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Trophic analysis of the fish community in the Ciénega Churince, Cuatro Ciénegas, Coahuila.

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Abstract. The fish community in the Churince system includes endemic, native and introduced species. Fish diets were analysed in order to evaluate the tropho-dynamics of the community. Nine sampling campaigns were carried out between February 2011 and May 2014, and 556 specimens of nine fish species were collected. Stomach contents were analysed using the Index of Relative Importance (IRI) and the Index of Absolute Importance (RIa). Similar groups were defined for the trophic chain using the average linkage method. Feeding strategies were stenophagic in only the species *Herichthys minckleyi* and euryphagic in the other eight species. The main food categories found in the stomach contents of the fish community were insects, crustaceans, gastropods, plants and teleosts. Four functional groups were defined for the trophic chain, with no top consumer fish species. Despite this, the fish were observed to be regulators, mainly of invertebrates. The chain reaction in the control of food was thus greater from the top to the bottom.

Introduction

The state of Coahuila is located in the Chihuahuense desert. This is the largest eco-region in Mexico and it harbours the second greatest diversity worldwide. Water is often the main limiting factor for the biota (ProNatura, 2012). The Cuatro Ciénegas basin is located in Coahuila. It has a great variety of singular aquatic environments formed by complex systems of subterranean currents, swamp-like wetlands, springs, canals, rivers, lakes, marshes (ciénegas) and temporal pools (Souza et al., 2004). A high endemism of flora and fauna is characteristic of the region, for which it was decreed a Biosphere Reserve (Reserva de la Biósfera) in 1994 (Wolaver et al., 2007).

Seven major runoff systems, related to their source, exist in the basin: the Becerra system, the Río Mezquites, the Río Puente Chiquito, the Tío Cándido system, Santa Tecla, the Río Salado de los Nadadores and the Churince system (Minckley, 1969). This last one is the least altered by human activity (Zamudio-Valdés, 1991).

The Cuatro Ciénegas basin represents a biologically historical natural laboratory, and its study may help understand how life started and evolved. The system has provided refuge for different taxonomic groups, mainly crustaceans, molluscs, fish, birds, mammals, insect larvae, mites and terrestrial and aquatic plants (Carabias et al., 1999). Fish constitute one of the most important aquatic groups regarding the ecology and biology of the area. Of the fish species found in the different pools that make up this wetland, 50% are endemic (Espinosa-Pérez, 1993).

The aquatic environments in Cuatro Ciénegas have been altered, mainly by grazing activities, agricultural expansion and the ceding of water rights (WWF México, 2012). Also, the native and endemic fish fauna in the Churince system has been endangered by the introduction of the exotic fish species *Hemichromis guttatus* Gunther, 1862 or “jewel fish”.

The feeding ecology of the different species in a fish community may be evaluated through the analysis of stomach contents. This is the best known and most used method for the study of fish diets and allows the development of strategies for the sustained management of aquatic ecosystems (Valente, 1992; Amundsen, Gabler and Staldvik, 1996; Segatti and Luciana 2003).

The present study examined the diet of the fish community following Graham and Vrijenhoek (1988), in order to describe the trophic dynamics of the community, considering that food composition is one of the most important factors in the conformation of the ecological niche

(Krebs, 1989). The part that fish species play in trophic chains is determined with respect to volume, quantity and presence, presenting these variables as approximations of predator feeding strategies (Hyslop, 1980; Valente, 1992; Segatti and Luciana, 2003) and applying them to the Index of Relative Importance proposed by Pinkas et al. (1971) and the Index of Absolute Importance. These measures annul any bias in the individual components, provide a more precise description of the importance of the diet and facilitate comparisons among studies (Bigg and Pérez, 1985; Cortés, 1997).

Materials and methods

Study area. The Cuatro Ciénegas basin an inter-mountain closed basin. With respect to climate and geography, it is located in the Chihuahuense desert or northern plateau, in the central region of the state of Coahuila. It is the second largest desert in North America and the largest eco-region in Mexico (Fig. 1). The climate is arid, with an average mean rainfall of less than 200 mm, Summer day temperatures occasionally above 44°C and Winter temperatures that may drop below 0°C (Minckley, 1969). Despite the dry climate, the basin harbours an extensive system of springs, streams and pools.

