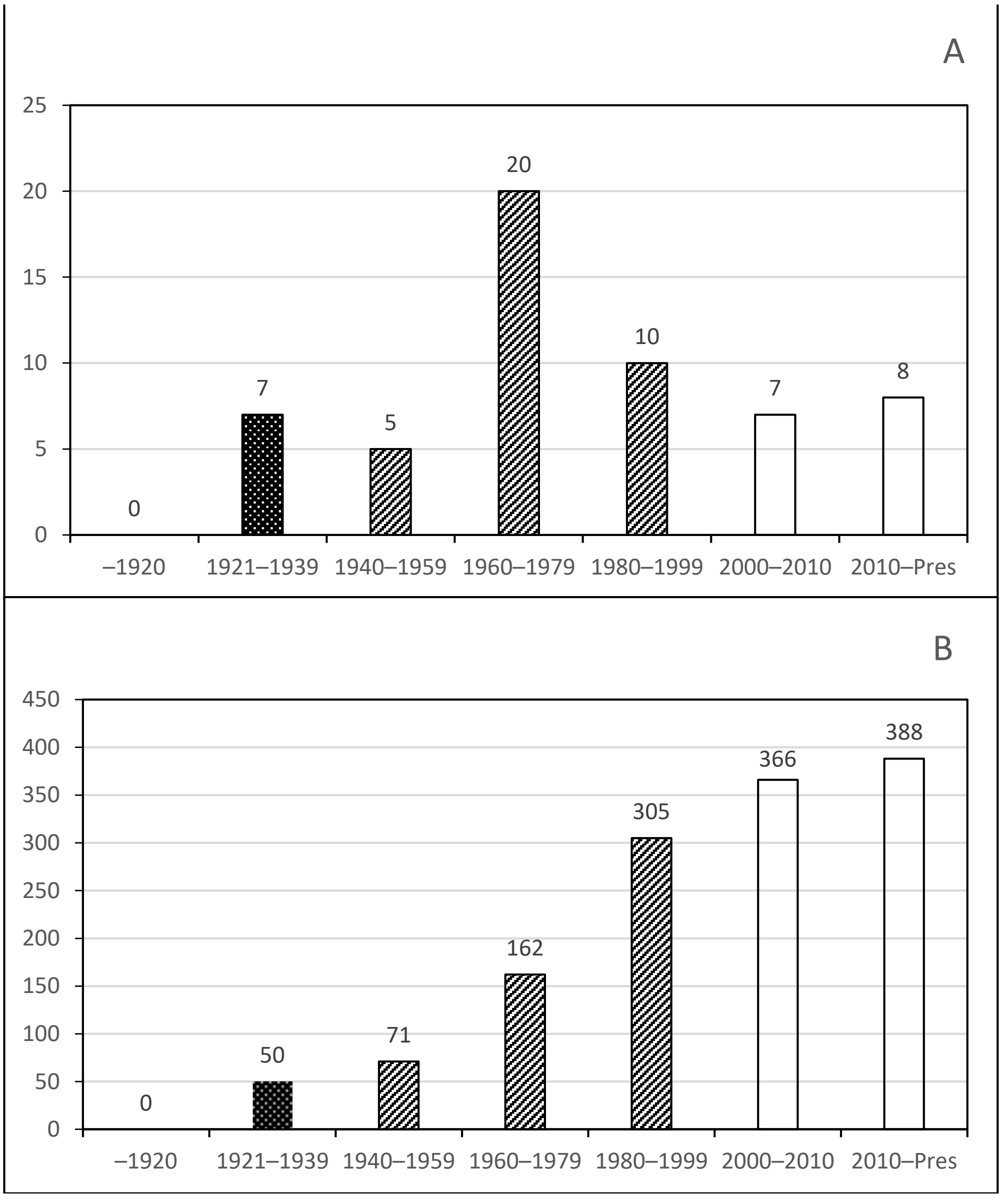

Figure 1. Historical progress of studies on Mexican Protists. (**A**) Number of publications. (**B**) Cumulative number of species found. ▩ Phase 1. Early studies dominated by foreign visitors; ▨ Phase 2. Towards the formation of Mexican protistologists; ▭ Phase 3. Consolidation of Protist studies.

3.1.2. Rotifers

During this phase, a few Mexican researchers conducted the earliest studies on rotifers [40], and several foreign scientists conducted biological expeditions, mainly in central Mexico. Subsequently, other authors like Ahlstrom [41], Carlin-Nilson [42], Sámano [43], Hoffman and Sámano [44,45], and Uéno [46] reported on the rotifers of Lake Patzcuaro and other Mexican localities. At the end of this phase, studies on rotifers expanded to other areas in central Mexico [47–51]. After this first period, the interest in the knowledge of rotifers was paused for several years.

