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pág. 21

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Feeding ecology of the catfish *Ictalurus punctatus* (Siluriformes: Ictaluridae) in a reservoir in Northeast Mexico

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ABSTRACT

Objective: To determine the main food of the catfish according to seasonal variability and the sex of the organism in the Venustiano Carranza Dam, Coahuila, Mexico.

Methodology: In total, 143 catfish stomachs from different seasons were examined. In the analysis of the stomach content, the detected organisms were determined until the taxonomic order rank. The seasonal and sex feeding variability were also analyzed. The Relative Importance Index and the Alimentary Index were applied. Non-parametric tests were carried out to compare stomach content between seasons and sexes.

Results: The total annual trophic spectrum for catfish consisted of 13 items, of which only the order Ephemeroptera was categorized as a frequent food. In the winter season the catfish consumed significantly more food compared to the other seasons, but there was no difference in the amount consumed by females and males ($p>0.05$).

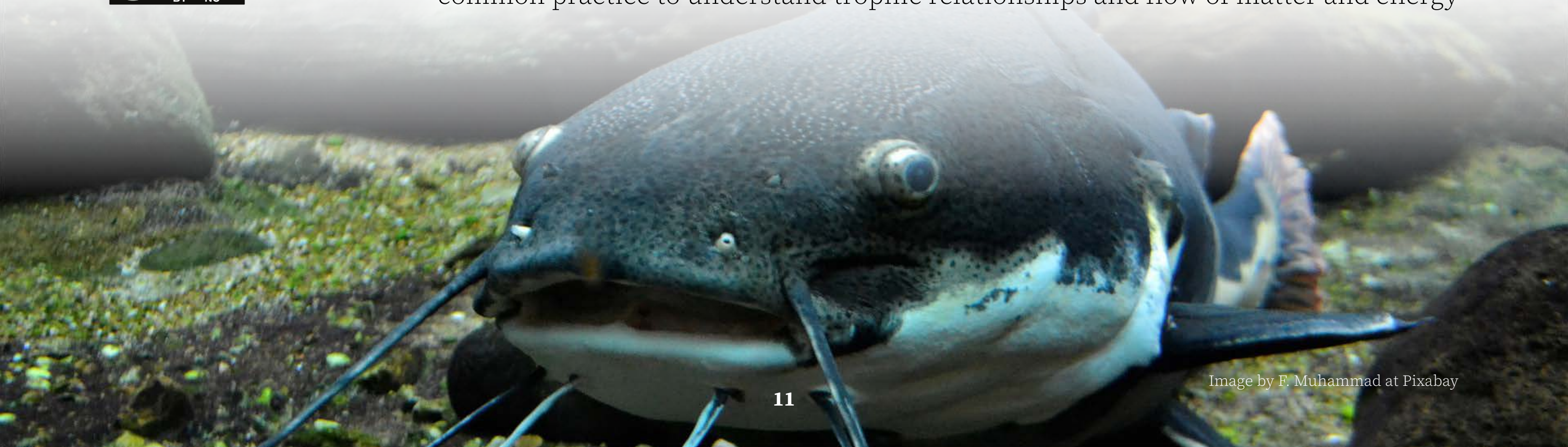
Implications: This information is relevant to highlight the importance of the biological integrity of the terrestrial site which surrounds the reservoir as a source of food for the catfish.

Conclusions: Catfish channel in the Venustiano Carranza Dam is a generalist species (13 alimentary items). There was a difference in food consumed during the different seasons of the year. However, there was no difference between the sexes.

Keywords: Fishery, food resources, freshwater management.

INTRODUCTION

Diversity and availability of food is a determining factor in fish populations because it affects parameters such as migration, behaviors, and temporal and spatial distribution (Behzadi *et al.*, 2018). The analysis of stomach contents of fish is a common practice to understand trophic relationships and flow of matter and energy



