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Source: The Southwestern Naturalist, 53(2):224-229. 2008.
Published By: Southwestern Association of Naturalists
DOI: http://dx.doi.org/10.1894/0038-4909(2008)53[224:SCIFAO]2.0.CO;2
URL: http://www.bioone.org/doi/full/10.1894/0038-4909%282008%2953%5B224%3ASCIFAO%5D2.0.CO%3B2

SPATIOTEMPORAL CHANGES IN FISH ASSEMBLAGES OF LOS TERREROS CREEK, AN ISOLATED STREAM SYSTEM IN HEADWATERS OF THE LERMA RIVER, CENTRAL MEXICO

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ABSTRACT—Los Terreros Creek, a reservoir-fragmented tributary in the upper Lerma River system of central Mexico, was sampled at four localities in wet (2001) and dry (2002) seasons to evaluate spatial and temporal patterns of fish assemblages, the conservation status of native fishes, and prevalence of exotic species. Two of five species present were non-native; the common carp (*Cyprinus carpio*) and the shortfin silverside (*Chirostoma humboldtianum*). Fish assemblages formed a strong gradient largely separating the lentic, reservoir-impacted, locality (downstream-most site) from the remaining lotic sites. The two most-upstream sites were not distinguishable based on structure of fish assemblages. Three of five species showed significant spatial variation in abundance. The Aztec shiner (*Aztecula sallaei*) occurred only at the lotic sites and the two species of silversides (*Chirostoma*) occurred only at the lentic site. Temporal trends in assemblages were less evident, but assemblages in the dry season had lower mean species-richness and mean abundance values. Analysis of distance matrices based on assemblages, site-specific environmental conditions, and spatial structure indicated that a strong, spatially structured environmental gradient was significantly associated with fish assemblages in the wet season, but not assemblages in the dry season. Los Terreros Creek still supports an assemblage of native fish that is typical for the upper Lerma River system. However, this relict system remains threatened by anthropogenic activities including changes in land use and further introduction of exotic species.

RESUMEN—El arroyo Los Terreros, un tributario fragmentado en la cuenca alta del río Lerma en el centro de México, fue muestreado en cuatro sitios en las temporadas de lluvias (2001) y secas (2002) para evaluar los patrones espaciales y temporales de los ensamble de peces, el estatus de conservación de las especies nativas y la presencia de especies exóticas. Dos de las cinco especies encontradas fueron no nativas, el pescado blanco o charal de Xochimilco (*Chirostoma humboldtianum*) y la carpa común (*Cyprinus carpio*). Los ensamblajes de peces formaron un fuerte gradiente en el que el sitio léntico, impactado por un embalse y el sitio más río abajo, se separó de los sitios lóticos. Los dos sitios río arriba no presentaron diferencias en cuanto a ensamblajes de peces. Tres de las cinco especies presentaron variación espacial significativa en su abundancia. La carpita azteca (*Aztecula sallaei*) se colectó solamente en los sititos lóticos y las dos especies de charal o pescado blanco (*Chirostoma*) se encontraron únicamente en el sitio léntico. Los patrones temporales en los ensamblajes fueron menos evidentes, sin embargo durante la temporada de secas las medias de la riqueza y abundancia de las especies fueron menores. Los análisis de las matrices de distancia basadas en los ensamblajes, variables ambientales en cada sitio y la estructura espacial, mostraron que el fuerte gradiente espacial y ambiental se asoció significativamente con los ensamblajes de peces durante la temporada de lluvias pero no durante la temporada de secas. El arroyo Los Terreros aun mantiene un ensamblaje de peces nativos que es típico para el alto Lerma. Sin embargo, este sistema relicto se ve amenazado por las actividades antropogénicas que entre otras incluyen cambios en el uso de terreno e introducción de especies exóticas.

Human-induced alterations disturb structure and function of aquatic ecosystems in many ways. Urban and industrial developments, such as construction of reservoirs, changes in land use, and introduction of non-native species, are principal threats that contribute to loss of aquatic biodiversity in riverine ecosystems (Matthews, 1998; Wooton, 1998; Diana, 2004). Natural disturbances, such as flood and drought, also impact fish assemblages (Matthews, 1998; Wooton, 1998; Taylor and Warren, 2001) and their effects may be exacerbated by anthropogenic impacts (Fausch et al., 2002; Taylor et al., 2006). The Lerma River system in west-central Mexico is no exception to these problems and native fish assemblages have changed considerably over the past 30 years (Soto-Galera et al., 1998; Mercado-Silva et al., 2006).