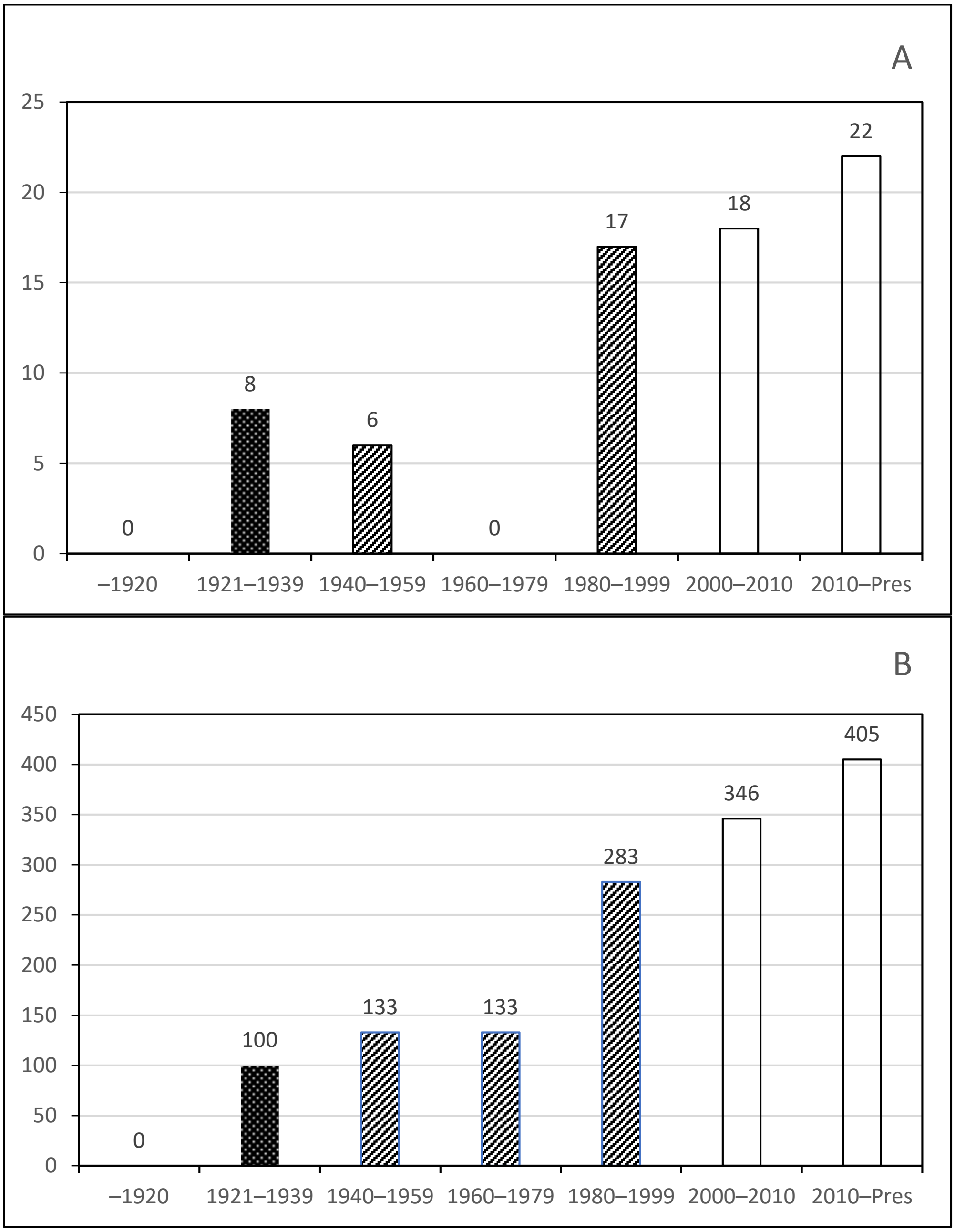

Figure 2. Historical progress of studies on Mexican Rotifers. (**A**) Number of publications (**B**) Cumulative species recorded in this region. ▩ Phase 1. Early studies included Mexican researchers but were dominated by foreign visitors; ▨ Phase 2. Towards the formation of Mexican rotiferologists, working with foreign researchers, and first species descriptions; ▭ Phase 3. Consolidation of rotifer studies and integrative taxonomy descriptions.

3.1.3. Water Mites

This phase also comprises the first descriptions of water mites in Mexico, contributed by the French naturalist Alfredo Dugés [52,53] (see Marshall [54]). Subsequently, Marshall [55] contributed to the first taxonomic account of Mexican water mites of the Yucatan Peninsula.