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in ecosystems. This knowledge contributes to fishery management programs and other inland waters fishing systems (Jacquemin *et al.*, 2014). There is great diversity in the way the different groups of fish feed and this also varies from one species to another. This can vary from a high degree of specialization to species which are generalist (Behzadi *et al.*, 2018; Mar *et al.*, 2014). The genus *Ictalurus* includes piscivor-omnivorous species, which have feeding preferences in bottoms of water bodies in semi-intensive or extensive systems (Arce-H *et al.*, 2017). Within this genus, one of the species with the greatest economic and nutritional importance worldwide is *I. punctatus*, whose production increased from 15.909 t in 1965 to 432.931 t in 2016 (FAO, 2021). In the federal state of Coahuila, Mexico, the species *I. punctatus* is reported as the second freshwater species of commercial importance, with a production of 281 t in 2017 (SIAP, 2017). In this context, it has been reported that in those aquatic species of commercial interest it is important to know the dietary diversity to maintain growth in their sizes and the viability of their populations (Hilling *et al.*, 2016). This is a factor of great importance to address the problem of food security in marginalized areas (Fisher *et al.*, 2017). Some studies on the food ecology and variability of the diet of channel catfish in freshwater systems, in the north-central part of the country, show a tendency of the populations of *I. punctatus* to consume mainly fish (Perciformes and Atheriniformes) (Tyus and Nikirk, 1990). In other regions of North America the contribution of elements from terrestrial ecosystems in the diet of *I. punctatus* have been reported (Edds *et al.*, 2002). For example, arthropods and seeds are important components for their diet too (Cardoza *et al.*, 2011). Herein we aimed to know if in our study area, *I. punctatus* shows selectivity in their eating habits from a seasonal and sexual perspective. The results of the present study allow us to increase information regarding the consumption patterns of *I. punctatus* resources in arid ecosystems, which may contribute to the management and maintenance of the populations of this species, thus promoting its sustainable use.

MATERIALS AND METHODS

Study area. The Venustiano Carranza Dam is in the northeast of the state of Coahuila, in northern Mexico, between coordinates 27° 25' 06'', 27° 32' 21''N and 100° 34' 50'', 100° 45' 20'' W (Figure 1). The reservoir has as main tributaries the Sabinas and Nadadores rivers and a storage capacity of 1.385 million m^3 of water. The average annual rainfall for the area is 375 mm, the months with highest rainfall are September and October, and the average annual temperature is 22 °C (CONAGUA, 2018). The main types of vegetation and soil cover for the surrounding area of the reservoir are the microphilic desert scrub, rosetophilic scrub, tamaulipan thornscrub, induced pasture, hydrophilic vegetation, secondary vegetation, and temporary agriculture (INEGI, 2017).

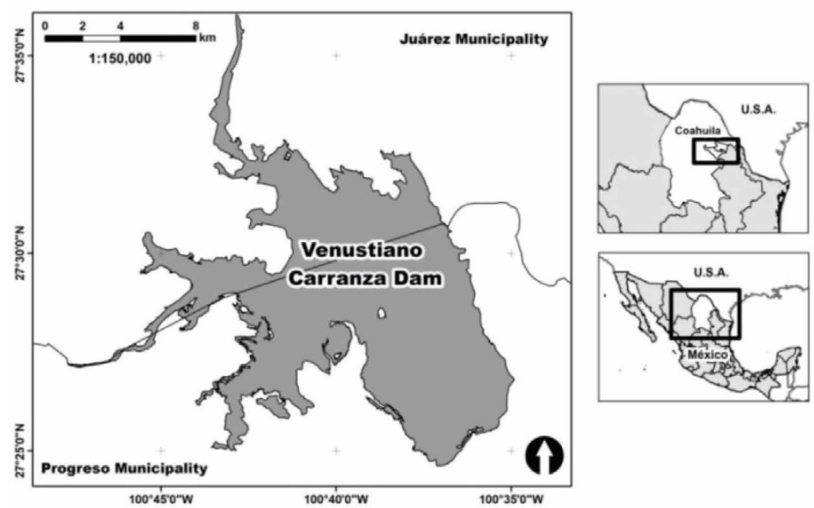

Figure 1. Geographic location of Venustiano Carranza Dam in Coahuila state, Mexico.

Collection and analysis of samples. Sampling was carried out seasonally in the period from July 2015 to June 2016. In total, 143 catfish individuals were analyzed, which were captured by commercial fishermen of the Venustiano Carranza Dam using gillnets of 2, 3 and 4 inches of mesh opening and 50 m in length. The seasons were considered as follows: spring (March, April and May), summer (June, July and August), autumn (September, October and November) and winter (December, January and February). Different biometric measurements such as weight, total length (TL), standard length (SL) with the support of a digital field balance (precision of 0.010 kg) and an ichthyometer (precision of 1 cm) were taken from each specimen (Espinosa-Pérez, 2014; Valdez-Zenil *et al.*, 2015). To determinate the trophic spectrum of the catfish, an analysis of the stomach contents of the captured organisms was performed. Sex was identified by direct observation of their state of gonadic maturity (Essner *et al.*, 2014). In some organisms the sex could not be determined so they were classified as not determined (Beltrán-Álvarez *et al.*, 2012). Stomachs were transferred to the laboratory for later analysis. The stomach content was analyzed in the laboratory with a stereoscope microscope and was determined to the taxonomic level of order (Cardoza *et al.*, 2011; Mar *et al.*, 2014). Taxonomic determination was based on specialized scientific literature. Undetermined plant or animal matter was considered detritus, with the exception of fish fragments (scales, spines, skin, etc.), which were classified as fish remains (Gerringer *et al.*, 2017). For each food type (item) the abundance (%N), weight (%W), frequency of occurrence (%OF) and volume (%V) were determined (Magnusson *et al.*, 2003; Mar *et al.*, 2014). To estimate the importance of the relation of each food type to total food consumed, the Relative Importance Index (RII) was applied (Pinkas *et al.*, 1970):