Historically, fish assemblages in the Lerma River system were characterized by species of the families Atherinidae, Cyprinidae, and Goodeidae (Alvarez, 1957; Romero, 1967; Barbour, 1973; Miller, 1986). Los Terreros Creek, a third-order and fourth-order stream located near Atlacomulco in the state of Mexico, is one of the few remaining streams in the Lerma system to retain much of its ecological integrity, although it is now fragmented by Trinidad Fabela Reservoir (Fig. 1). The watershed is in the Priority for Conservation Hydrologic Region 65, which is considered by the Comision Nacional para el Manejo y Uso de la Biodiversidad (Mexico) as a high diversity zone in need of conservation and protection from human impacts that might negatively affect the ecosystem (Arriaga et al., 2002). The region has a temperate climate with seasonal variation in rainfall; the wet season, May-October, has ≤160 mm of precipitation and the dry season, November–April, has <80 mm.

The objectives of the study were two-fold. From a general conservation perspective, we assessed status of native fishes above the reservoir and prevalence of exotic species, such as the common carp (*Cyprinus carpio*), that inhabit the system and potentially threaten native lotic assemblages. We also sought to identify important spatial and temporal patterns of distribution and abundance of species above the reservoir. To accomplish this, we monitored fish assemblages from four sites along Los Terreros Creek in wet (July 2001) and dry (February 2002) seasons.

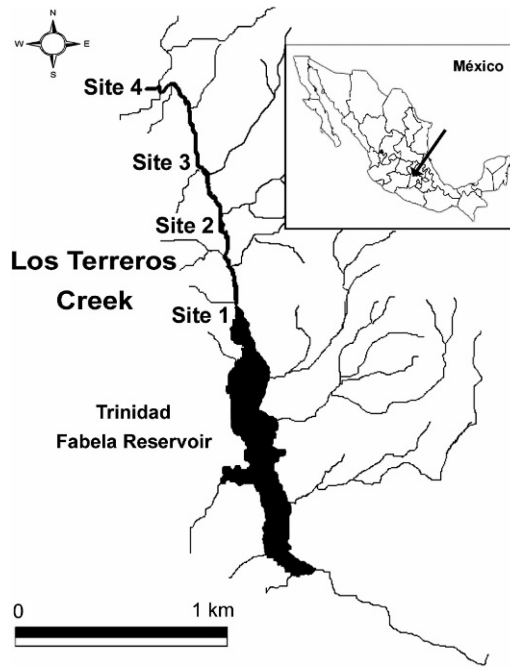

FIG. 1—Map of Los Terreros Creek showing the location of sampled sites in central Mexico (modified from Instituto Nacional de Estadistica Geografia E Informatica, 2002).

MATERIALS AND METHODS—The four sampling sites from this study are shown in Figure 1. Site 1 (19°50′N; 99°47′W) was at the upper end of Trinidad Fabela Reservoir where the lotic environment transitioned into lentic conditions. Site 2 (19°51′N; 99°47′W) was on the creek ca. 800 m upstream from Site 1, Site 3 (19°51′N; 99°47′W) was 1,700 m upstream from Site 1, and Site 4 (19°52′N; 99°47′W) was ca. 3,100 m upstream from the reservoir.

We sampled fishes with a seine, 5.5-m (length) by 1-m (depth) by 4.8-mm (mesh size) in size. At each site, we made ≤5 seine hauls depending on site and season. Although not independent samples, this allowed us to assess within-site variation in structure of assemblage, and identify differences among sampling localities and between the two sampling dates (wet season 2001 and dry season 2002). All fishes were field-fixed in a 10% formalin solution and transported to the lab for enumeration. We also measured several environmental variables at each site including dissolved oxygen (mg/l), temperature (°C), transparency (cm), conductivity (μs/cm), total dissolved solids (mg/l) and pH. All environmental variables were standardized to dimensionless quantities (z-scores) and data for each species were square-root transformed before statistical analyses.