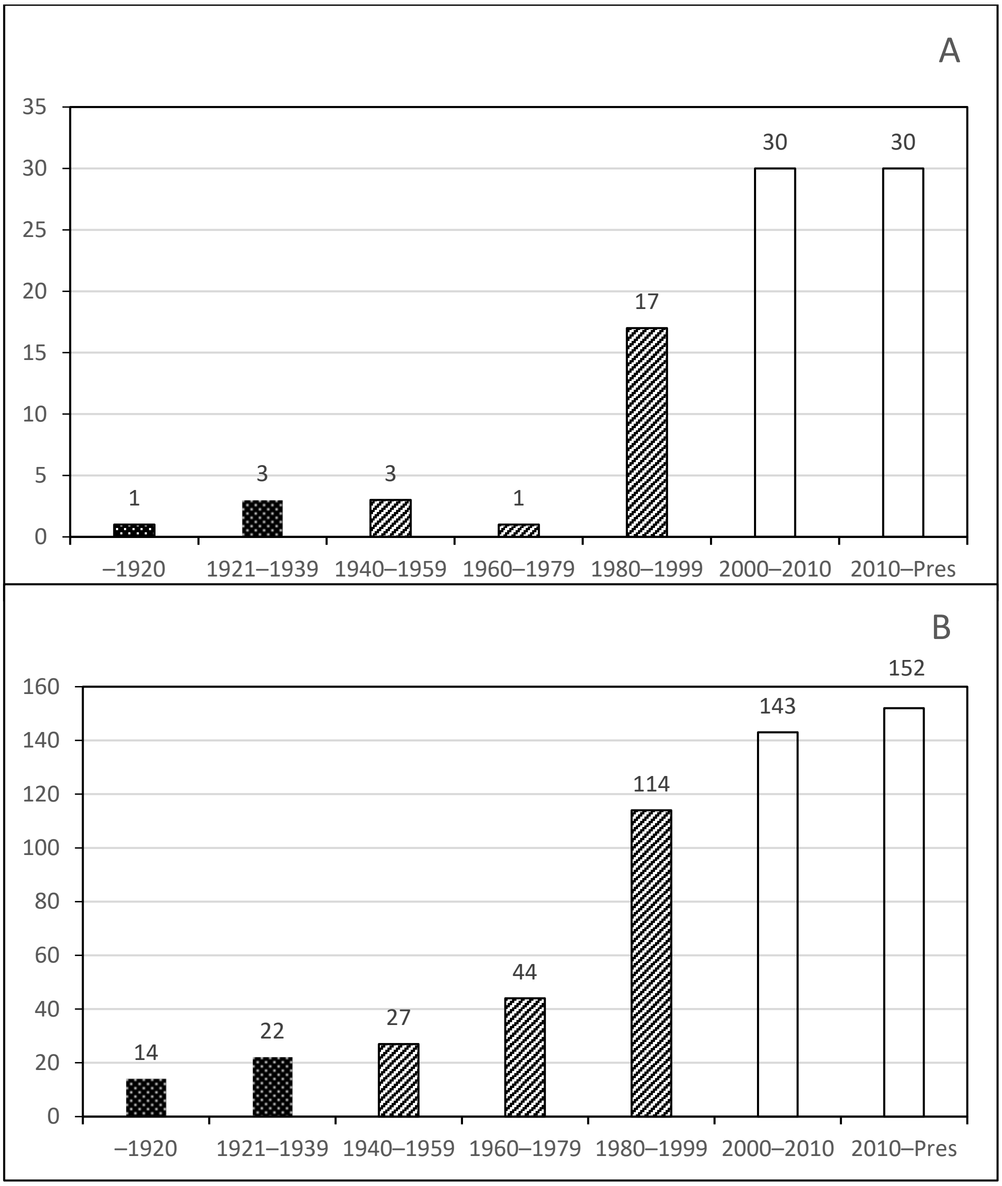

Figure 3. Historical progress of studies on Mexican Cladocera (Anomopoda and Ctenopoda). (**A**) Number of publications. (**B**) Cumulative number of species recorded. ▩ Phase 1. Early studies by foreign visitors; ▨ Phase 2. The consolidation of Mexican cladocerologists in the last period (1980–1999); ▭ Phase 3. Mature period and formation of 2nd and 3rd generation of researchers on this topic, and discovery of exotic species.

3.1.4. Cladocerans

Juday [56] recorded 14 species from three locations near Mexico City about the cladoceran studies in this phase. This period ended with the creation of a hydrobiological station in Lake Pátzcuaro, Michoacán, in 1938, thus promoting additional studies like those by Brehm [57], Osorio Tafall [58], and Uéno [46].

