

Signals of decline of flagship species *Ambystoma altamirani* Dugès, 1895 (Caudata, Ambystomatidae) in a Mexican natural protected area

Jesica Gabriela Guerrero de la Paz¹, Norman Mercado-Silva¹, Raúl E. Alcalá¹, Luis Zambrano²

¹ Centro de Investigación en Biodiversidad y Conservación, Universidad Autónoma del Estado de Morelos. Av. Universidad 1001, Col. Chamilpa, CP 62209, Cuernavaca, Morelos, Mexico

² Instituto de Biología, Universidad Nacional Autónoma de México. Cto. Exterior S/N, C.U., Coyoacán, CP 04510, Ciudad de México, Mexico

<http://zoobank.org/AD1FF170-0CEA-4223-B629-80D4462CBD78>

Corresponding author: Norman Mercado-Silva (norman.mercado@uaem.mx)

Academic editor: Günter Gollmann ♦ Received 16 July 2020 ♦ Accepted 27 September 2020 ♦ Published 23 October 2020

Abstract

Mexico is home to 18 species of salamanders in the family Ambystomidae. Endangered *Ambystoma altamirani* Dugès, 1895 is a flagship species for the Lagos de Zempoala National Park (LZNP) in central Mexico, a protected area subject to numerous anthropogenic threats. *Ambystoma altamirani* populations in the Park have been little studied. In 2016–2017, we surveyed four streams where populations of the species had been previously reported. Habitat variables did not differ amongst streams and three had invasive rainbow trout, but we were only able to locate one *A. altamirani* population in Quila, a small, cold water stream lacking fish. We captured an average of 88 individuals (total $n = 354$; range 53–109) across all samples in this stream, including larvae, juveniles and adults. Population estimates ranged between 53 and 127 individuals. The absence in other streams suggests reductions in the spatial extent of *A. altamirani* in the LZNP. We suggest rainbow trout presence in numerous streams have led to local extirpation of *A. altamirani* and that removal and blockage of the invasive fish and a planned re-introduction strategy might help in restoring this flagship species.

Key Words

mountain stream siredon, rainbow trout, salamander, Trans-Mexican Volcanic Belt, Zempoala

Introduction

Amphibians are the most threatened vertebrate group in the world with numerous populations experiencing severe declines (Young et al. 2001; Stuart et al. 2004; Hussain and Pandit 2012). Climate change, disease and habitat destruction are perhaps the most important causes of these declines (McCallum 2007; Wake and Vredenburg 2008). Mexico exhibits the fourth greatest diversity of amphibians in the world (~360 species, Sarukhán and Dirzo 1992; Flores-Villela and Canseco-Márquez 2004). Salamanders in the genus *Ambystoma* are amongst the most threatened

groups in Mexico; 17 of 18 species are endemic and have relatively-small geographic ranges (SEMARNAT 2019; Frías-Álvarez et al. 2010; Parra-Olea et al. 2014; Frost 2020; IUCN 2020).

Ambystoma altamirani Dugès, 1895, an endangered salamander endemic to the Trans-Mexican Volcanic Belt, inhabits streams and lakes at altitudes of 2450 to 3487 m, in areas surrounded by grasses and temperate conifer forests (Lemos-Espinal et al. 1999; Uribe-Peña et al. 1999; Lemos-Espinal et al. 2016; Woolrich-Piña et al. 2017), especially stream areas dominated by mud substrate (Villareal-Hernández et al. 2020). It is a flagship

species for the Lagos de Zempoala National Park (LZNP) (States of Morelos and Mexico). The Park, created in 1936, encompasses seven endorheic lakes and associated streams where *A. altamirani* were once abundant. The Park is exposed to a variety of anthropogenic stressors, including human use, illegal logging, stream capture for human consumption and invasive species introductions (CONANP 2008; Zambrano and Valiente 2008). Invasive fishes, such as rainbow trout, are particularly dangerous for amphibian populations (Estrella-Zamora et al. 2018).

Studies and monitoring data for *A. altamirani* in the LZNP are scarce. Initial descriptive and taxonomic studies for *A. altamirani* in the area date from the 1940s (Taylor and Smith 1945; Maldonado-Koerdell 1947), but its populations were only monitored between 2003 and 2008, when the species was reported from only four lakes and associated streams in the LZNP: Lake Zempoala, Lake Tonatiagua, Lake Quila and Lake Acoyotongo (CONANP 2009). Ten years after the last monitoring event, we initiated this study to 1) document the extent of the populations of *A. altamirani* in four streams where the species had been previously captured, 2) measure habitat and physical-chemical parameters for these streams, 3) quantify their abundance and 4) explore the potential effect of non-native rainbow trout on the presence of *A. altamirani*.