We used nonmetric multidimensional scaling to ordinate samples (seine hauls) and provide a picture of variation in assemblage across sites and wet or dry seasons. Using seine hauls as samples in the ordination

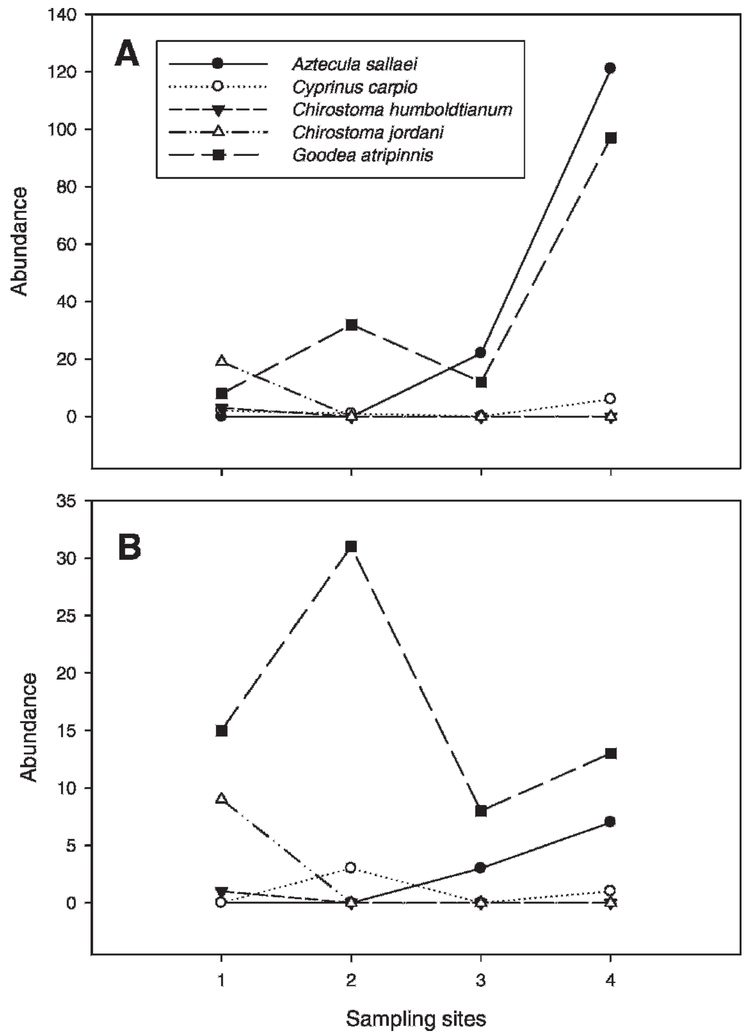

FIG. 2—Abundances of species are plotted by site. Sites correspond to numbers in Figure 1. Abundances for wet (A) and dry (B) seasons are shown.

allowed us to assess within-site variability of fish assemblages. Nonmetric multidimensional scaling is an indirect ordination method that is not based on any distributional assumptions (McCune and Grace, 2002), is useful for summarizing complex community data (Gauch, 1982), and is not plagued with problems of other ordination methods such as correspondence analysis and detrended correspondence analysis (Wartenburg et al., 1987; Jackson and Somers, 1991; Legendre and Legendre, 1998). The technique is based on an iterative search algorithm that minimizes departure from monotonicity in the relationship between dissimilarity in the original data matrix and distances in the reduced ordination space (McCune and Grace, 2002). A multi-response permutation procedure was used to test for differences in site-specific fish assemblages across space and time. Both nonmetric multidimensional scaling and the multi-response permutation procedure were conducted with PC-ORD software (McCune and Mefford, 1999). Changes in abundances of individual species across space and time were assessed with Kruskall-Wallis (space) and Mann-Whitney (time) tests using Systat (SPSS, Inc., 2000). The Mantel test was used to identify environmental and spatial associations with samples using XLSTAT software (Addinsoft, 2006). Matrices of distances (km) among sites, and site-specific differences based on assemblages (Bray Curtis distances) and environmental variables (Euclidean distances), were constructed for Mantel and partial-Mantel analyses. Distance and environmental matrices contained redundancy, as each site had only one set of values for environmental data and one score for distance calculations. The assemblage matrix treated samples

