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NOTES ON GEOGRAPHIC DISTRIBUTION

Filling gaps: on the distribution of *Crotalus intermedius* Troschel, 1865 (Squamata, Viperidae) and its first record in the State of Mexico, Mexico

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Abstract. *Crotalus intermedius* Troschel, 1865 is a venomous snake endemic to Mexico, inhabiting high-elevation forests and shrublands. This study presents the first formal record of *C. intermedius* from the State of Mexico and its potential distribution. Only 11.4% of its potential range overlaps with natural protected areas (NPA), with 10.1% in federal NPAs, including our new record from Monte Tláloc within Iztaccíhuatl-Popocatépetl National Park, and 1.3% in state NPAs. This finding fills a distribution gap in *C. intermedius* distribution and increases the number of venomous reptile species recorded in the State of Mexico to 16.

Key words. Coniferous forest, distribution model, Iztaccíhuatl-Popocatépetl National Park, Mexican Small-headed Rattlesnake, Monte Tláloc, natural protected areas

Monter-Pozos Á, Reyes-Velázquez EA, Hernández-Gallegos O, Gómez-Benitez A (2025) Filling gaps: on the distribution of *Crotalus intermedius* Troschel, 1865 (Squamata, Viperidae) and its first record in the State of Mexico, Mexico. Check List 21 (2): 443–450. https://doi.org/10.15560/21.2.443

INTRODUCTION

Crotalus intermedius Troschel, 1865, Mexican Small-headed Rattlesnake, is a venomous species endemic to Mexico, measuring up to 590 mm in snout–vent length (Campbell and Lamar 2004). This diurnal terrestrial snake displays climbing behavior while hunting for its prey, which primarily consists of lizards and occasionally on rodents (Canseco-Márquez and Gutiérrez-Mayén 2010; Bryson et al. 2013; Schramer et al. 2020). It inhabits coniferous forests, shrublands, and cloud forests at elevations between 2000 and 4080 m across the states of Hidalgo, Puebla, Tlaxcala, Veracruz, Guerrero, and Oaxaca (Canseco-Márquez and Gutiérrez-Mayén 2010; Yañez-Arenas et al. 2014; Fernández-Badillo et al. 2016; Hernández-Jandete et al. 2017; Palacios-Aguilar and Flores-Villela 2018; Perea-Pérez et al. 2019). *Crotalus intermedius* is classified as Highly Vulnerable according to its Environmental Vulnerability Score (EVS) of 15 (the adjusted EVS for Mexico is a metric to estimate species' vulnerability based on geographic distribution, vegetation formations occupied, and human persecution; Wilson et al. 2013), and it is listed as threatened in the Norma Oficial Mexicana (SEMARNAT 2010). Contrary to these classifications, the IUCN Red List assesses the species as Least Concern, revealing a discrepancy in conservation assessments. No previous formal records of *C. intermedius* exist from the State of Mexico. Lemos-Espinal and Smith (2020) reported 10 species of *Crotalus* Linnaeus, 1758 in the State of Mexico but excluded *C. intermedius*. This omission reveals the limited knowledge of *C. intermedius*, one of the least studied rattlesnake species in Central Mexico. Here, we present the first formal record of *C. intermedius* in the State of Mexico and model its potential distribution to enhance our understanding of this poorly known species.

METHODS

On 21 June 2023, during a nocturnal hike in the San Pablo Ixayox Ejido, Monte Tláloc, Texcoco de Mora municipality, State of Mexico, Mexico, AMP observed a juvenile rattlesnake (Figure 1A–C). The individual was identified as *Crotalus intermedius* (see results). The site features small remnant patches of oak forest and

OPEN ACCESS

Academic editor: Sebastian Lotzkat
Received: 23 September 2024
Accepted: 31 March 2025
Published: 9 April 2025