Within the basin, spring water flows from the surface of the subsoil through canals in a karst wash. The main source of the subterranean water in the system is the old water that was deposited there at the end of the Pleistocene (Wolaver et al., 2007). It is believed that the water in the basin is a relic of a shallow sea that existed 35 million years ago, characterised by low levels of NaCl and carbonates and rich in sulfates, magnesium and calcium. One of the most important characteristics of the ecosystem is a low level of phosphorus, both in the water and in the soil, in comparison with similar environments (Elser et al., 2005). Phosphorus is an essential nutrient in various cellular processes, to obtain energy and to transfer genetic information, among others, but it is not an abundant element in the world and may be obtained only from organic or volcanic refuse and through plate tectonics. Thus, phosphorus availability is a limiting factor for all forms of life. However, life persevered in Cuatro Ciénegas where the biota is characterised by a high endemism in all domains of life, in spite of having phosphorus levels below the detection level (0.3 M) (Minckley, 1969; Scanlan, Mann and Carr, 1993).

The Cuatro Ciénegas basin, as is mentioned above, has seven major runoff systems which are probably connected in a natural way, either underground or on the surface during the rainy season, although man-made irrigation canals have modified or interconnected most of the systems, eliminating many habitats by diminishing the level of the water table (Minckley and Cole, 1968).

The present study was carried out in the Churince system which, considering the water level and its physico-chemical characteristics, is divided into five areas: Poza Churince, Poza Bonita, Laguna Intermedia, Laguna Grande and Río Churince. This last one connects Poza Churince to Poza Bonita (Fig. 2). The Churince system is the oldest marsh in the Cuatro Ciénegas valley. In 1991 (Zamudio-Valdés) it was considered the least altered by human activity, however from the year 2006 to 2009 a sudden 30 m decrease in the level of the water table was recorded. This affected Laguna Grande in the hydrological system of Churince turning it into a desolate space full of saltpetre (Carrera, 2011).

Fish sampling. Nine samplings were carried out in the Ciénega Churince from February 2011 to May 2013. Specimens were collected with a 3 x 1.5 m, 0.5 cm mesh size seine, a drop net locally known as “atarraya”, dipnets and carp traps for the jewel fish. The fish were analysed and deposited in the Colección Nacional de Peces of the Instituto de Biología, UNAM.

Stomach content analyses. Fish stomachs were dissected and the degree of digestion and of filling was determined following Hyslop (1980) and Laevastus (1980) respectively. Data were recorded for volumetric percentage: food volume with respect to stomach content volume, numerical percentage: the number of individuals of each food category out of the total number of individuals of all food categories in the stomach, and frequency of occurrence expressed as a percentage: the number of stomachs with one to more individuals of each food category out of all the analysed stomachs. The data were integrated into the Index of Relative Importance (IRI) (Pinkas et al., 1997), the Index of Absolute Importance (RIa) adapted by George and Hadley (1979), and the feeding coefficient.

Trophic level or position. This was determined in accordance with the feeding habits of each species with respect to the Index of Relative Importance and the feeding coefficient, and defined

as the 1st level (primary producers), 2nd level (primary, secondary and tertiary) and 3rd level (decomposers) categories (Tyler, 1994).

Trophic niche amplitude. This measure quantitatively defines an organism as a generalist when it feeds on a variety of food items, and as a specialist when it preferentially eats one type of prey. The Levins' standardised index was used. It states that the amplitude may be estimated from the uniformity in the distribution of the individuals among the diverse food resources. The measure provides values of 0 to 0.60 when an organism is a specialist and values above 0.60 when it is a generalist (Krebs, 1989).

Trophic chain. The degree of similarity in the fish diets was determined using accumulative hierarchical numerical classification analysis techniques in order to define groups of species that share similar prey. The formation of similar trophic groups was based on the average linkage method. A matrix was constructed using the Bray-Curtis dissimilarity index. Dendrograms were used for graphic representations.

Results

Collected specimens. A total of 569 specimens of nine species and five families of fish were collected (Table 1). The main characteristics and the feeding description of each species are presented here.

Cyprinodon atrorus Miller, 1968, cachorrito del Bolsón – Bolsón Pupfish. This species is endemic of Cuatro Ciénegas and is classified as threatened in the Norma Oficial Mexicana NOM-059-SEMARNAT-2010. It is distributed from Laguna Intermedia to half way along the Río Churince, where 75 specimens were collected (Table 1). Of these, 62% of the stomach contents were digested and 38% were half digested. Also, 28% of the stomachs were full, 52% were almost full and 20% were empty. The trophic spectrum (Fig. 3) of the species had six food categories, of which the insects and crustaceans were the preferred categories in the diet of this species according to the feeding indices IRI and RIa and the feeding coefficient (Table 2). The Levins index value was 0.77. Analysed material: CNPE-IBUNAM18857, CNPE-IBUNAM18858, CNPE-IBUNAM18859, CNPE-IBUNAM18860, CNPE-IBUNAM18868, CNPE-IBUNAM18883, CNPE-IBUNAM18892, CNPE-IBUNAM18900, CNPE-

IBUNAM18913, CNPE-IBUNAM18926, CNPE-IBUNAM18933, CNPE-IBUNAM18937, CNPE-IBUNAM18943, CNPE-IBUNAM18957, CNPE-IBUNAM18958.