$$RII=(\%N+\%V) \times \%FO$$

Where %N is the numerical proportional abundance of a food type, %V the volume and %FO the frequency of occurrence. To categorize the food items, the Alimentary Index (AI) was applied, which groups the food types based on its relative importance (Lauzanne, 1975):

$$AI = \%OF \times \%V / 100$$

The classification used allows a differentiation between the most used (preferred) food resources, from those that are possibly a product of isolated or accidental eventuality. The result of AI for each item varies from 0 to 100% and is categorized as follows: a) preferential food (AI>50), b) secondary (25<AI<50), c) frequent (10<AI<25) and d) accidental (AI<10) (Lauzanne, 1975; Raymundo-Huizar and Saucedo, 2008). RII and AI were obtained for the total annual food spectrum, by seasons of the year and by sex of the organisms. Finally, because the assumptions of normality and homogeneity of variance for the analyzed data were not met, the non-parametric Kruskal-Wallis test was used to determine possible differences in food consumption (weight) between seasons. Similarly, the non-parametric Mann-Whitney test to determine differences in the food consumed (weight) between males and females was applied (Zar, 1999). Statistical analysis was performed with the Past ver. 3.25 software (Hammer *et al.*, 2001).

Results and Discussion

In total, 143 individuals of channel catfish were analyzed; of which 41 correspond to males, 64 to females and 38 of undetermined sex. The Total Length (TL) of the catfish analyzed varied from 23 to 48 cm. The total annual trophic spectrum for the catfish consist of 13 trophic items or categories, of which 11 correspond to the following orders, based on the Relative Importance Index: Ephemeroptera (mayflies nymphs), Charales (algae), Odonata (dragonfly larvae), Decapoda (crayfish), Cypriniformes (carp eggs), Perciformes and Characiformes (fish), Orthoptera (grasshoppers), Fabales (huizache seeds), Spirobolida (millipedes) and Hemiptera (bugs), as well as the categories of Fish Remains and Detritus (Table 1). According to the Alimentary Index, all food items for annual trophic spectrum were categorized as accidental foods (AI<10), with the exception of the order Ephemeroptera (AI=11.09), which was categorized as a frequent food.

Seasonal feeding analysis. In relation to the seasonal analysis, spring was the period in which the catfish's food spectrum showed the greatest diversity in the use of resources (10 food items). The Detritus and the Fish Remains were the most important resources for this season (63.66% of the RII). Summer showed the lowest diversity of resources (4 food items). Detritus and the order Charales (algae) were the most important resources in this season (79.56% of the RII). Decapoda (crayfish) and Charales orders represented 61.76% of the RII for the autumn season. For the winter season, the order Ephemeroptera (ephemeral) individually constitute 95.97% of the RII. For the spring and autumn seasons all food items were classified as accidental foods (AI<10), however, in the summer season the Detritus was classified as a frequent food (AI=12.90). Similarly, the order Ephemeroptera reached the category of secondary food (AI=37.50) for the winter season. For the last two seasons mentioned, all other food types were classified as accidental (Table 2). The food consumed by the channel catfish represented by weight in the winter season was significantly higher than in the rest of the seasons (Kruskal-Wallis; H=12.16, $p<0.05$). Average food consumed in this season was of 3.44±1.47 g.

Table 1. Annual trophic spectrum of the catfish in Venustiano Carranza Dam. Numerical Abundance (%N), Frequency of Occurrence (%FO), Volume (%V), Relative Importance Index (RII) and Alimentary Index (AI).