Methods

The LZNP (total area = 4790 ha) is in the headwaters of the Balsas River Basin (Pacific Slope) in Central Mexico (Fig. 1). The mean monthly average temperature in the area ranges from 5 (January) to 18 °C (May) with an average annual precipitation of 1550 mm (CONANP 2008). Until 1979, the LZNP had seven lakes, but three are currently dry and the other four experience fluctuating water levels (depending on seasonal rains) (Bonilla Barbosa and Novelo Retana 1995; Quiróz-Castelán 2008; Godínez-Ortega et al. 2017). The LZNP has numerous intermittent and permanent streams leading to endorheic permanent or ephemeral lakes. Streams are usually first to second order systems 50–200 cm wide, with clear, cold waters. Some streams have been tapped for water use in nearby towns. Non-native carp (*Cyprinus carpio* L., 1758), largemouth bass (*Micropterus salmoides* Lacépède, 1802), tilapia (*Oreochromis* sp.), grass carp (*Ctenopharyngodon idella* Valenciennes, 1844) and rainbow trout (*Onchorhynchus mykiss* Walbaum, 1792) have all been introduced at some point during the last 40 years into LZNP lakes. While some of these species have disappeared from the lakes, others have thrived. Rainbow trout were introduced to several LZNP lakes (Contreras-MacBeath and Urbina 1995) and expanded into LZNP streams.

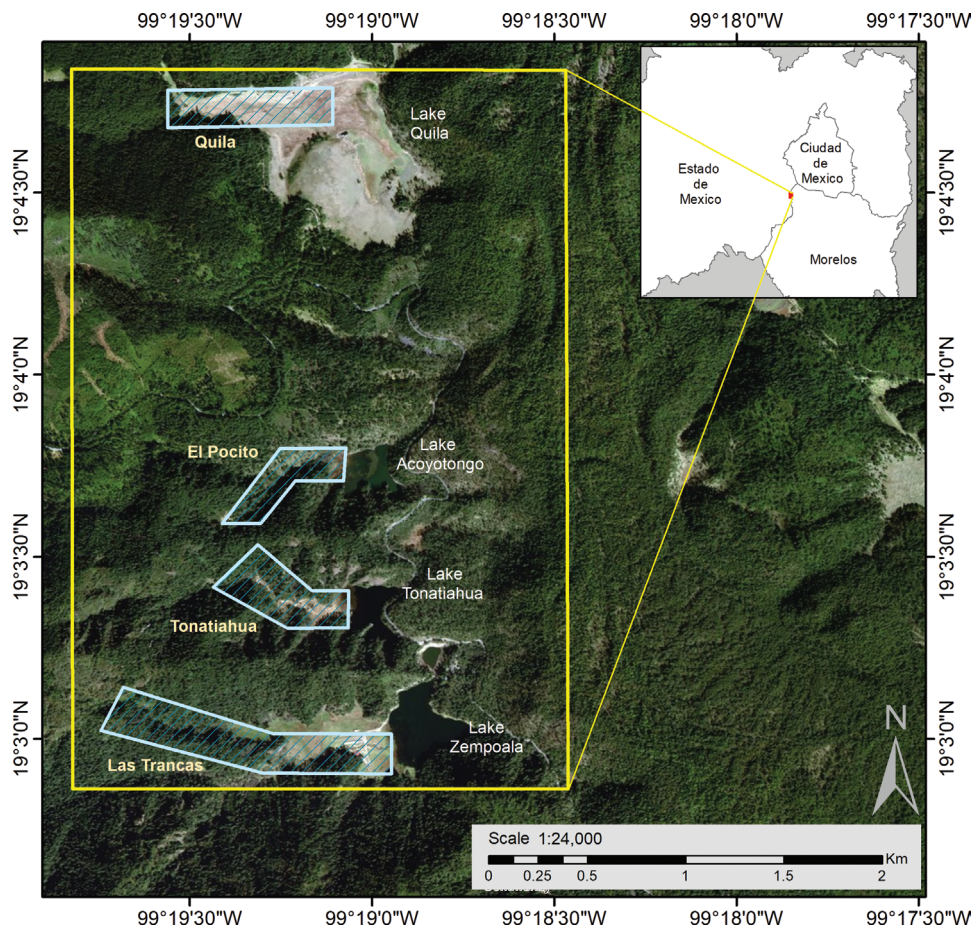


Figure 1. Streams Quila, Tonatiagua, las Trancas and El Pocito in the Parque Nacional Lagunas de Zempoala, in the States of Morelos and Mexico, Mexico. Polygons show approximate extent of area surveyed.