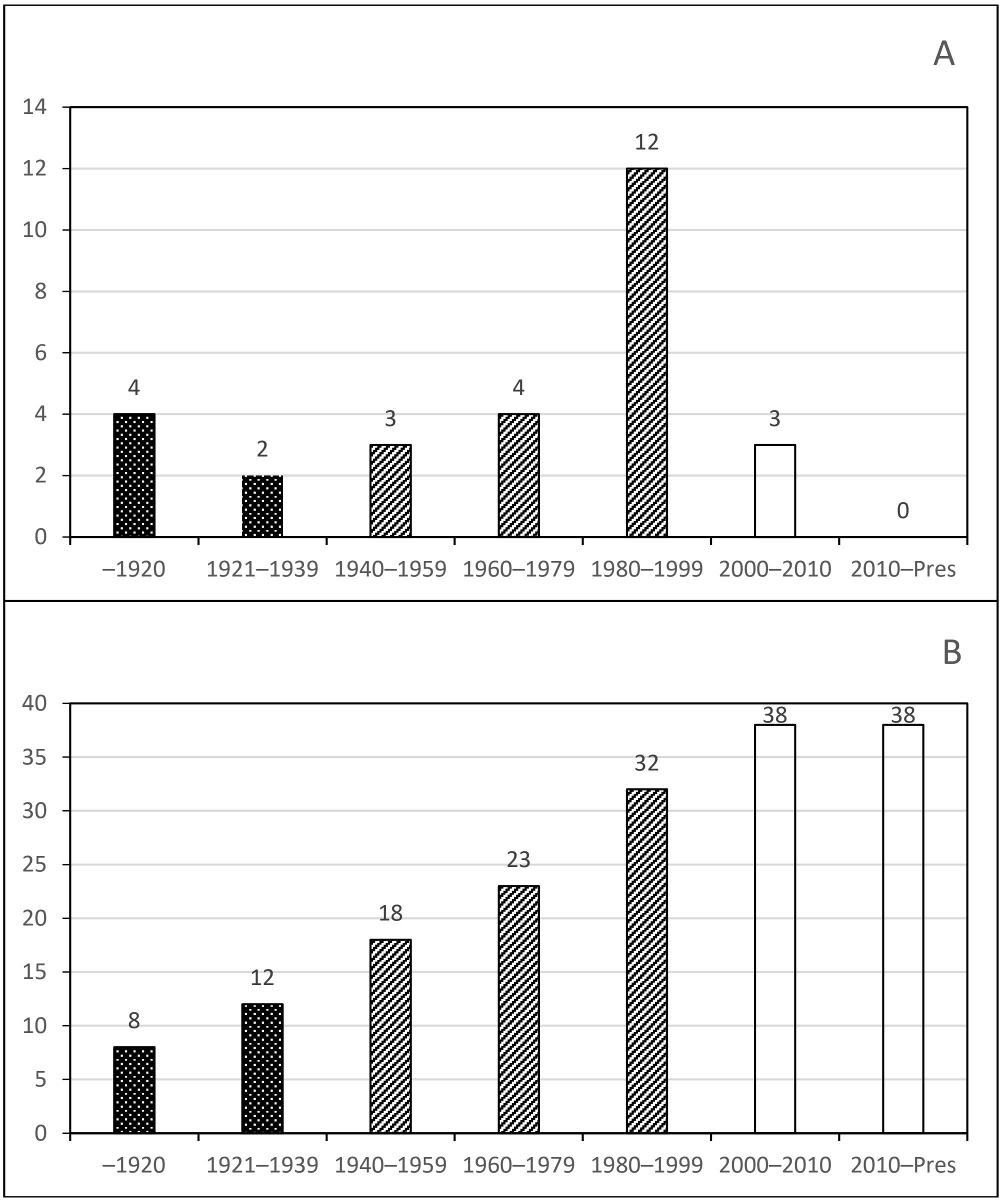

Figure 4. Historical progress of studies on Large Branchiopoda: Anostraca + Notostraca + Cyclestherida + Laevicaudata + Spinicaudata in Mexico. (**A**) Publications. (**B**) Cumulative species number: Phase 1. Early studies by foreign visitors; Phase 2. First publications of Mexican researchers alone or with specialists from around the world; Phase 3. Mature phase and discovery of unknown diversity.

3.1.5. Large Branchiopods

The scientific publications on large Mexican branchiopods started early in this phase, in 1860, with the description of a clam shrimp, *Cyzicus mexicanus* [59]. Three other notostracans were subsequently described by Packard [59]. Richard [60], Daday [61,62], and Linder [63] reported or described other clam shrimps and branchiopods from different localities.

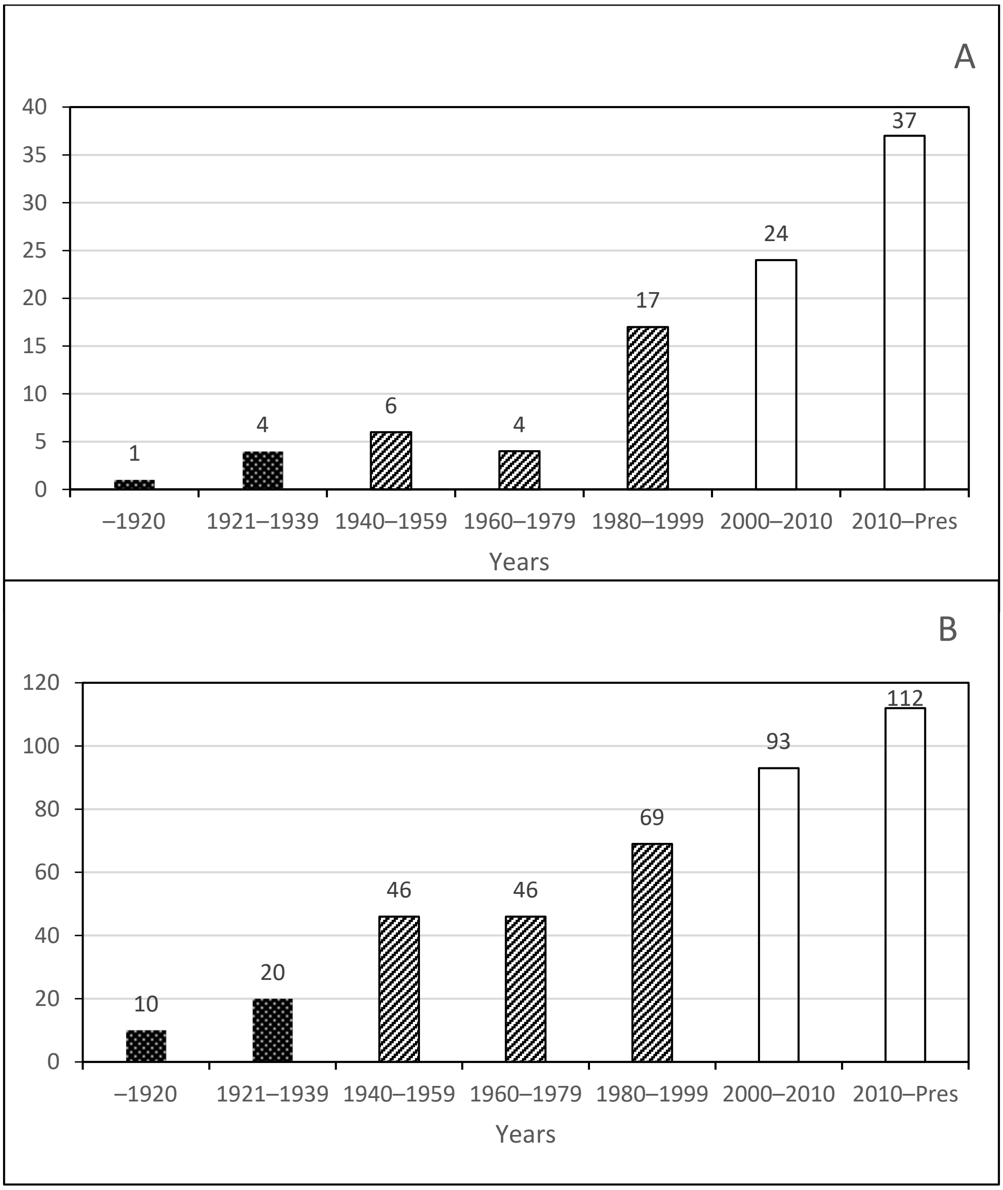

Figure 5. Historical progress of studies on Mexican Copepoda (Cyclopoida + Calanoida). (**A**) Number of publications (**B**) Cumulative number of species ▩ Phase 1. Early studies by foreign visitors; ▨ Phase 2. The first generation of Mexican copepodologists, mainly in the last two decades (1980–1999); ▭ Phase 3. Mature phase with integrative taxonomy and the discovery of exotic species.