Alimentary item		%N	%OF	%V	RII	%RII	AI
Invertebrates	Ephemeroptera	85.920	19.608	56.572	2793.960	78.118	11.093
	Odonata	2.299	9.804	3.267	54.569	1.526	0.320
	Decapoda	1.437	9.804	0.879	22.702	0.635	0.086
	Orthoptera	0.287	1.961	0.395	1.337	0.037	0.008
	Spirobolida	0.287	1.961	0.263	1.078	0.030	0.005
	Hemiptera	0.287	1.961	0.128	0.814	0.023	0.003
Fishes	Cypriniformes	0.287	1.961	6.653	13.608	0.380	0.130
	Perciformes	0.287	1.961	1.417	3.341	0.093	0.028
	Characiformes	0.287	1.961	0.599	1.737	0.049	0.012
	Fish remains	2.586	15.686	20.489	361.964	10.120	3.214
Detritus	Detritus	3.736	25.490	6.227	253.956	7.101	1.587
Plants	Charales	2.011	13.725	2.825	66.389	1.856	0.388
	Fabales	0.287	1.961	0.287	1.125	0.031	0.006
	Total	100		100		100	

Table 2. Seasonal trophic spectrum to the catfish in Venustiano Carranza Dam. Relative Importance Index (%RII) and Alimentary Index (AI).

Alimentary item		Spring		Summer		Autumn		Winter	
		%RII	AI	%RII	AI	%RII	AI	%RII	AI
Invertebrates	Ephemeroptera	15.845	0.537	3.596	1.521	0	0	95.976	37.508
	Odonata	4.018	0.379	0	0	12.034	2.790	0.553	0.126
	Decapoda	7.846	0.522	0	0	36.123	6.816	0	0
	Orthoptera	1.425	0.211	0	0	0	0	0	0
	Spirobolida	1.170	0.141	0	0	0	0	0	0
	Hemiptera	0	0	0	0	6.497	0.788	0	0
Fishes	Cypriniformes	0	0	0	0	0	0	0.851	0.754
	Perciformes	0	0	0	0	0	0	0.214	0.161
	Characiformes	1.820	0.320	0	0	0	0	0	0
	Fish remains	23.694	4.357	16.840	6.202	11.155	2.472	1.922	1.714
Detritus	Detritus	39.969	6.479	49.212	12.904	8.546	1.529	0.484	0.295
Plants	Charales	2.996	0.646	30.352	7.552	25.644	3.026	0	0
	Fabales	1.216	0.153	0	0	0	0	0	0
	Total	100		100		100		100	

Feeding Analysis by sex of organisms. The food spectrum of the catfish was more diverse for females than for males (11 and 8 items, respectively). The order Ephemeroptera was the most important for both sexes. This order represented 93.74% and 91.79% of the RII for both females and males, respectively. The same order was the only one that reached the category of frequent food for both sexes (23.95 and 11.00 AI, for both females and males), the rest of the food was classified as accidental (Table 3). The food consumed by the catfish was 0.86±0.38 g for females, while for males it was 0.80±0.27 g, respectively. There is no significant difference in the food consumed between females and males (Mann-Whitney U=1196, $p>0.05$ for weight).

Table 3. Trophic spectrum for sex for the catfish in Venustiano Carranza Dam. Relative Importance Index (%RII) and Alimentary Index (AI).

Alimentary item		Female		Male	
		%RII	AI	%RII	AI
Invertebrates	Ephemeroptera	93.745	23.955	91.790	11.007
	Odonata	0.412	0.028	0.706	0.031
	Decapoda	0.046	0.001	1.988	0.106
	Orthoptera	0.065	0.011	0	0
	Spirobolida	0.058	0.007	0	0
	Hemiptera	0.051	0.003	0	0
Fishes	Cypriniformes	0.388	0.181	0	0
	Perciformes	0	0	0.567	0.087
	Characiformes	0	0	0.350	0.037
	Fish remains	3.372	1.427	0.298	0.025
Detritus	Detritus	1.755	0.335	2.075	0.215
Plants	Charales	0.048	0.002	2.226	0.117
	Fabales	0.060	0.008	0	0
	Total	100		100	

Some studies on *I. punctatus* suggest that the spatial and temporal variability of its feeding is due to multiple factors, among which stand out: availability of resources, ontogeny, physicochemical quality of water (mainly temperature), seasonality and interspecific competition. The interaction of these factors results in the composition of the diet for a given period (Haubrock *et al.*, 2018; Schmitt *et al.*, 2018). Because of its broad food spectrum, which includes aquatic and terrestrial resources, the channel catfish has been cataloged historically as an omnivorous-opportunistic species; generally, this diet presents variations in relation to the seasonal availability of resources (Edds *et al.*, 2002; Dagel *et al.*, 2010; Cardoza *et al.*, 2011; Braun & Phelps, 2016).