Our study had two independent but complementary phases. In phase one (accomplished between September and October 2016), we carried out sampling in the four streams where the species was reported in a 2003–2008 survey (CONANP 2009). We sampled 1–4 km reaches in each of four permanent streams: Las Trancas (19°2.96'N, 99°19.05'W, emptying into Lake Zempoala), Tonatiahua (19°3.7'N, 99°19.06'W, emptying into Lake Tonatiahua), El Pocito (19°3.76'N, 99°19.08'W, emptying into Lake Acoyotongo) and Quila (19°4.75'N, 99°19.15'W, which used to feed Lake Quila, now just a marsh during the rainy season) (Fig. 1). In each reach, we haphazardly established between 3 and 20 different sampling points or transects where we obtained environmental data and carried out sampling activities. In each sampling point, we used funnel traps to sample for *A. altamirani* (Sparling et al. 2001; Wilson and Dorcas 2003). A trap was set in a pre-selected pool in a stream for 16–24 hours and then checked for *A. altamirani*. When transects were implemented, a 150–200 m stretch of stream was sampled visually, with hand dip nets or using a backpack electrofisher (ETS Electrofishing Systems) with reduced voltage (Brown and May 2007; Dgebuadze and Bashinskiy 2016). During visual samples, two surveyors walked along the stream banks searching for *A. altamirani*, taking note of the presence of fish. When hand dip-netting, two surveyors walked upstream in the creek, scooping rocks, undercuts and submerged vegetation at depths 24–52 cm with 1 cm-mesh hand dip nets. Electrofishing was implemented by sampling in all available habitats (i.e. undercuts, amongst rocks, in submerged vegetation) in a transect. All individual *A. altamirani* or fish captured were placed in buckets with water prior to processing. Rainbow trout presence (via observation or by individuals captured during electrofishing or hand dip net surveys) was recorded for each stream. In each sampling point or transect, we obtained habitat and water physical-chemical data. We used a Hanna multimeter (HI9829) to obtain information on water temperature (°C), pH (standard units), dissolved oxygen (DO) (% and mg/l), conductivity ($\mu\text{S}/\text{cm}$) and total dissolved solids (mg/l). Average depth and water velocity (m per second) were measured (Global Waters flow meter) at three points in a site or transect (Table 1).

The second phase of the study consisted in estimating *A. altamirani* abundance. During the initial survey in 2016, we were only able to locate *A. altamirani* in Quila Stream. Thus, the following procedures describe sampling and individual processing only in Quila Stream from January to December 2017. The Quila Stream segment we

surveyed using hand dip nets consists of a 1.2 km stream stretch with abundant undercuts running through a meadow with no tree cover. The stream meanders down from a water extraction facility to a marshy area that used to form Quila Lake. The 2017 sampling period encompassed three sampling events during the dry-cold (Jan – Mar 2017), rainy (Jul – Sept 2017) and the wet-cold (Oct – Dec 2017) seasons. From each captured individual, we obtained snout-vent length (SVL), tail width, head width (all in mm) and body mass (g) using a Vernier and weight scale (Ohaus Scout). Sex and stage (larva, juvenile, adult) were obtained following Semlitsch and Wilbur (1988). Individuals ≥ 55 mm SVL were marked in all but the last sampling event with visible implant elastomer (VIE) tags (Northwest Marine Technology) and then released back to the same stream section where they were captured. VIE tags are a common, safe and effective method used in salamander population estimate studies (Ralston Marold 2001; Heemeyer et al. 2007). Identification of previously marked individuals was carried out in surveys 2–9. Two different easy-to-detect-under-UV-light elastomer colours, green and pink, were used for tagging and identifying captured individuals. Following Donnelly et al. (1994), we developed a coding system where the location of differently coloured marks in different areas of the body (dorsal area, the anterior part of front and hind legs or abdomen) led to a given individual-specific number which was used for tracking capture events. After marking or being recaptured, every individual was returned, unharmed, to the same area of the stream where it was captured.

We tested for differences in each physical-chemical and habitat variable across streams using analyses of variance (ANOVA) (JASP ver. 0.10.2.0). From *A. altamirani* collection data, we obtained the total number of individuals captured and recaptured per sampling event and calculated descriptive statistics on the total number of individuals for all sampling events. Further, we tested for differences in abundance between the three sampling seasons (Kruskall-Wallis test, JASP ver. 0.10.2.0). We used the Cormack-Jolly-Seber model (Jolly 1965, Manly 1984) to estimate *A. altamirani* population in Quila Stream in all but the first and last sampling events.

Results

Ambystoma altamirani was captured only in Quila Stream in 2016. Sampling methods implemented in the other three streams rendered no *A. altamirani*. Rainbow trout were observed or captured in the Trancas, Tonatiahua and El Pocito streams. Trout were not captured or seen in Quila Stream. Physical-chemical and habitat variables were similar throughout sites, transects and sampling periods (all $p > 0.05$). Generally, all sites and transects had, on average, 65 mg/l (67%) DO, slightly basic pH, relatively cold water (11 °C), with low conductivity (68 $\mu\text{S}/\text{cm}$) and total dissolved solids (45 mg/l). Sites were relatively shallow (15–47 cm) and had water velocities 0.1–0.6 mps (Table 1).

Table 1. Physical-chemical and habitat variable range (min. – max.) for sites and transects in four streams of the Parque Nacional Lagunas de Zempoala (Mexico) in 2016–2017.