3.1.6. Copepods

Regarding copepods, Pearse [64] described the first copepod from Mexico, soon synonymized by Marsh [65] as *Mastigodiaptomus albuquerquensis*. Subsequently, Juday [56] provided a list of zooplankton crustaceans from two localities around Mexico City, and Marsh [66] described *Diaptomus mexicanus*, which was later described in detail [67]. Further taxonomic work on Mexican freshwater copepods was provided by Friedrich Kiefer [68], who worked on several samples from Mexico that were sent to the Karlsruhe Natural History Museum. He described diaptomid and cyclopid species from different areas of Mexico. Additional accounts on copepods were published by Brehm [57] and Uéno [46]. Wilson [69] and Pearse and Wilson [70] reported on the Yucatan copepods and cladocerans.

The Spanish researcher B. Osorio Tafall was active as a scientist in the 1940s. He described several species that are now deemed valid [71–73].

3.2. Phase 2: Towards the Formation of Mexican Limnologists (1950s to the End of XX Century)

This second phase includes works conducted by foreign scientists, closely collaborating with Mexican researchers in most cases.

3.2.1. Protists

During this period, most of the protozooplankton studies in Mexico were developed under an alpha-taxonomy perspective [74]. Most Neotropical species were recorded from artificial lakes [75,76]. Examples of this phase include some contributions that were made on species from Mexico City by López-Ochoterena [77], Pérez-Reyes and Salas-Gómez [78], and Lugo-Vázquez [79].

3.2.2. Rotifers

About the Rotifera, this phase started at the end of the 1980s and early 1990s, with scattered contributions [80–85]. Subsequent taxonomical studies allowed important advances in the knowledge of the Mexican rotifer diversity [86–93]. At the end of this period, Sarma [94] compiled the rotifer species recorded in Mexico at that time, an account including 283 rotifer species: Monogononta (275) and Bdelloidea (8). Two years later, Elías-Gutiérrez et al. [95] analyzed the known diversity of the Mexican freshwater zooplankton (rotifers, cladocerans, and copepods) and emphasized that the presumed cosmopolitanism of these groups should be questioned because of the discovery of species complexes with restricted geographical distributions and strong morphological affinities.

3.2.3. Water Mites

The taxonomic study of water mites continued during this 2nd phase: Cook [96,97] described new Mexican species and published a book on neotropical water mites reporting 177 species for Mexico and describing 139, thus significantly increasing the country listings. Vidrine [98] and Otero-Colina [99] added more new species. In 1978, C. Cramer-Hemkes launched a large project about the taxonomy, ecology, and distribution of Mexican water mites; many species descriptions were produced from this initiative [100–109].

3.2.4. Cladocerans

During this period, only three formal studies on cladocerans were published [110–112], with a few sporadic surveys remaining as gray literature.

The end of this period is characterized by the work of a rising generation of four Mexican researchers and three Indians that moved to Mexico (i.e., Roberto Rico-Martínez, Marcelo Silva-Briano, Manuel Elías-Gutiérrez, Jorge Ciros-Pérez, Singaraju Sri Subrahmanya Sarma, Nandini Sarma, Gopal Murugan), all of them influenced by a series of courses organized by Prof. Henri J. Dumont (University of Ghent, Belgium). The course (1991–1998) trained 85 students (Dumont, in litt.), and two Mexicans continued and defended their PhDs there.

So, after the 1990s, the first studies on cladocerans by this new generation of Mexican researchers started to yield publications [113–116]. In this phase, Hebert and Finston [117] discovered two new species of *Daphnia* here. The only known blind cladoceran of the Americas, *Spinalona anophthalmia*, was described by Ciros-Pérez and Elías-Gutiérrez [118]. Other new species were described during this period [119–121].

3.2.5. Large Branchiopods

During the second phase, revisions of large branchiopods were conducted mainly by foreign researchers [122–125]. Additional works on the genus *Artemia* were published by Bowen [126], Abreu-Grobois, and Beardmore [127,128]. Spicer [129] described a new *Streptocephalus* from Veracruz. Martin [130] documented *Eulimnadia belki* on Cozumel Island. *Streptocephalus woottoni*, endemic to northern Baja California and southern California, USA, was described by Eng et al. [131] and is currently considered an endangered species.

Mexican researchers' first descriptions of branchiopods started during this phase with contributions by Maeda-Martínez [132–136], a former student of H. Dumont. Fugate [137] described *B. sandiegonensis*, endemic to northern Baja California (Norte) and southern California, USA.

3.2.6. Copepods

During the second phase, copepods were studied mainly by foreign researchers such as Comita [138], Lindberg [139], and Brehm [110], who described *Mastigodiaptomus montezumae*. Fernando and Smith [140] compiled the available data on the copepods from Mexico and Central America.

In the second half of this period, Suárez-Morales et al. [80] published a brief study of the plankton of a Mexican tropical lake. Subsequently, the freshwater copepod research in Mexico was strongly encouraged by the taxonomic contributions of J.W. Reid, who provided the first comprehensive list and records of Neotropical free-living copepods [141,142]. She promoted many other taxonomic within this period [143–149].

3.3. Phase 3: The Mature Phase of Zooplankton Studies (21st Century)

The third phase started in the 21st century and is currently in progress when modern diversity approaches are consistently applied together with studies based on integrative taxonomy sensu Dayrat [150], as well as new paradigms and hypotheses derived from more detailed morphological studies and DNA sequencing. This phase is a mature stage of zooplankton studies in Mexico, with modern descriptions led by Mexican researchers and the training of a new generation of taxonomists, like M. Gutiérrez-Aguirre, A. Cervantes Martínez, N.F. Mercado-Salas, and A. E. García-Morales. All contribute significatively to the current knowledge of the Mexican freshwater zooplankton.