Cyprinodon bifasciatus Miller, 1968, cachorrito de Cuatro Ciénegas – Cuatro Ciénegas Pupfish. This species is restricted to thermal waters (26.7ºC - 34.5ºC) in or near springs, streams and wetlands that have a constant flow of hot water and unchanging physical characteristics (Arnold, 1972). It is classified as threatened in the NOM-059-SEMARNAT-2010. It is distributed from half way along the Río Churince to the freshwater spring Manantial de Agua Dulce, where 99 specimens were collected at specific points (Table 1). The analysis showed that 37% of the stomachs were full, 56% were almost full and 6% were empty. Also, 51% of the stomach contents were half digested and 49% were digested. The trophic spectrum (Fig. 3) presented eight food categories of which, according to the feeding indices IRI and RIa and the feeding coefficient (Table 2), insects and crustaceans were the preferred food items, with plants as the secondary food item. The Levins index value was 0.75. Analysed material: CNPE-IBUNAM18870, CNPE-IBUNAM18876, CNPE-IBUNAM18889, CNPE-IBUNAM18897, CNPE-IBUNAM18898, CNPE-IBUNAM18903, CNPE-IBUNAM18905, CNPE-IBUNAM18916, CNPE-IBUNAM18928, CNPE-IBUNAM18939, CNPE-IBUNAM18940, CNPE-IBUNAM18947, CNPE-IBUNAM18948.

Gambusia marshi Minckley & Craddock, 1962, guayacón de los Nadadores – Robust Gambusia. This species swims near the surface, is aggressive and is distributed widely in the Bolsón de Cuatro Ciénegas (Miller, Minckley and Norris, 2009). It is native to the basin and is classified as threatened in the NOM-059-SEMARNAT-2010. It is the only species that is found throughout the Churince system. In order to analyse the diet, the collected specimens were divided into two groups based on the physical and chemical characteristics of the system (e.g. temperature, plants in the water and outside, and species with which they interact in the marsh). The first group gathered 76 specimens that were distributed from Laguna Intermedia to half way along the Río Churince (Table 1) based on the distribution of *C. atrorus*, and the second group gathered 100 specimens with the distribution of *C. bifasciatus* as reference. Of the stomachs of the first group, 18% were full, 22% were almost full, 59% were almost empty, 1% were empty, 61% were half digested and 39% were digested. The trophic spectrum (Fig. 3) presented seven food categories of which, according to the feeding indices IRI and RIa and the feeding coefficient (Table 2),

insects and crustaceans were the preferred food items of the *G. marshi* of the first group, with a Levins index value of 0.86. Of the stomachs of the second group, 19% were full, 52% were almost full, 29% were almost empty, 47% were half digested and 53% were digested. The trophic spectrum (Fig. 3) presented six food categories of which, according to the feeding indices IRI and RIa and the feeding coefficient (Table 2), plants and insects were the principal food categories, followed by crustaceans as the secondary food item in the diet. The Levins index value was 0.95. A dendrogram (Fig. 4) presents a comparison of the diet of the two gambusia groups. Analysed material: CNPE-IBUNAM18856, CNPE-IBUNAM18861, CNPE-IBUNAM18865, CNPE-IBUNAM18872, CNPE-IBUNAM18874, CNPE-IBUNAM18878, CNPE-IBUNAM18879, CNPE-IBUNAM18884, CNPE-IBUNAM18887, CNPE-IBUNAM18891, CNPE-IBUNAM18893, CNPE-IBUNAM18896, CNPE-IBUNAM18899, CNPE-IBUNAM18901, CNPE-IBUNAM18906, CNPE-IBUNAM18909, CNPE-IBUNAM18912, CNPE-IBUNAM18915, CNPE-IBUNAM18920, CNPE-IBUNAM18923, CNPE-IBUNAM18925, CNPE-IBUNAM18929, CNPE-IBUNAM18931, CNPE-IBUNAM18932, CNPE-IBUNAM18934, CNPE-IBUNAM18936, CNPE-IBUNAM18938, CNPE-IBUNAM18942, CNPE-IBUNAM18944, CNPE-IBUNAM18946, CNPE-IBUNAM18949, CNPE-IBUNAM18953, CNPE-IBUNAM18960.