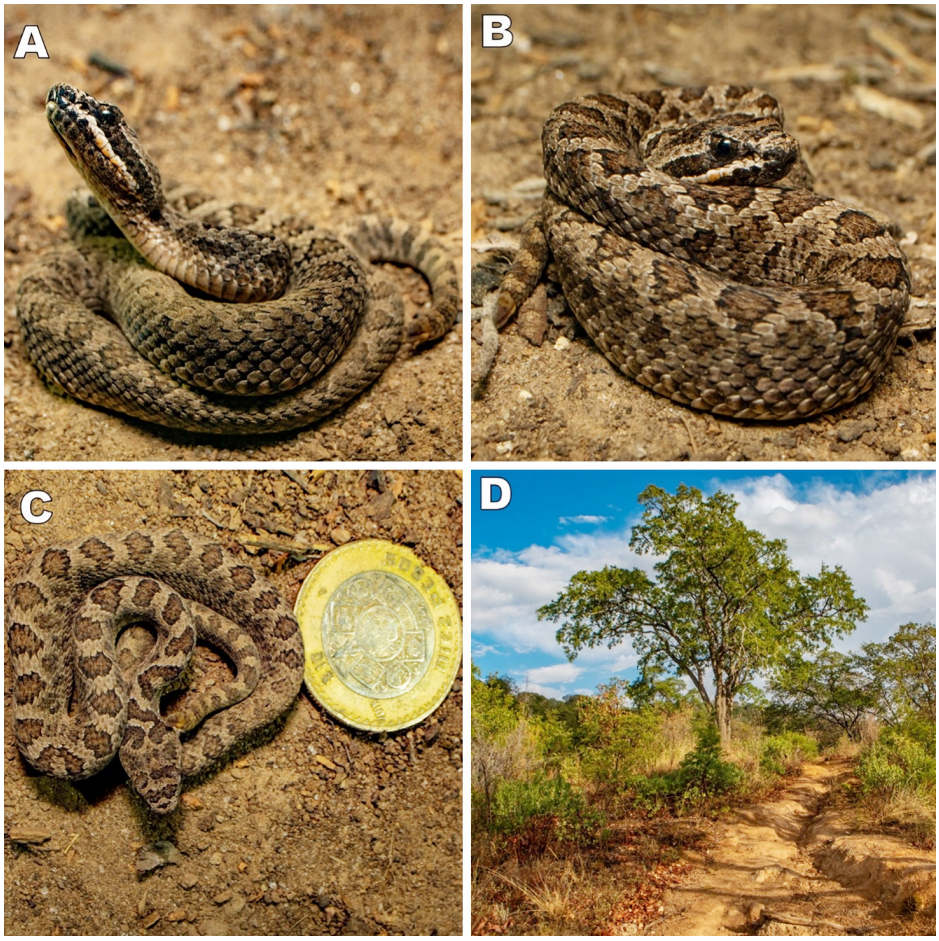

Figure 1. The juvenile of *Crotalus intermedius* reported herein. **A, B.** Dorsolateral views. **C.** Dorsal view of the individual, with a size comparison using a 10 Mexican pesos coin (diameter = 28 mm). **D.** Habitat where the individual was found. photographs taken by AMP

agricultural fields, with cattle grazing in the area (Figure 1D). The organism was photographed and then released at the same location where it was observed.

The photographs of the specimen (F420) were deposited in the Colección Herpetológica of the Universidad Michoacana de San Nicolás de Hidalgo (CHUM) and the record was also uploaded to the iNaturalist platform (https://www.naturalista.mx/observations/168864545).

We modeled the potential distribution of *C. intermedius* to understand the knowledge gaps in the distribution of the species. We initially compiled 198 occurrence records from databases (GBIF and VertNet), scientific publications, and our field observation in the State of Mexico. These points were filtered based on recent taxonomic updates, the known distribution of the species, and to avoid spatial autocorrelation by employing resampling techniques. After filtering, 77 records were retained for modeling (Appendix 1). As an example of a record omitted due to taxonomic updates, the specimen IBUNAM15646, housed in the Colección Nacional de Anfibios y Reptiles (CNAR) and collected at Villa de Allende in the western State of Mexico in 1981, was initially classified as *C. intermedius* in the CNAR catalog. However, after direct examination of the specimen by AGB and EARV, it was reclassified as *Crotalus triseriatus* Wagler, 1830 based on scutellation characteristics. An example of a record omitted due to the known distribution of the species is IBUNAM18435, also housed in CNAR, which was reportedly collected in the municipality of Huitzilac, in northwestern Morelos state. This locality is 104 km away from the nearest confirmed point for *C. intermedius*. This record would imply the presence of *C. intermedius* in the rest of the territory of the State of Morelos or in Mexico City, but this species is not found in these areas. Further inquiries confirmed that the record in GBIF was incorrect, as the corresponding voucher specimen in CNAR is cataloged as *Masticophis mentovarius* (Duméril, Bibron & Duméril, 1854).

Environmental variables were obtained from WorldClim (Fick and Hijmans 2017), including 19 bioclimatic variables and a digital elevation model (DEM) at a 30 arc-seconds resolution. We conducted a multiple correlation analysis in Google Earth Engine (Gorelick et al. 2017) to select the bioclimatic variables for the model, resulting in the selection of BIO1, 2, 3, 5, 7, 8, 9, 12, 14, 15, and 19. However, due to their similar and low importance values after a practice run model, variables BIO12 and 14 were omitted. Using the DEM, we calculated the aspect and slope and included these three variables in the model. We downloaded the land use shapefile from the CONABIO geoportal (CONABIO 2022) and rasterized it. Finally, we obtained latitude and longitude layers using QGIS v. 3.36.1.