3.3.1. Protists

The current and most complete list of protists includes a compilation of 197 families, 445 genera, and 1170 species of heterotrophic flagellates and ciliates recorded after more than one century of studies in Mexico [151]. Previously, 238 species of planktonic tintinnid ciliates have been recorded, chiefly in marine and brackish environments [74].

Recently, two main, partially opposed concepts to explain the biogeographical patterns of protists were proposed [152,153], one stating a continuous, ubiquitous distribution of all protists and the other declaring that 30% of their diversity is endemic.

With the aid of new sequencing technologies, a high microbial eukaryotic alpha diversity has been discovered in aquatic and terrestrial habitats. For example, the 18S gene diversity in freshwater environments has been proven to be much higher than the diversity based solely on morphological evidence [154]. Likewise, all phylogeny-oriented metabarcoding studies have discovered high eukaryotic diversity in terrestrial and aquatic environments. Thus, it is now accepted that cryptic speciation is a pervasive pattern among protist species [155]. The debate continues because neither the introduction of ecological, ethological, or molecular aspects revealed a general pattern on the species level. However, some functional diversity patterns were found using the superior categories [5,7,156,157].

Recent studies on the alpha taxonomy of protists continued in Mexico [76,158–161], and it was expanded to other areas of the country [162–164]; however, the protozooplankton biodiversity from the Mayan aquifer in Yucatan Peninsula and other interesting aquatic systems remain poorly understood.

3.3.2. Rotifers

During this recent period, the studies involving rotifers became more intense, encompassing different approaches such as diversity, ecology (e.g., space-time variations, abundance, etc.), and molecular. On the diversity view, Silva-Briano et al. [165] described *Brachionus araceliae*. Later, García-Morales and Elías-Gutiérrez [166] published the first regional comprehensive list involving rotifer DNA analyses. After this study, the species descriptions included DNA data, thus setting a new standard [167,168]. These are among the few known rotifer species described based on integrative taxonomy worldwide.

Recent studies dealing with the diversity, seasonal variation, and abundance of zooplankton, including rotifer species listings, are in work by Sarma et al. [169]. The current list of rotifer species from Mexico includes 405 species of freshwater and brackish rotifers belonging to 27 families and 75 genera. (Supplementary Table S1).

3.3.3. Water Mites

In this phase, many new water mite taxa were described by Cramer-Hemkes [170], Marin-Hernández and Cramer-Hemkes [171], and Ramírez-Sánchez and Rivas [172]. Currently, 258 species of water mites are recorded from Mexico, comprising 62 genera; Hygrobatoidea is the superfamily with the highest number of genera and species in Mexico, especially *Koenikea*, *Atractides*, and *Limnesia*, followed by the superfamily Arrenuroidea with the highly diverse genus *Arrenurus*.

The analysis of the genetic information and the use of new sampling methods has allowed a better overview of the water mite diversity in different microhabitats, as in Montes-Ortiz and Elías-Gutiérrez [173,174], Montes-Ortiz et al. [175,176], and Elías-Gutiérrez and Montes-Ortiz [177].

3.3.4. Cladocerans

During this third phase, the studies on cladocerans continued, in some cases in collaboration with foreign specialists, describing new taxa, like the works by Elías-Gutiérrez and Smirnov [178], Cervantes-Martínez et al. [179], Kotov et al. [180–182], and also Elías-Gutiérrez et al. [183,184], and Garfias-Espejo and Elías-Gutiérrez [185]. In addition, Elías-Gutiérrez et al. [20] published the first large scale-study in the world involving Cladocera (61 species), and Copepoda (21 species), together with DNA sequences of the mitochondrial gene for the Cytochrome Oxidase (COI), with the key collaboration of Paul Hebert (Guelph University, Canada).

After this study, the first descriptions, including integrative taxonomy, started, being *Leberis chihuahuensis* from northern Mexico, the first cladoceran described worldwide with this method [186]. Other species described with this approach include *Scapholeberis duranguensis* by Quiroz-Vázquez and Elías-Gutiérrez [187]. Additional studies involving Mexican species of cladocerans and DNA barcodes were by Elías-Gutiérrez and Montes-Ortiz [177], Martínez-Caballero et al. [188], Montes-Ortiz and Elías-Gutiérrez [173], and Montoliu-Elena et al. [189].

3.3.5. Large Branchiopods

During this phase, Mexican researchers continued with descriptions of new large branchiopods, either in collaboration with foreign colleagues or alone. Maeda-Martínez et al. [21–23] published a review of the knowledge of these groups. The brine shrimp *Artemia* has been recorded in 11 Mexican states [21]. Data from genetics [190,191] and mtDNA (16S and COI) [192] support the discovery of six populations reported as *Artemia franciscana*. The rest of the population remains as *Artemia* sp. due to the lack of proper systematic characterization [21]. Based on mitogenomic analyses, Sainz-Escudero et al. [193] reported a relatively significant divergence between *Artemia* populations from Mexico and San Francisco Bay, USA (the type locality of *A. franciscana*). They suggested nuclear DNA analyses to reach a systematic conclusion. These authors proposed *Artemia monica* as the valid name for the New World *A. franciscana* group. Maeda-Martínez et al. [22] cited as *Triops* sp., all known Mexican tadpole shrimp populations and revised the existence of biochemical [194], molecular (12S mtDNA) [195], histological [196], reproductive [197], and morphological [194] differences. Studies show the existence of several species, and therefore a systematic reevaluation is needed. New species in this period include Obregón-Barboza et al. [198] and Maeda-Martínez et al. [199]. A review of *Branchinecta* species was published by Obregón-Barboza et al. [200], including the first record of *B. gigas* Lynch, 1937 for Mexico. COI data revealed two distinct clades within *B. lindahli*, but cryptic taxa are not present in the populations of the studied taxon [201].