Stream	DO (%)	DO (mg/l)	pH	T (°C)	Cond. ($\mu\text{S}/\text{cm}$)	TDS (mg/l)	Vel. (cm/s)	Depth (cm)
Trancas	65–67	5.0–5.23	7.7–8.4	10.0–12.5	69–74	40–49	0.2–0.6	15–45
Tonatiahua	63–70	5.16–5.24	7.2–8.3	10.5–12.0	70–75	40–45	0.2–0.4	19–37
Pocito	65–69	5.3–5.17	7.5–8.0	10.0–12.5	68–72	40–47	0.1–0.6	16–43
Quila	65–70	5.2–5.15	7.2–8.4	10.5–13.0	60–73	45–49	0.3–0.5	15–47

From January to December 2017, we captured 354 individuals of *A. altamirani* in Quila Stream, 247 individuals were marked and 210 individuals were recaptured at least once. We captured (recaptures in parentheses) 109 (0), 66 (38) and 86 (64) individuals in January, February and March 2017, respectively. We captured 53 (25), 84 (68) and 88 (82) individuals in July, August and September 2017, respectively. We captured 104 (78), 95 (83) and 106 (73) individuals in October, November and December 2017, respectively. Over the course of all months, we captured an average 87.8 (SD = 18.7, range = 53–109) individuals. We found no statistical difference in abundance between samples obtained in different seasons ($H = 3.2$, $p = 0.202$). Population estimates for the Quila population were 72 (lower and upper C.I. = 58 and 77), 107 (99, 113), 53 (54, 55), 98 (92, 103), 107 (100, 112), 128 (116, 139) and 127 (108, 146), for sampling periods 2 to 8, respectively.

Considering all 354 individuals captured, the SVL range was 9.0 – 182 mm (Fig. 2); tail and head width



Figure 2. *Ambystoma altamirani* from Quila Stream in the Parque Nacional Lagunas de Zempoala, in the States of Morelos and Mexico, Mexico. Individual shown (SVL = 182 mm) was captured in November 2017.

range were 0.5 – 23 and 5.0 – 25 mm, respectively; and body mass range was 0.5 – 59 g. Of 247 marked individuals, 160 were adults (100 female; 60 male) and 87 juvenile, when first encountered. A total of 107 larvae were collected.

Discussion

Our results illustrate a potentially dire situation for *A. altamirani* populations in the LZNP and provide information that should alert and help managers throughout its range. This area is undergoing fast environmental deterioration (Young et al. 2001; Collins and Storfer 2003) which, in addition to synergistic effects from climate change, emerging diseases and exotic (alien) species, will continue to increase pressure on remnant populations (Villareal-Hernández et al. 2020).

In addition to the LZNP populations, *A. altamirani* has been recorded from the Las Cruces mountains (States of Mexico and Mexico City) and other areas in the upper Lerma River basin (Reilly and Brandon 1994; Lemos-Espinal et al. 1999; Lemos-Espinal et al. 2015; Woolrich-Piña et al. 2017; Monroy-Vilchis et al. 2019). Despite having some level of federal or state protection, other freshwater ecosystems in the area face similar threats as they do in the LZNP. These threats, relatively small range and declining populations have led to *A. altamirani* being listed in both international (Shaffer et al. 2008) and national (SEMARNAT 2019) Red Lists. Recent studies have further identified possible genetic bottlenecks and small effective population sizes in *A. altamirani* populations in nearby areas (Heredia-Bobadilla et al. 2017; Monroy-Vilchis et al. 2019).

Absence of previously known *A. altamirani* populations in three of four LZNP streams we surveyed suggests the species might be extirpated from these systems. Our study revisited lotic sites where a 2003–2008 survey still reported the species from four lakes and their streams (CONANP 2009). This report did not clearly specify the number of individuals captured in each stream or sampling event or provided population estimates for studied sites. However, it does report that between 22 and 118 individuals were collected in aquatic systems of the LZNP in the period of study. We believe our evidence should prompt further efforts for surveys, attempting better quantification of *A. altamirani* populations in the protected area.

Our abundance and population estimates for Quila Stream suggest the species is relatively stable in this system. Our estimates are similar to those reported for similar species in Mexico; samples of 190, 161 and 306 individuals of *A. ordinarium*, *A. leorae* and *A. altamirani*, respectively, have been reported in other recent studies (Calderón et al. 2011; Sunny et al. 2014; Lemos-Espinal et al. 2016). However, further analyses should identify the effective population size as there was asymmetry in adult sex proportion (1.0 females vs. 0.6 males) and we observed temporal variation in abundance.