Lepomis macrochirus Rafinesque, 1819, mojarra oreja azul – Bluegill Sunfish. This species is a bottom dweller in temperate slow-moving waters and deep, calm and stagnant areas where aquatic plants and other types of vegetation are common (Miller, Minckley and Norris, 2009). It is a native species distributed in Laguna Intermedia where 13 specimens were collected. Of these, 24% of the stomachs were full, 38% were half full and 38% were almost empty. The stomach content in all the stomachs was half digested. The trophic spectrum (Fig. 3) presented six food categories of which, according to the feeding indices IRI and RIa and the feeding coefficient (Table 2), insects and crustaceans were the main categories in the diet. The Levins index value was 0.60. Analysed material: CNPE-IBUNAM18864, CNPE-IBUNAM18895, CNPE-IBUNAM18921, CNPE-IBUNAM18927.

Lepomis megalotis (Rafinesque, 1820), orejona roja – Longer Sunfish. This species is usually found in the higher parts of rivers and their tributaries, in standing clear or muddy waters, and in shallow water bodies. It is a native species distributed in Laguna Intermedia where 12 specimens

were collected (Table 1). Of these, 42% of the stomachs were almost full, 33% were almost empty and 25% were empty. The stomach content in all the stomachs was half digested. The trophic spectrum (Fig. 3) presented seven food categories of which, according to the feeding indices IRI and RIa and the feeding coefficient (Table 2), crustaceans and insects were the main categories in the diet. The Levins index value was 0.75. The specimens used for the analysis were not deposited in the Collection as they were damaged during the study.

Micropterus salmoides (Lacepède, 1802), lobina negra – Largemouth Bass. This is a benthic species that tolerates a wide variety of conditions, but prefers warm, moderately clear, slow-moving or standing waters. It is a native species distributed in Laguna Intermedia where 48 specimens were collected (Table 1), of which 4% of the stomachs were full, 47% were almost full, 47% were almost empty and 2% were empty. The stomach content in 89% of the stomachs was half digested and that in 7% was digested. The trophic spectrum (Fig. 3) presented five food categories of which, according to the feeding indices IRI and RIa and the feeding coefficient (Table 2), insects and crustaceans were the primary categories in the diet. The Levins index value was 0.95. Analysed material: CNPE-IBUNAM18886, CNPE-IBUNAM18888, CNPE-IBUNAM18908, CNPE-IBUNAM18911, CNPE-IBUNAM18918, CNPE-IBUNAM18919, CNPE-IBUNAM18922, CNPE-IBUNAM18924.

Herichthys minckleyi (Kornfield & Taylor, 1983), mojarra de Minckleyi – Minckley's Cichlid. Minckley's Cichlid has three morphological types, or "morphs" (Kornfield and Taylor, 1983; Minckley, 1969; Husley, Hendrickson and García de León, 2005). The main polymorphism is in the pharyngeal teeth. It is possible to find individuals with very big and strong teeth (molariform), as well as very fine, pointed and delicate teeth (papilliform). It has been documented that individuals with molariform teeth mainly eat snails, while those with papilliform teeth feed on organic matter, among other things (Minckley, 1969; Kornfield and Taylor, 1983). The piscivorous morph has a much longer head and body and its diet includes fish, especially *C. bifasciatus*. Piscivorous fish may have molariform pharyngeal teeth, although this combination is rare, and most have papilliform teeth. The two main morphs with two different body shapes are sympatric, while piscivores are mostly restricted to areas near the source of thermal waters. Piscivores adopt a cryptic colouration with vertical bands that favours the predatory behaviour of "sitting and waiting" for the *Cyprinodon* sp. (Minckley, 1969; Kornfield

and Taylor, 1983). This species is endemic of Cuatro Ciénegas and is considered in danger of extinction in the NOM-059-SEMARNAT-2010. In the Ciénega Churince, it is distributed through part of the Río Churince to the freshwater spring Manantial de Agua Dulce, where nine specimens were collected (Table 1). Of these, 55% of the stomachs were full, 33% were almost full, 11% were empty, 62% of the stomach contents were half digested and the rest were digested. The trophic spectrum (Fig. 3) presented eight food categories of which, according to the feeding indices IRI and RIa and the feeding coefficient (Table 2), gastropods were the main food item and teleosts and plants the secondary food items. The Levins index value was 0.77. Analysed material: CNPE-IBUNAM18869, CNPE-IBUNAM18882, CNPE-IBUNAM18917, CNPE-IBUNAM18951, CNPE-IBUNAM18954, CNPE-IBUNAM18959.