Obregón-Barboza et al. [202] reviewed the Mexican populations of the fairy shrimps *Thamnocephalus mexicanus* and *T. platyurus*, studied their morphology, and 16S and COI haplotypes, thus confirming two separate biological lineages at the species level.

3.3.6. Copepods

During this period, the taxonomic work on copepods increased notably, with many descriptions and new records of species. DNA data have also been integrated with other taxonomic, ecologic, and biogeographical data.

Currently, over 30 species of the copepod order Calanoida are known in Mexico. Some genera are represented by one species (Supplementary Table S1). The diaptomid genus *Mastigodiaptomus* is the most diverse (13 species) (Supplementary Table S1); some new species of this genus have been described recently using integrative taxonomy [31,203]. *Mastigodiaptomus ha* is the second diaptomid species found on a Caribbean Island. *Leptodiaptomus* is the second most diverse diaptomid genus in Mexico (7 species), mainly recorded in the Nearctic region of this country (Supplementary Table S1). However, it is suspected that it comprises other cryptic species. *Leptodiaptomus garciai* has been recorded in the unique saline Lake Alchichica, a crater lake, by Montiel-Martínez et al. [71], in the Mexican Transition Zone (MTZ) between the Nearctic and Neotropical regions [204,205]. Several other species of this genus are known from central and western Mexico [206].

Cyclopidae can inhabit inland permanent and ephemeral freshwater systems and even high-altitude ponds or lakes. This family is the most successful and widespread group of free-living freshwater copepods. It includes over 60 genera and a record of more than 800 species worldwide [29,207]. The most updated information for Mexico includes 82 cyclopid species with members of three subfamilies: Halicyclopinae, with five species in two genera considered as endemic for the Yucatan Peninsula [208,209], Cyclopinae with 46 species in 11 genera, and Eucyclopinae with 31 species in six genera (Supplementary Table S1). The latter two subfamilies are the most widespread in Mexico, with endemic, introduced, and exotic species [206,210,211]. In this period, Suárez-Morales and Walsh [212] described two new species of *Eucyclops*, and Mercado-Salas et al. [213] described six new species of the same genus from different parts of Mexico, proposing new taxonomic characters. Some cyclopids can colonize bromeliads in the Neotropical region [214,215].

Members of the order Harpacticoida mainly inhabit the benthic habitats of the water systems. However, they can be found in the limnetic region, associated with invertebrates and vertebrates, and, recently, in bromeliads as well [214].

Harpacticoid copepods remain largely understudied in Mexico compared to the orders Calanoida and Cyclopoida; there are only a few species effectively recorded for Mexican freshwaters, like *Cletocamptus sinaloensis* by Gómez et al. [216], *Eduardonitocrella mexicana* by Suárez-Morales and Iliffe [217], and *Cletocamptus gomezi* by Suárez-Morales et al. [218]. In the last 20 years, different checklists of copepods that comprised harpacticoids allowed a better understanding of their distributional patterns and diversity [27,144]. Recently, Gómez and Morales-Serna [24] updated the inventory of this order for Mexico, including records of marine, brackish, saline, and freshwater species to assemble the current list of 21 known species for freshwater systems (Supplementary Table S1).

There is some evidence that several Mexican species exhibit different distributional patterns, i.e., *Cletocamptus sinaloensis* have been recorded in lagoons and estuarine systems of Sinaloa State [216], whereas *C. gomezi* is endemic to a high –altitude lake [219].

The increase of the knowledge of freshwater zooplankton during this last period, not only in Mexico but the rest of the world, allowed the detection of exotic or invasive species, such as the *Daphnia* (*Ctenodaphnia*) *lumholtzi*, that previously invaded the East of the USA and Canada [20]. The following section will discuss this species and other exotic or invasive zooplankters.

3.4. Exotic/Invasive Zooplankton Species in Mexico

This section deals with a topic that could not be properly or consistently treated in the previous phases. Our current knowledge of the Mexican zooplankton diversity has allowed us to consider an overview of this aspect. The study of the effect of exotic species on local diversity is essential, as induced changes in native communities could be of great relevance.

An account of documented exotic zooplankters in Mexico includes the cladocerans as *Daphnia curvirostris*, first reported by Nandini et al. [220], *Daphnia magna* introduced for ecotoxicological studies [221], and *Daphnia* (*Ctenodaphnia*) *lumholtzi* [20,222]. *Moina macrocopa* probably was introduced in a net by a researcher of Amphibia [189]. As for copepods, Suárez-Morales and Arroyo-Bustos [223] recorded *Skistodiaptomus pallidus* as an intra-continental exotic species in Sinaloa, north of Mexico. The Euro-Asian cyclopoid *Thermocyclops crassus* is also an introduced species [210], as are two other species of *Mesocyclops* (*M. pehpeiensis* and *M. thermocyclopoides*) [224–226].

3.5. Conservation of the Zooplankton

Aside from the large branchiopods, little is said about the conservation of endemic or endangered species [227]. Several species of Mexican zooplankton are likely to disappear together with their habitats, like the recently described rotifer *Brachionus paranguensis*, whose type locality is drying [167].