The 2003–2008 study did not report on water physical-chemical or other habitat variables, but our 2016–2017 surveys indicated little difference in parameters amongst systems. Thus, habitat variables do not seem to factor heavily in the presence and absence of *A. altamirani* in our study. Presence of the carnivore rainbow trout, however, seems to be key to the absence of *A. altamirani* in lotic habitats of the LZNP. Alien species are known to have a negative impact on native amphibian communities (Larson et al. 2002; Bosch et al. 2006). *Ambystoma mexicanum* and *A. dumerillii* have experienced impacts from common carp and tilapia, especially as larvae or juveniles (Huacuz-Elías 2002; Valiente 2006; Zambraño et al. 2010). Rainbow trout was introduced into Central Mexican aquatic ecosystems in the early 1900s and expanded its range. Once established, it affected native fauna via foodweb interactions and disease spread (Consuegra et al. 2011; Mercado Silva et al. 2012; Sepúlveda et al. 2013; Estrella-Zamora 2018). While efforts for trout removal and for impeding their access to novel stream reaches have had success elsewhere (Contreras-MacBeath et al. 2016; Meyer et al. 2017; Shelton et al. 2017), the practice is relatively novel in Mexico. Such efforts, however, would help protection of remnant *A. altamirani* populations in the LZNP. We suggest that Quila Stream being disconnected from a lentic water body where trout could be planted and its being isolated from human use comparatively to the other lakes, might be reasons why the species remains.

While our study identified potential declines of *A. altamirani* populations in the LZNP streams, we note that these amphibians have also been reported in the Park's lakes, that we did not sample lentic systems due to logistics limitations and that several other permanent and ephemeral streams remain unsampled. It is thus possible that Lakes Acoyotongo, Tonatiahua and Zempoala hold *A. altamirani* populations. However, these Lakes are known to contain trout and, in the case of Tonatiahua and Zempoala, also grass carp *Ctenopharyngodon idella* and other invasives (Contreras-MacBeath and Urbina 1995). If these Lakes contain *A. altamirani*, we believe it is unlikely they can re-populate streams if trout are not first removed. Further, even when these salamanders might have a wider variety of habitats in lentic systems, they will also be subject to competition from non-natives. This study was carried out over a short period of time; a longer term study with intensified sampling efforts throughout the LZNP might render additional populations of *A. altamirani*.

Despite the above, our work is one of few for *A. altamirani* in the LZNP, reports perhaps the largest individuals known for the species and has identified some of the threats faced by this flagship species. Our results should inform park managers about the importance of initiating non-native species removals and blockages and the protection of viable *A. altamirani* populations. These efforts should be adopted soon, as synergistic threats to the species might further threaten its viability in the wild.

Acknowledgements

Partial support for this project was provided by PRODEP project DSA/103.5/15/3073 awarded to NMS (author). N. Martínez-Lendech produced Fig. 1; M. Adams and three anonymous reviewers revised earlier versions of this manuscript. This paper is a result of the MS thesis project for JGGP (1st author) in the Master's programme Biología Integrativa de la Biodiversidad y la Conservación (MBIByC, <http://www.mbibyc.mx/>), of the Centro de Investigación en Biodiversidad y Conservación, Universidad Autónoma del Estado de Morelos, Mexico. JGGP's MS degree was supported by CONACYT.

References

- Bosch J, Rincón PA, Boyero LUZ, Martínez-Solano I (2006) Effects of introduced salmonids on a montane population of Iberian frogs. *Conservation Biology* 20(1): 180–189. <https://doi.org/10.1111/j.1523-1739.2005.00296.x>
- Bonilla Barbosa JJ, Novelo Retana A (1995) Manual de Identificación de Plantas Acuáticas del Parque Nacional Lagunas de Zempoala, México. Cuadernos del Instituto de Biología no. 26. Universidad Nacional Autónoma de México, México, 168 pp.
- Brown LR, May JT (2007) Aquatic vertebrate assemblages of the upper Clear Creek watershed, California. *Western North American Naturalist* 67(3): 439–451. [https://doi.org/10.3398/1527-0904\(2007\)67\[439:AVAOTU\]2.0.CO;2](https://doi.org/10.3398/1527-0904(2007)67[439:AVAOTU]2.0.CO;2)
- Calderón MAM, Díaz JA, Ortuño IS (2011) Abundancia, actividad espacial y crecimiento de *Ambystoma ordinarium* Taylor 1940 (Caudata: Ambystomatidae) en Michoacán, México. *Biológicas Revista de la DES Ciencias Biológico Agropecuarias* 13(1): 50–53. <https://www.biologicas.umich.mx/index.php?journal=biologicas&page=article&op=view&path%5B%5D=102&path%5B%5D=102>
- Collins JP, Storfer A (2003) Global amphibian declines: sorting the hypotheses. *Diversity and Distributions* 9(2): 89–98. <https://doi.org/10.1046/j.1472-4642.2003.00012.x>
- CONANP (2008) Programa de Conservación y Manejo del Parque Nacional Lagunas de Zempoala, México. Comisión Nacional de Áreas Naturales Protegidas, Ciudad de México.
- CONANP (2009) Monitoreo del Ajolote (*Ambystoma altamirani*) en el Parque Nacional Lagunas de Zempoala. Report by the Comisión Nacional de Áreas Naturales Protegidas, Ciudad de México.
- Contreras-MacBeath T, Urbina F (1995) Historia Natural del Área de Protección de Flora y Fauna Silvestre: Corredor Biológico Chichinautzin. Cuernavaca, Morelos. SEP-FOMES-UAEM, 35 pp.
- Contreras-MacBeath T, Mejía Mojica H, Rivas González M, Preciado Chino I (2016) Re-introduction of the Morelos minnow in the “Barranca de Chapultepec” protected area, Cuernavaca, Morelos, Mexico. In: Soorae PS (Ed.) *Global Re-introduction Perspectives: 2016. Case-studies from around the globe*. Gland, Switzerland: IUCN/SSC Reintroduction Specialist Group and Abu Dhabi, UAE: Environment Agency-Abu Dhabi, 25–29.
- Consuegra S, Phillips N, Gajardo G, García de Leaniz C (2011) Winning the invasion roulette: Escapes from fish farms increase admixture and facilitate establishment of non-native Rainbow Trout. *Evolutionary Applications* 4(5): 660–671. <https://doi.org/10.1111/j.1752-4571.2011.00189.x>