Hemichromis guttatus Günther, 1862, jewel fish – Jewel Cichlid. This opportunist feeder lives in the water column. Fish of this genus are bi-parental, build nests on the bottom, care for them together and deposit their eggs on another substrate after fecundation. The species is exotic to the area, as it originated in Africa. It was first reported in March 1996 for the freshwater spring Manantial de Agua Dulce by Ana Ludlow (Contreras-Balderas and Ludlow, 2003). It is distributed in Poza Bonita, the Río Churince and the freshwater spring Manantial de Agua Dulce, where 102 specimens were collected. The trophic spectrum (Fig. 3) presented seven food categories of which, according to the feeding indices IRI and RIa and the feeding coefficient (Table 2), insects were the main food category and crustaceans and plants were the secondary food items. The Levins index value was 0.34. Analysed material: CNPE-IBUNAM18871, CNPE-IBUNAM18873, CNPE-IBUNAM18877, CNPE-IBUNAM18880, CNPE-IBUNAM18881, CNPE-IBUNAM18902, CNPE-IBUNAM18904, CNPE-IBUNAM18914, CNPE-IBUNAM18930, CNPE-IBUNAM18935, CNPE-IBUNAM18941, CNPE-IBUNAM18945, CNPE-IBUNAM18950.

Cyprinella xanthicara (Minckley & Lytle, 1969), sardinita de Cuatrociénegas – Cuatrocienegas Shiner. This pelagic species lives in large springs of clear water, in streams fed by springs, in areas with currents and in areas where there is friction between currents and standing water. It tends to concentrate above and below riffles over marl, gravel, rocks and floculated clay. It is more abundant in the high parts of streams fed by springs, just below the source of the water (Miller, Minckley and Norris, 2009). It is endemic in Cuatro Ciénegas and is considered in

danger of extinction in the NOM-059-SEMARNAT-2010. In the Churince system, it is distributed in Laguna Intermedia, where 35 specimens were collected (Table 1). Of these, 31% of the stomachs were almost full and 69% were almost empty. Of the stomach contents, 37% were half digested and 63% were digested. The trophic spectrum (Fig. 3) presented six food categories of which, according to the feeding indices IRI and RIa and the feeding coefficient (Table 2), insects and crustaceans were the main food items. The Levins index value was 0.56. Analysed material: CNPE-IBUNAM18862, CNPE-IBUNAM18866, CNPE-IBUNAM, CNPE-IBUNAM18875, CNPE-IBUNAM18885, CNPE-IBUNAM18890, CNPE-IBUNAM18894, CNPE-IBUNAM18910, CNPE-IBUNAM18863, CNPE-IBUNAM18867, CNPE-IBUNAM18907.

Composition of the diet in the fish community. The dendrogram for the Index of Relative Importance formed four main groups: A only *H. minckleyi*; B: B1 *L. macrochirus*, *C. atrorus* and B2 *C. bifasciatus*, *H. guttatus*; C: C1 *Dionda* sp., C2 *G. marshi* int, *M. salmoides* and C3 *L. megalotis*; and D *G. marshi* man (Fig. 5).

The trophic chain (Fig. 7) analysed with the Bray-Curtis index (Fig. 6) provided four main groups: A *H. minckleyi*; B: B1 *L. macrochirus*, *C. atrorus* and B2 *C. bifasciatus*, *H. guttatus*; C: C1 *C. xanthicara*, C2 *G. marshi* int, *M. salmoides* and C3 *L. megalotis*; D *G. marshi* man.

Discussion

Nine species of five families of fish were collected. The sample size of each species was different due to various factors such as the season, but it mainly responded to the distribution of each species in the system, as the water level varies throughout the year, as well as the physico-chemical characteristics such as the exposure to evaporation, plants and temperature, among other factors, to which each species reacts in a different way. The fish species collected in Laguna Intermedia included *L. megalotis*, *L. macrochirus*, *M. salmoides* and *C. xanthicara*, apart from *C. atrorus* which was also found in Poza Bonita and half way along the Río Churince in the area nearest Poza Bonita. In contrast, *H. guttatus*, *H. minkleyi* and *C. bifasciatus* were collected from half way along the Río Churince to the freshwater spring Manantial de Agua Dulce. *Gambusia marshi* was distributed throughout the system.

Considering that it was not possible to identify the stomach contents of all the groups down to the lowest possible taxonomic level, these were characterised based on general categories allowing the results to be standardised.