From the original descriptions, and after new fieldwork, *Spinalona anophthalma*, *Macrothrix marthae*, and *Moina hutchinsoni* have yet to be found again [118,178,228]. As for copepods, we did find *Leptodiaptomus mexicanus* once, but not *L. dodsoni* and *Mastigodiaptomus maya*. Also, several copepod species are endemic to the Yucatan Peninsula [229]. However, a common, widespread species, *Mastigodiaptomus montezumae*, is the only copepod in the IUCN red list of endangered species.

Conservation problems are also related to species and habitats threatened by human impact, including the fragile and diverse hypogean copepod fauna of the Yucatan Peninsula, currently threatened by the unregulated construction of a railway with unforeseen damages to the freshwater fauna.

4. Final Remarks and Conclusions

As we intended to demonstrate, there has been a progressive maturation of the zooplankton studies in Mexico, with increasing participation and leadership of Mexican researchers. In the last 40 years, the number of species known from this country has increased by 58% of protists, 67% rotifers, 71% cladocerans, 39% large branchiopods, and 59% copepods. Nevertheless, being a megadiverse country, we estimate that the species inventory of the Mexican zooplankton still needs to be completed.

Recent studies focused on some of Mexico's most important groups of freshwater biodiversity have been considered a world example by combining integrative taxonomy, DNA analyses, and their complete access to public databases [230]. However, the large territorial extension, difficult access to the study sites, progressive lack of taxonomists, reduced funds for science, and unsafe traveling conditions in different regions of the country, are the main risk factors to continuing expanding studies on Mexican zooplankton.

The group of current zooplankton taxonomists is training a third generation of active taxonomists and ecologists of zooplankton, covering different groups such as cladocerans [189], copepods [206,231], as well as additional taxa like the ostracods [232] and water mites [176].

This third generation will be able to continue expanding our knowledge of the zooplankton taxa in Mexico and help in the conservation of the freshwater ecosystems and their biota.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w15050858/s1, Table S1: Species richness of freshwater Protists, Rotifera, Cladocera an Copepoda recorded in Mexico (Aladro-Lubel et al., 2007, 2009; Albores-Celorio, 1969; Arevalo-Navarro, 1999; Bravo-Hollis, 1922, 1924; Cabral-Dorado, 2006; Elliot and Hayes, 1955; Figueroa-Torres and Moreno-Ruíz, 2003; Flores-Flores, 2012; Flores-Orta, 1983; González-Labastida, 1995; Hernández-Anaya, 1981; Kusel-Fetzmann, 1973; López-Ochoterena, 1962, 1964, 1965; López-Ochoterena and Barajas, 1964; López-Ríos, 1972; Lugo-Vázquez, 1993; Macek et al., 2022; Madrazo-Garibay and López-Ochoterena, 1973, 1985, 1986, 1990; Marrón-Aguilar and López-Ochoterena, 1969; Méndez-Sánchez, 2014, 2017; Méndez-Sánchez et al., 2018; Mendoza-González, 1973; Moreno-Ruíz, 1985; Nomdedeu and López-Ochoterena, 1988; Osorio-Tafall, 1941, 1942, 1944; Pérez-Reyes and Salas Gómez, 1960, 1961; Peštová et al., 2008; Ponce-Márquez et al., 2019; Potekhin and Mayén-Estrada, 2020; Ramírez de Guerrero, 1970; Saadi-González, 2018; Sámano and Sokoloff, 1931; Sánchez-Rodríguez et al., 2011; Sigala-Regalado, 2008; Sokoloff, 1930a, b, 1931, 1936; Tiscareño-Silva, 2008; Rico-Martínez & Silva-Briano; 1993; Dussart & Defaye 1995; Sarma et al., 1996; Suárez-Morales et al., 1996; Sarma & Elías-Gutiérrez, 1997; Sarma & Elías-Gutiérrez, 1998; Suárez-Morales & Reid, 1998; Elías-Gutiérrez et al., 1999; Sarma, 1999; Sarma & Elías-Gutiérrez, 1999a; Sarma & Elías-Gutiérrez, 1999b; Suárez-Morales et al., 2000; Elías-Gutiérrez et al., 2001; Suárez-Morales & Gutiérrez-Aguirre, 2001; Elías-Gutiérrez & Suárez-Morales, 2003; Garfias-Espejo & Elías-Gutiérrez, 2003; Suárez-Morales & Elías-Gutiérrez 2003; Suárez-Morales & Reid 2003; Suárez-Morales, 2004; García-Morales & Elías-Gutiérrez, 2004; Sinev et al., 2005; Suárez-Morales & Iliffe, 2005; Elías-Gutiérrez et al., 2006; García-Morales & Elías-Gutiérrez, 2007; Segers, 2007; Silva-Briano et al. 2007; Elías-Gutiérrez et al., 2008; Elías-Gutiérrez & Valdéz-Moreno, 2008; Mercado-Salas et al., 2009; Mercado-Salas & Suárez-Morales, 2009; Nandini et al., 2009; Suárez-Morales & Walsh, 2009; Suárez-Morales et al., 2010; Mercado-Salas & Suárez-Morales 2011; Sinev & Silva-Briano, 2012; García-Morales & Elías-Gutiérrez, 2013; Gutiérrez-Aguirre et al., 2013; Gutiérrez-Aguirre & Cervantes-Martínez, 2013; Mercado-Salas & Álvarez-Silva, 2013; Mercado-Salas et al., 2013; Sinev & Zawiska, 2013; Mercado-Salas & Suárez-Morales 2014; Gutiérrez-Aguirre et al., 2014; Mercado-Salas et al., 2015; Gutiérrez-Aguirre & Cervantes-Martínez, 2016; Mercado-Salas et al., 2018; Elías-Gutiérrez et al., 2019; Gutiérrez-Aguirre et al., 2020; Suárez-Morales et al., 2020; Sarma et al., 2021).

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