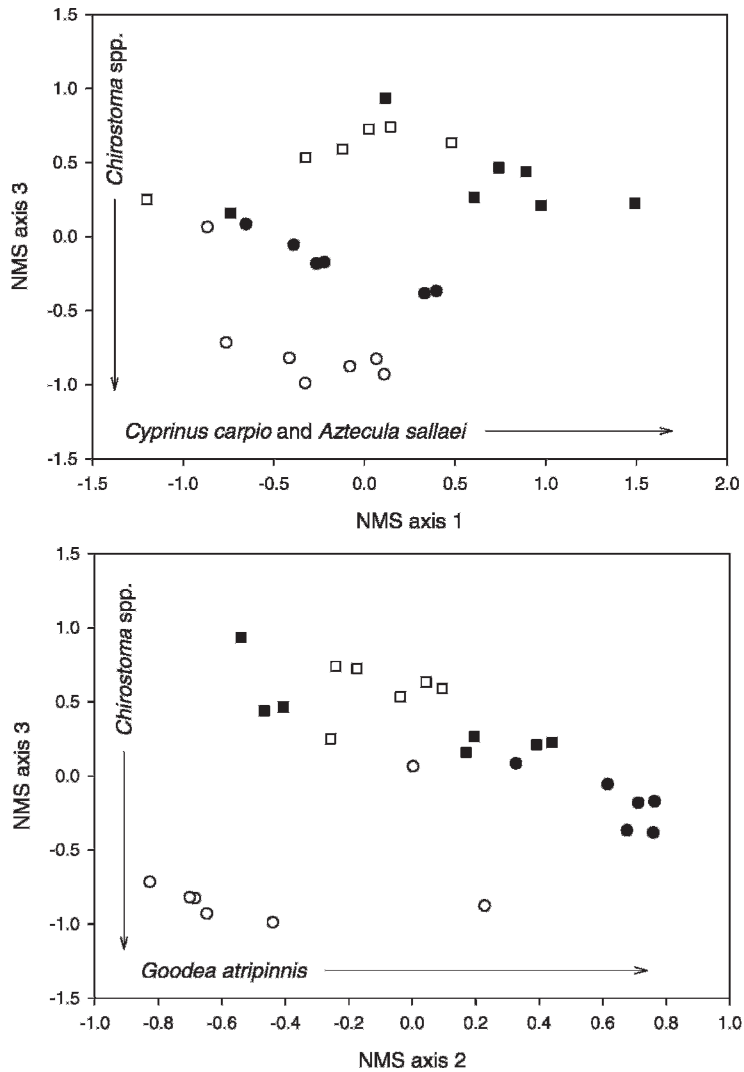

FIG. 3—Analysis of samples using nonmetric multidimensional scaling (NMS) based on species-abundance values from four sites and two seasons in Los Terreros Creek, central Mexico: site 1, open circles; 2, closed circles; 3, open squares; and 4, closed squares. First, second, and third axes accounted for 27, 25, and 43%, respectively, of variation in the original data matrix. Arrows indicate increasing abundances for listed species.

as in the nonmetric multidimensional scaling procedure, thus maintaining within-site variability of assemblage. Significance of Mantel tests was determined with a randomization procedure based on 1,000 permutations (Fortin and Gurevitch, 1993).

RESULTS AND DISCUSSION—Five species of fish were collected from Los Terreros Creek. The Aztec shiner (*Aztecula sallaei*) is endemic to the Alto Lerma subprovince, the blackfin goodea (*Goodea atripinnis*) and the charal (*Chirostoma jordani*) are endemic to the Lerma basin, and the shortfin silverside (*Chirostoma humboldtianum*) and common carp (*Cyprinus carpio*) are introduced in this system. Abundances were variable across sites and times (Fig. 2).

Three axes representing gradients in structure of fish assemblages were obtained by the nonmetric multidimensional scaling analysis (Fig. 3). Together, the three axes accounted for 95% of variation in the original matrix of abundance of species. The third axis accounted for most of the variation (43%) and the first and

TABLE 1—Kruskal-Wallis (KW; $df = 3$) and Mann-Whitney (MW; $df = 1$) tests were used to identify significant spatial and temporal trends in abundances of species in central Mexico.