The diet of *C. atrorus* included mainly insects, followed by crustaceans which were eaten in large quantities but low volumes. Algae and minerals were also observed in the stomach contents, but were not included in the analysis. Arnold (1972) and Minckley (1969) stated that the diet of this species is herbivorous, considering the elongated and convoluted shape of the intestine. However, the results obtained in this study establish it as a secondary predator with a generalist feeding habit.

Minckley (1969) and Miller, Minckley and Norris (2009) analysed the stomach contents of adult *C. bifasciatus*, found organic matter and substrate residues, and stated that it fed on plants, animals and even its own eggs. In this study, however, insects and crustaceans were recorded as the preferred categories, with plants as the secondary food item. This species is considered an omnivore which allows it to feed at different trophic levels as a primary or secondary consumer.

The first group of *G. marshi* in Laguna Intermedia fed mainly on insects and crustaceans, with a greater importance on the number and volume than on the occurrence. According to the Levins index, its diet was generalised and heterogeneous with an omnivore feeding habit which allows it to be found in different trophic levels. The diet of the second group of *G. marshi* included plants and insects as the dominant, as well as the preferred, food items, with crustaceans as the secondary food item. As in the previous case, the Levins index established its diet as generalised and heterogeneous with omnivore habits. The dendrogram (Fig. 4) carried out with Simpson's similarity index for the two gambusia groups provided a 60% similarity in the diet of both groups, indicating that they presented a similar feeding behaviour, although the feeding categories recorded a different importance in each group. Miller, Mickley and Norris (2009) stated as main food items detritus, insects and other invertebrates. This coincides with the results recorded in this study which established the feeding importance of insects and crustaceans, apart from plants which were also considered a main food item. Thus, both groups are considered generalists and omnivores.

315 Stuber, Gebhart and Maughan (1982) classified *L. macrochirus* as an opportunist consumer, as it
316 was able to change its diet in accordance to the availability of food items, though it fed mainly on
317 zooplancton and small insects. In this study, we recorded insects and crustaceans as the dominant
318 feeding categories of this species, with a predominance of heavy and numerous prey items. The
319 diet of this species is thus generalised and heterogeneous.

320 Miller, Mickley and Norris (2009) characterised *L. megalotis* as an opportunist that fed on easy to
321 catch prey, such as insects and small invertebrates. In our study, we recorded crustaceans and
322 insects, in that order, as the most important feeding categories, and defined a generalised and
323 heterogeneous diet for this species.

324 Miller, Mickley and Norris (2009) stated that *M. salmoides* juveniles fed on small crustaceans,
325 insects and insect larvae, while the adults ate mainly fish, prawn, large insects and occasionally a
326 frog, mouse or other animal that swam or fell into the water. Juveniles and adults were not
327 compared in this study but, in general, insects were recorded as the dominant food item of the
328 species, with crustaceans also a preferred food with a greater contribution in number of and total
329 weight of prey. This species is thus a secondary consumer with heterogeneous and generalised
330 feeding habits.

331 *Herichthys minckleyi*, as was mentioned above, presented three morphotypes. Specimens were
332 found feeding mainly on gastropods, with teleosts and plants as secondary food items, indicating
333 that only one type of morph was found. This is considered a generalist species with an
334 heterogeneous diet.

335 Jewel fish are known to be opportunist species. In this study, these were found feeding mainly on
336 insects, with plants and crustaceans as secondary categories. The Levins index classified them as
337 omnivores with a specialised diet.

338 Page and Burr (1991) reported that *C. xanthicara* ate mainly algae and other plants. However,
339 this study recorded crustaceans and insects as the preferred categories in its diet. This species has
340 a very characteristic stomach, as it appears to have a gizzard from where digestion starts. It is
341 defined as a species with a generalised and heterogeneous diet.

The Bray-Curtis similarity dendrogram (Fig. 5) formed two general groups, and after considering the nearest groups, four main groups were generated. Group A with only *H. minckleyi* which is different from all the other species. Grupo B presents a medium similarity, as do the two subgroups: B1 with *L. macrochirus* and *C. atrorus*, and B2 with *C. bifasciatus* and *H. guttatus*; however, some species are more similar than others. Group C presents a medium similarity for four species and is divided into three subgroups: C1 with only *C. xanthicara*, C2 with *G. marshi* int and *M. salmoides* with a high similarity, and C3 with *L. megalotis*. Group D with only *G. marshi* man.