- Donnelly MA, Guyer C, Juterbock JE, Alford RA (1994) Handling live amphibians. In: Heyer ER, Donnelly MA, McDiarmid RW, Hayek LAC, Foster MS (Eds) *Measuring and Monitoring Biological Diversity. Standard Methods for Amphibians*. Smithsonian Institution Press, Washington, 277–284.
- Dgebuadze YY, Bashinskiy IV (2016) Electrofishing method improves evaluation of amphibian larvae abundance: a case of “beaver rivers”. *Integrative Zoology* 12(4): 345–350. <https://doi.org/10.1111/1749-4877.12246>
- Estrella-Zamora AB, Smith GR, Lemos-Espinal JA, Woolrich-Piña GA, Montoya Ayala R (2018) Effects of non-native Rainbow Trout on two species of endemic Mexican amphibians. *Freshwater Science* 37(2): 389–396. <https://doi.org/10.1086/697700>
- Flores-Villela O, Canseco-Márquez L (2004) Nuevas especies y cambios taxonómicos para la herpetofauna de México. *Acta Zoológica Mexicana (nueva serie)* 20(2): 115–144. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0065-17372004000200008
- Frias-Alvarez P, Zúñiga-Vega JJ, Flores-Villela O (2010) A general assessment of the conservation status and decline trends of Mexican amphibians. *Biodiversity and Conservation* 19(13): 3699–3742. <https://doi.org/10.1007/s10531-010-9923-9>
- Frost DR (2020) Amphibian species of the world: an online reference. Version 6.1 (Accessed August 2020). Electronic Database accessible at: <https://amphibiansoftheworld.amnh.org/index.php>. American Museum of Natural History, New York. doi.org/10.5531/db.vz.0001
- Godínez-Ortega JL, Oliva-Martínez MG, Escobar-Oliva MA, Mendoza-Garfías B (2017) Diversidad algal del Parque Nacional Lagunas de Zempoala, México, excepto diatomeas. *Hidrobiológica* 27(1): 45–58. <https://doi.org/10.24275/uam/izt/dcbi/hidro/2017v27n1/Godinez>
- Heemeyer JL, Homyack JA, Haas CA (2007) Retention and readability of visible implant elastomer marks in Eastern Red-backed Salamanders (*Plethodon cinereus*). *Herpetological Review* 38(4): 425–428.
- Heredia-Bobadilla RL, Monroy-Vilchis O, Zarco-González MM, Martínez-Gómez D, Mendoza-Martínez GD, Sunny A (2017) Genetic variability and structure of an isolated population of *Ambystoma altamirani*, a mole salamander that lives in the mountains of one of the largest urban areas in the world. *Journal of Genetics* 96: 873–883. <https://doi.org/10.1007/s12041-017-0823-6>
- Huacuz-Elías DC (2002) Programa de Conservación y Manejo de *Ambystoma dumerillii*: El Achoque del Lago de Pátzcuaro. FMCN/UMSNH/SEMARNAT. Morelia, México.
- Hussain QA, Pandit AK (2012) Global amphibian declines: A review. *International Journal of Biodiversity and Conservation* 4(10): 348–357. <https://doi.org/10.5897/IJBC12.008>
- IUCN (2020) The IUCN Red List of Threatened Species. Version 2020-1. <https://www.iucnredlist.org> [Downloaded on 19 March 2020]
- Jolly GM (1965) Explicit estimates from capture-recapture data with both death and immigration-stochastic model. *Biometrika* 52(1/2): 225–247. <https://doi.org/10.1093/biomet/52.1-2.225>
- Larson GL, Hoffman RL, Moore SE (2002) Observations of the distributions of five fish species in a small Appalachian stream. *Transactions of the American Fisheries Society* 131(4): 791–796. [https://doi.org/10.1577/1548-8659\(2002\)131<0791:OOTD OF>2.0.CO;2](https://doi.org/10.1577/1548-8659(2002)131<0791:OOTD OF>2.0.CO;2)
- Lemos-Espinal JA, Smith GR, Ballinger RE, Ramírez-Bautista A (1999) Status of protected endemic salamanders (*Ambystoma*: Ambystomatidae: Caudata) in the Transvolcanic Belt of Mexico. *British Herpetological Society Bulletin* 68: 1–4. <https://www.thebhs.org/publications/the-herpetological-bulletin/issue-number-69-autumn-1999/2712-hb069-01/file>