Species	Sites		Time	
	KW statistic	*P*-value	MW statistic	*P*-value
Goodea atripinnis	7.35	0.06	88.00	0.92
Cyprinus carpio	5.92	0.12	114.50	0.15
Aztecula sallaei	15.49	<0.01	124.50	0.59
Chirostoma umboldtianum	12.92	<0.01	100.50	0.41
C. jordani	20.84	<0.01	99.00	0.55

second axes accounted for 27 and 25%, respectively. The third axis, which largely separated Site 1 from the other sites (Fig. 3), was strongly correlated with *Chirostoma*, both species occurred only at Site 1 ($r = -0.67$ and -0.82; *C. humboltianum* and *C. jordani*, respectively). The first axis was strongly associated with *C. carpio* and *A. sallaei* ($r = 0.74$ and 0.80, respectively) and the second axis was correlated with *G. atripinnis* ($r = 0.67$).

When samples were grouped by time (wet and dry seasons), analysis using the multi-response permutation procedure indicated no significant difference (A = 0.03, $P = 0.091$). However, when grouped by sites, there was an overall significant effect (A = 0.34, $P < 0.001$). Pairwise comparisons indicated that sites 3 and 4 were not significantly differentiated (A = 0.07, $P = 0.46$), but all other comparisons were significantly different (A = 0.29–0.34, $P \leq 0.02$). Similarly, when individual species were tested for differences in abundance among sites and between wet and dry seasons, three species showed spatial effects (*A. sallaei*, *C. humboldtianum*, and *C. jordani*) and none showed temporal effects (Table 1).

Mantel and partial-Mantel tests indicated different spatial and environmental associations with fish assemblages for collections in wet and dry seasons. For collections in the wet season, fish assemblages were spatially ($r = 0.65$, $P < 0.001$) and environmentally structured ($r = 0.45$, $P < 0.001$). When the spatial structure was statistically removed, the significant environmental association was no longer apparent ($r = -0.05$, $P = 0.63$). For fish assemblages in the dry season, there was no significant spatial or environmental association.

Based on our analyses using nonmetric multidimensional scaling and the multi-response permutation procedure, the spatial variation of abundance and distribution of species forms a strong gradient, largely separating the reservoir-influenced site (Site 1) from stream assemblages. The two most-upstream sites (Sites 3 and 4) were not distinguishable based on structure of species assemblage. Three species largely contributed to this variation, two of which were detected only at the reservoir site (*Chirostoma*) and one that occurred only at all three sites above the reservoir (*A. sallaei*). The other two species occurred variably at all four localities. Mantel and partial-Mantel tests allowed us to further examine variability of assemblage in the context of the local environment and spatial arrangement of sites. These analyses indicated strong, spatially structured environmental associations with fish assemblages during the wet season, but not during the dry season. There was no evident temporal trend in structure of assemblage, although there were differences in mean abundance (21.5 and 11.3) and mean species richness (2.5 and 1.8) between the wet and dry season sites, respectively.

From these results, we suggest that *A. sallaei* is a lotic-adapted species sensitive to an altered flow regime and intolerant of reservoir habitats, whereas *C. jordani* and *C. humboldtianum* are lacustrine species (Barbour, 1973; Miller and Smith, 1986) that were only detected at the reservoir-influenced site. *Goodea atripinnis* did not show spatiotemporal variation in abundance and appears to be a generalist species tolerant to environmental change (Soto-Galera et al., 1998). *Cyprinus carpio* also did not show restrictions in its distribution throughout Los Terreros Creek. This species now occurs throughout the creek and reservoir, and has been nominated as among 100 of the ''world's worst'' invaders because of its adaptation to a broad variety of habitats and extreme environments (Invasive Species Specialist Group, http://www.iss.org/database).

Los Terreros Creek still supports an assemblage of native species that is typical for the upper Lerma River system (Miller, 2005). The conservation value of the creek is exemplified by its federal status as a conservation priority. However, human-induced activities such as introduction of *C. carpio* and changes in land use still represent a threat for the native species of this relict system.

This study was conducted with financial support from the Universidad Autonoma del Estado de Mexico (project grant UAEMEX/2140). We are grateful to C. A. Mastachi Loza for his support with data collection. We thank Mississippi State University for computational support.

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Submitted 12 October 2006. Accepted 16 November 2007. Associate Editor was Gary P. Garrett.