The trophic chain of the community indicates the presence of second degree consumer species, that is, carnivores and omnivores that may be found in different places within the chain. No top consumer fish species were recorded, as no species was strictly an ichthyophage and only fish eggs and fish remains were found. However, the ichthyophage morph of *H. minckleyi* was not collected, and neither was the consumption of eggs of different species strictly analysed, or birds, snakes and other larger organisms considered, apart from fisheries and other factors that may regulate fish populations. Even without top consumer fish species, the top-bottom chain reaction in the control of food was potentially greater than the bottom-top chain reaction, as the fish community regulates the populations of plants, crustaceans, invertebrates, and others (Carpenter and Kitchel, 1993; Jeppsen et al., 1997; Lovgren and Pearsson, 2002).

The primary producers found in this study included plants and algae, though the algae were not analysed. Souza et al. (2004) mentioned that stromatolites and photosynthetic bacteria (cyanobacteria) form the base of the food pyramid, characteristic of the early Cambrian (540 million years ago). This could apply particularly to Laguna Intermedia where stromatolites are located.

Conclusions

In conclusion, the fish community in Ciénega Churince is structured by nine species of five families. The trophic spectrum of the six species *C. atrorus, G. marshi* int, *L. macrochirus, L. megalotis, M. salmoides* and *C. xanthicara* indicates that insects and crustaceans are important in their diet, as preferred categories. The trophic spectrum of *C. bifasciatus, G. marshi* man, *H. minckleyi* and *H. guttatus* differed, as secondary food categories were recorded, providing a

significant importance and constituting a dietary supplement. These categories were crustaceans, insects, gastropods, teleosts and plants. Most of the fish species (eight) were euryphagic, and only one (*H. minckleyi*) may be considered stenophagic as it presented only one preferred food category. The similarity recorded for the preferred categories has no taxonomic relationship, but it does present a notable pattern of similarity regarding the distribution of the fish species in the marsh. The trophic chain proposed in this study presents four functional and hierarchical general groups, with no top consumer fish species in any group since no strictly ichthtyophagic species were recorded. Considering this, it may be stated that there is a low abundance of top fish predators, and it is estimated that their regulating control does not fall directly on the fish populations, but it does on the aquatic invertebrates.

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References

1. Amundsen, P. A., H. M. Gabler and F. J. Staldvik. 1996. A new approach to graphical analysis of feeding strategy from stomach contents data modification of the Castello (1990) method. *Journal of Fish Biology*. 48: 607-614. doi: 10.1111/j.1095-8649.1996.tb01455.x

2. Arnold, E. T. 1972. Behavioral ecology of two pupfishes (Cyprinodontidae, genus *Cyprinodon*) from northern Mexico. D. Phil. Thesis. Arizona State University Tempe. 158 p.

3. Bigg, M. A. and M. A. Perez. 1985. Volumen modificado: *A frequency-volume method to assess marine mammal food habits.* Editores: J. R. Beddington, R. J. H. Beverton and D. M. Lavigne. Marine mammals and fisheries. George Allen & Unwin London. 277-283.

4. Carabias, L. J., E. Provencio, J. de la Maza y S. Moncada. 1999. *Programa de Manejo del Área de Protección de Flora y Fauna Cuatrociénegas*. 1ª edición. Instituto Nacional de Ecología. 13-29.

5. Carrera, A. 2011. El Churince esta a punto de morir en Cuatrociénegas. Nota periodística 29 de Agosto 2011. Milenio.

6. Contreras-Balderas, S. y A. Ludlow. 2003. *Hemichromis guttatus* Gunther, 1862 (Pisces: Cichlidae), nueva introducción en México, en Cuatro Ciénegas, Coahuila. *Vertebrata Mexicana.* 12: 1-5.

7. Cortés, E. 1997. A critical review of methods of studying fish feeding based on analysis of stomach contents: application to elasmobranch fishes. *Canadian Journal of Fisheries and Aquatic Sciences.* 54: 726-738.

8. Elser, J. J., H. J. Schampel., F. Garcia-Pichel, D. B. Wade, V. Souza, L. Eguiarte, A. Escalante and D. J. Farmer. 2005. Effects of phosphorous enrichment and grazing snails on modern stromatolitic microbial communities. *Freshwater Biology*. 50: 1808-1825.

9. Espinosa-Pérez, H. 1993. Riqueza y diversidad de peces. Ciencias. No. Especial. 77-84.

10. George, E. L. and W. F. Hadley. 1979. Food and habitat partitioning between rock bass (*Ambloplites rupestris*) and smallmouth bass (*Micropterus dolomieu*) young of the year. *Transactions of the American Fisheries Society*. 108: 253-261.

11. Graham, H. J. and R. C. Vrijenhoek. 1988. Detrended correspondence analysis of dietary data. *Transactions of the American Fisheries Society.* 117: 29-36.