Studies for the species in reservoirs in the semi-arid zone of northern Mexico have shown that the catfish is generalist and flexible in its diet throughout the year. (Cardoza *et al.*, 2011). In the present study, this generalist behavior was consistent, because the food spectrum for the catfish in the Venustiano Carranza Dam consisted of 13 different taxonomic orders and the dominant items consumed show variability in relation to the seasons. Except for the order Ephemeroptera, all food items consumed annually were classified as accidental foods, since the individuals examined consumed significant amounts (high volume) of a specific food type in short periods of time (low frequency). However, certain preference for some types of food is reported for some reservoirs; for example, the preference for some species of forage fishes for the Lázaro Cárdenas Dam in Durango state, Mexico (Cardoza *et al*., 2011). It is worth highlighting the role of the order Ephemeroptera in feeding of the catfish for the period evaluated. Although it reached only the category as a secondary food for the winter season, the order Ephemeroptera occurred in three of four seasons and was the only food that was not classified as accidental in the total annual balance. The particular importance of this order and other groups of insects has also been reported for other catfish populations (Hill *et al*., 1995; Dagel *et al*., 2010; Hilling *et al*., 2016). Changes in catfish food preferences in relation to the seasons are also a reflection of their opportunistic and broad-spectrum eating habits (Braun & Phelps, 2016). The present study confirms this, through the occurrence in specific seasons of some food types, such as the orders Ephemeroptera and Odonata, that use the aquatic environment as reproduction site. We also emphasize the importance of algae (Charales) and Detritus for catfish feeding in the dam throughout the year. Although both items are cataloged in the annual balance as accidental food, they practically occur in all four seasons of the year, which represents a frequent resource for the catfish population. In the case of algae, there are studies from reservoirs in North America that suggest that the consumption of algae as part of the catfish diet is very important. Far from being accidentally consumed by individuals, the algae become selected food of a spectrum available in the aquatic environment (Dagel *et al*., 2010; Cardoza *et al*., 2011). The highest consumption of food in weight and volume documented in this study for the winter season, compared to other periods of the year is probably a result of the preparation of energy of the organisms for the reproductive period, which takes place from February to August, depending on the conditions such as water temperature or habitat (Wellburn, 1988). However, it is necessary to continue with investigations that complement the explanations of seasonal variability of catfish feeding. On the other hand, for systems of fisheries in reservoirs in Mexico, there are general norms that regulate the exploitation of commercial species such as catfish, which includes minimum catch sizes, amount of daily catch per species, establishment of periods of no-fishing or “veda”, among other general aspects (DOF, 2006). However, despite the fact that the channel catfish is one of the most important freshwater species for food and recreation through semi-intensive and extensive cultivation in reservoirs, for the majority of fisheries there are no comprehensive, management programs that ensure their viability and sustainability over time (Braun and Phelps, 2016; Lara-Rivera *et al*., 2015). Therefore, we consider it important for future planning and management to include the integral conservation of the reservoir system, specifically the conservation and restoration of riparian vegetation in the middle and upper part of the basin, avoiding ecosystem fragmentation (mainly by dams), maintaining, and recovering the original vegetation that surrounds the reservoir (Schnier *et al.*, 2016). Some food types such as insects (Ephemeroptera and Odonata), algae (Charales) and Detritus are important components for catfish feeding and they need an acceptable biological integrity of the environment surrounds the reservoir to be available for fish populations. Numerous studies demonstrate the importance of the integrity of river and reservoir systems as a measure to favor the provision of food sources for channel catfish (Cardoza *et al.*, 2011; Edds *et al.*, 2002; Dagel *et al.*, 2010; Braun and Phelps, 2016).

CONCLUSIONS

Thirteen food items for annual catfish spectrum were determined. The most important food was the order Ephemeroptera, since it was the only one that reached the annual category as frequent food. We detected seasonal differences in feeding of the catfish. For spring and autumn all foods were categorized as accidental, while for the summer and winter the Detritus and the order Ephemeroptera were categorized as frequent and secondary, respectively. In the winter season, more food was consumed compared to the other seasons of the year. There was no difference in food intake between females and males. Further complementary studies on the evaluation of the diet of other commercial and non-commercial species and their interaction in terms of competition with the channel catfish, determination of variability in feeding based on the species ontogeny, determination of areas of importance within the reservoir (important nutrition zones), assessments of population ecology, among others, are recommended.

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