- Lemos-Espinal JA, Smith GR, Woolrich-Piña GA (2015) Diet of larval *Ambystoma altamiranoi* from Llano de los Ajolotes, Mexico. *Current Herpetology* 34(1): 75–79. <https://doi.org/10.5358/hsj.34.75>
- Lemos-Espinal JA, Smith GR, Hernández-Ruiz Á, Montoya-Ayala R (2016) Stream use and population characteristics of the endangered salamander, *Ambystoma altamirani*, from the Arroyo Los Ajolotes, State of Mexico, Mexico. *The Southwestern Naturalist* 61(1): 28–32. <https://doi.org/10.1894/0038-4909-61.1.28>
- Maldonado-Koerdell M (1947) Notas anfibiológicas. I. Observaciones sobre algunos anfibios de la Cuenca de México. *Revista de la Sociedad Mexicana de Historia Natural* 8: 229–242.
- Manly BFJ (1984) Obtaining confidence limits on parameters of the Jolly-Seber model for capture-recapture data. *Biometrics* 40(3):749–758. <https://doi.org/10.2307/2530918>
- McCallum ML (2007) Amphibian decline or extinction? Current declines dwarf background extinction rate. *Journal of Herpetology* 41(3): 483–491. [https://doi.org/10.1670/0022-1511\(2007\)41\[483:A-DOECD\]2.0.CO;2](https://doi.org/10.1670/0022-1511(2007)41[483:A-DOECD]2.0.CO;2)
- Mercado-Silva N, Lyons J, Díaz-Pardo E, Navarrete S, Gutiérrez-Hernández A (2012) Environmental factors associated with fish assemblage patterns in high gradient streams of Mexico’s Atlantic slope. *Revista Mexicana de Biodiversidad* 83: 117–128. <https://doi.org/10.22201/ib.20078706e.2012.1.800>
- Meyer KA, Kennedy P, High B, Campbell MR (2017) Purifying a Yellowstone Cutthroat Trout stream by removing Rainbow Trout and hybrids via electrofishing. *Transactions of the American Fisheries Society* 146(6): 1193–1203. <https://doi.org/10.1080/00028487.2017.1362470>
- Monroy-Vilchis O, Heredia-Bobadilla R-L, Zarco-González MM, Ávila-Akerberg V, Sunny A (2019) Genetic diversity and structure of two endangered mole salamander species of the Trans-Mexican Volcanic Belt. *Herpetozoa* 32: 237–248. <https://doi.org/10.3897/herpetozoa.32.e38023>
- Parra-Olea G, Flores-Villela O, Mendoza-Almeralla C (2014) Biodiversity of amphibians in Mexico. *Revista Mexicana de Biodiversidad, Supl.* 85: S460–S466. <https://doi.org/10.7550/rmb.32027>
- Quiroz Cástelan H, Mondragón Eslava O, Molina Astudillo I, García Rodríguez J, Díaz Vargas M (2008) Dinámica espacio-temporal de oxígeno-temperatura en los lagos Zempoala y Tonatiagua. *Acta Universitaria – Universidad de Guanajuato* 18(1): 57–65. <https://doi.org/10.15174/au.2008.159>
- Ralston Marold MA (2001) Evaluating visual implant elastomer polymer for marking small, stream-dwelling salamanders. *Herpetological Review* 32(2): 91–92. <https://ssarherps.org/herpetological-review-pdfs/>
- Reilly SM, Brandon RA (1994) Partial paedomorphosis in the Mexican stream ambystomatids and the taxonomic status of the genus *Rhyacosiredon* Dunn. *Copeia* 3: 656–662. <https://doi.org/10.2307/1447181>
- Sarukhán J, Dirzo R (1992) México Ante los Retos de la Biodiversidad. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Mexico City, 343 pp.
- SEMARNAT (2019) Modificación al anexo normativo III, lista de especies en riesgo de la Norma Oficial Mexicana NOM-059-Ecol-(2010) Protección ambiental-Especies nativas de México de flora y fauna silvestres-Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-Lista de especies en riesgo, publicado el 30 de diciembre del 2010. [14 noviembre 2019] https://www.dof.gob.mx/nota_detalle.php?codigo=5578808