12. Husley, C. D., D. A. Hendrickson and F. J. García de León. 2005. Trophic morphology, feeding performance and prey use in the polymorphic fish *Herichthys minckleyi*. *Evolutionary Ecology Research*. 7: 303-3024.

13. Hyslop, E. J. 1980. Stomach contents analysis - a review of methods and their application. *Journal of Fish Biology*. 17: 411-429.

14. Krebs, C. J. 1989. *Ecological methodology*. Harper Collins, New York.

15. Kornfield, I. and J. N. Taylor. 1983. A new species of polymorphic fish, *Cichlasoma minckleyi*, from Cuatro Cienegas, Mexico (TELOSTEI: Cichlidae). *Proceedings of the Biological Society of Washington.* 96(2): 253-259.

16. Laevastus, L. T. 1980. *Manual y métodos de biología pesquera.* Editorial Acribia, Madrid. 243 p.

17. Lovgren, J. y L. Persson. 2000. Fish-mediated indirect effects in a littoral food web. *Oikos*. 96:150-156.4

18. Miller, R. R., W. L. Minckley y S. M. Norris. 2009. *Peces dulceacuícolas de México*. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad/El Colegio de la Frontera Sur/Sociedad Ictiológica Mexicana, A.C./Desert Fishes Council. México. 559 p.

435 Trad. de Juan J. Schmitter-Soto. 1ra edición en inglés, 2005. The University of Chicago
436 Press. Chicago.

437 19. Minckley, W. L. and G. A. Cole. 1968. *Speocirolana thermydronis* (Crustacea: Isopoda)
438 from northeast Mexico, re-discovery [sic], habitat, and supplemental description. *Tulane*
439 *Studies Zoology and Botany*. 15: 2-4.

440 20. Minckley, W. L. 1969. Environments of the Bolson of Cuatro Cienegas, Coahuila,
441 Mexico: with special reference to the aquatic biota. The University of Texas at El Paso.
442 *Science Series*, Number Two. 34-50.

443 21. Page, L. M. and B. M. Burr. 1991. *A field guide to freshwater fishes of North America*
444 *north of Mexico*. Houghton Mifflin Company, Boston, Massachusetts. 432 p.

445 22. Pinkas, L., M. S. Oliphant and I. L. K. Iverson. 1971. Food habits of albacore, bluefin
446 tuna, and bonito in California waters. California Explores the Ocean: *Fish Bulletin*. 152:
447 1-105.

448 23. Pro Natura, 2012. ttps://www.pronaturane.org/sblock/web01/index.php?new=17&mnu=2
449 (13/01/2015)

450 24. Scanlan, D. J., N. H. Mann and N. G. Carr. 1993. The response of the pico planktonic
451 marine cyanobacterium *Synechococcus* species Wh7803 to phosphate starvation involves
452 a protein homologous to the periplasmic phosphate-binding protein of *Escherichia coli*.
453 *Mol. Microbiol.* 10: 181-191.

454 25. Segatti, N. H. y R. D. Luciana. 2003. Métodos para avaliação da alimentação natural de
455 peixes: o que estamos usando? *Interciencia INCI*. 28: 100-104.

26. Souza, V., A. Escalante, L. Espinoza, A. Valera, A. Cruz, L. E. Eguiarte, F. García y J. Elser. 2004. Cuatro Ciénegas un laboratorio natural de astrobiología. *Ciencias*. 5-12.

27. Stuber, R. J., G. Gebhart and O. E. Maughan. 1982. Habitat suitability index models: Bluegill. U. S. D. l. *Fish and Wildlife Service*. 26 p.

28. Tyler, G. M. 1994. *Ecología y Medio Ambiente*. Primera edición. Editorial Iberoamérica. 345-360.

29. Valente, A. C. N. 1992. A alimentacao natural dos peixes (métodos de estudo). Instituto de Zoología Dr. Augusto Nobre, Universidade do Porto. *Série Monografias*. 4.

30. Wolaver, Brad D., J. M. J. Sharp, V. C. Tidwell, J. M. Rodriguez-Martinez and D. A. Hendrickson. 2007. An integrative approach to sustainable groundwater and associated groundwater-dependent system management in arid karst aquifers: Cuatrociénegas Basin, Mexico. *International Association Hydrogeologists.* 10 p.

31. WWF México. 2012. http://www.wwf.org.mx/wwfmex/esp_peces4c2.php consultada 22/01/2014.

32. Zamudio-Valdés, J. A. 1991. Los copépodos de vida libre (Crustacea, Maxillopoda) del Valle de Cuatro Ciénegas, Coahuila, México. Tesis Profesional, Universidad Autónoma de Nuevo Léon, México. 3-5.