- Semlitsch RD, Wilbur HM (1988) Effects of pond drying time on metamorphosis and survival in the salamander *Ambystoma talpoideum*. *Copeia* 4: 978–983. <https://doi.org/10.2307/1445721>
- Sepúlveda M, Arismendi I, Soto D, Jara F, Farias F (2013) Escaped farmed salmon and trout in Chile: incidence, impacts, and the need for an ecosystem view. *Aquaculture Environment Interactions* 4: 273–283. <https://doi.org/10.3354/aei00089>
- Shaffer HB, Parra-Olea G, Wake D, Flores-Villela O (2008) *Ambystoma altamirani*. The IUCN Red List of Threatened Species.
- Shelton J, Weyl O, Van Der Walt J, Marr S, Impson D, Maciejewski K, Tye D, Dallas H, Esler K (2017) Effect of an intensive mechanical removal effort on a population of non-native rainbow trout *Oncorhynchus mykiss* in a South African headwater stream. *Aquatic Conservation, Marine and Freshwater Ecosystems* 27(5): 1051–1055. <https://doi.org/10.1002/aqc.2752>
- Sparling DW, Fellers GM, McConnell LL (2001) Pesticides and amphibian population declines in California, USA. *Environment Toxicology Chemistry* 20: 1591–1595. [https://doi.org/10.1897/1551-5028\(2001\)020<1591:PAAPDI>2.0.CO;2](https://doi.org/10.1897/1551-5028(2001)020<1591:PAAPDI>2.0.CO;2)
- Stuart SN, Chanson JS, Cox NA, Young BE, Rodrigues AS, Fischman DL, Waller RW (2004) Status and trends of amphibian declines and extinctions worldwide. *Science* 306(5702): 1783–1786. <https://doi.org/10.1126/science.1103538>
- Sunny A, Monroy-Vilchis O, Reyna-Valencia C, Zarco-González MM (2014) Microhabitat types promote the genetic structure of a micro-endemic and critically endangered mole salamander (*Ambystoma leorae*) of Central Mexico. *PLoS ONE* 9(7): e103595. <https://doi.org/10.1371/journal.pone.0103595>
- Taylor EH, Smith HM (1945) Summary of the collections of amphibians made in México under the Walter Rathbone Bacon traveling scholarship. *Proceedings of the United States National Museum* 95: 521–613. <https://doi.org/10.5479/si.00963801.95-3185.521>
- Uribe-Peña Z, Ramírez-Bautista A, Casas-Andreu G (1999) Anfibios y reptiles de las serranías del Distrito Federal, México (Vol. 32). Universidad Nacional Autónoma de México, Ciudad de México.
- Valiente E (2006) Efecto de las especies introducidas en Xochimilco para la rehabilitación del hábitat del ajolote (*Ambystoma mexicanum*). Tesis Doctoral. Universidad Nacional Autónoma de México, México.
- Villarreal-Hernández V, Smith GR, Montoya-Ayala R, Lemos-Espinal JA (2020) Abundance, distribution, population structure, and substrate use of *Ambystoma altamirani* along the Arroyo los Axolotes, State of Mexico, Mexico. *Herpetological Conservation and Biology* 15(1): 188–197. http://www.herpconbio.org/Volume_15/Issue_1/Villarreal-Hernandez_etal_2020.pdf
- Wake DB, Vredenburg VT (2008) Are we in the midst of the sixth mass extinction? A view from the world of amphibians. *Proceedings of the National Academy of Sciences* 105 (Supplement 1): 11466–11473. <https://doi.org/10.1073/pnas.0801921105>
- Wilson JD, Dorcas ME (2003) Quantitative sampling of stream salamanders: Comparison of dipnetting and funnel trapping techniques. *Herpetological Review* 34: 128–130. <https://ssarherps.org/herpetological-review-pdfs/>
- Woolrich-Piña G, Smith GR, Lemos-Espinal JA, Estrella-Zamora AB, Montoya-Ayala R (2017) Observed localities for three endangered, endemic Mexican ambystomatids (*Ambystoma altamirani*, *A. leorae*, and *A. rivulare*) from central Mexico. *Herpetological Bulletin* 139: 12–15.
- Young BE, Lips KR, Reaser JK, Ibáñez R, Salas AW, Cedeño JR, Muñoz A (2001) Population declines and priorities for amphibian conservation in Latin America. *Conservation Biology* 15(5): 1213–1223. <https://doi.org/10.1046/j.1523-1739.2001.00218.x>
- Zambrano L, Valiente E (2008) Mitigación del impacto de las especies introducidas en la zona lacustre de Xochimilco. Gobierno del Distrito Federal, Instituto de Biología de la UNAM, México.
- Zambrano L, Valiente E, Vander Zanden MJ (2010) Food web overlap among native axolotl (*Ambystoma mexicanum*) and two exotic fishes: carp (*Cyprinus carpio*) and tilapia (*Oreochromis niloticus*) in Xochimilco, Mexico City. *Biological Invasions* 12(9): 3061–3069. <https://doi.org/10.1007/s10530-010-9697-8>

ZOBODAT - www.zobodat.at

Zoologisch-Botanische Datenbank/Zoological-Botanical Database

Digitale Literatur/Digital Literature

Zeitschrift/Journal: [Herpetozoa](#)

Jahr/Year: 2020

Band/Volume: [33](#)

Autor(en)/Author(s): Guerrero de la Paz Jesica Gabriela, Mercado-Silva Norman, Alcala Raul E., Zambrano Luis

Artikel/Article: [Signals of decline of flagship species *Ambystoma altamirani* Dugès, 1895 \(Caudata, Ambystomatidae\) in a Mexican natural protected area 177-183](#)