We implemented Maxent v. 3.4.4 software (Phillips et al. 2006) to model the potential distribution, utilizing the occurrence points of *C. intermedius* and the environmental variables mentioned above. We configured the model with a fixed random seed and ran it 10 times with subsampling. To evaluate model performance, we set aside 25% of the occurrence data for testing. We set the maximum number of iterations to 10,000 to ensure the model converged adequately. Additionally, we enabled the output of data for generating response curves. The minimum training presence threshold was applied to conservatively define suitable habitats, ensuring all recorded presence locations were included in the predicted distribution. We obtained the permutation importance for each variable by randomly permuting the values of each environmental variable and measuring the resulting decrease in the model's AUC (Area Under the Curve), which reflects the model's dependence on that variable. The AUC was calculated from the model's ability to distinguish between presence and background points.

RESULTS

***Crotalus intermedius* Troschel, 1865**
Figure 1

New record. MEXICO — State of Mexico • Texcoco de Mora municipality, San Pablo Ixayox Ejido, Monte Tláloc; 19.4584, −098.8035; 2694 m elev.; 21.VI.2023; Álvaro Monter-Pozos obs.; agricultural field with remnant patches of oak forest; 1 ♂, CHUM F420.

Identification. The individual was identified as *C. intermedius* juvenile (snout–vent length = 22 cm) based on diagnostic characteristics described by Canseco-Márquez and Gutiérrez-Mayén (2010), including a black postocular stripe bordered by small white stripes, extending from behind the eyes to the neck; pale supralabials; infralabials with black bars; and dorsally, a pair of longitudinally elongated nuchal spots. The identification was verified by Jonatan Torres Pérez Coeto and Leonardo Fernández Badillo.

Distribution model. The AUC value was 0.977, demonstrating a good resolution of the model. Our model suggests that *C. intermedius* is potentially distributed across six biogeographic provinces in Mexico: the Trans-Mexican Volcanic Belt (in the states of Mexico, Puebla, Tlaxcala, Veracruz, and Oaxaca), Sierra Madre Oriental (Hidalgo, Puebla, and Veracruz), Oaxaca Province (Oaxaca, Veracruz, and Puebla), Southern Altiplano (Hidalgo, Puebla, State of Mexico, and Tlaxcala), Sierra Madre del Sur (Oaxaca and Guerrero), and the Pacific Coast (Oaxaca; Figures 2, 3).

Latitude was the most influential environmental variable, with a permutation importance value of 62.3%, delimiting the presence of *C. intermedius* between 16 and 20°N. The second most important variable was BIO8, mean temperature of the wettest quarter (10.4%), highlighting the significance of temperatures around 14 °C during the rainy season. This was followed by longitude (8.8%), indicating that *C. intermedius* inhabits between 094 and 100°W in Mexico, and BIO15, precipitation seasonality (8.3%), suggesting

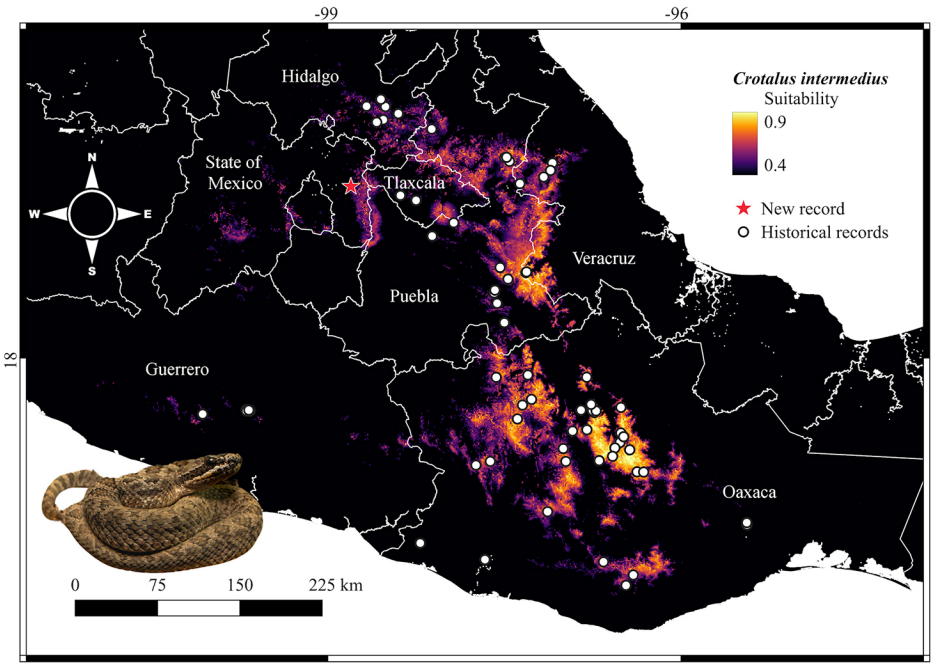

Figure 2. Modelled potential distribution of *Crotalus intermedius*, showing suitable areas in bright colors, historical records indicated with circles, and the new record in the State of Mexico marked with a red star.

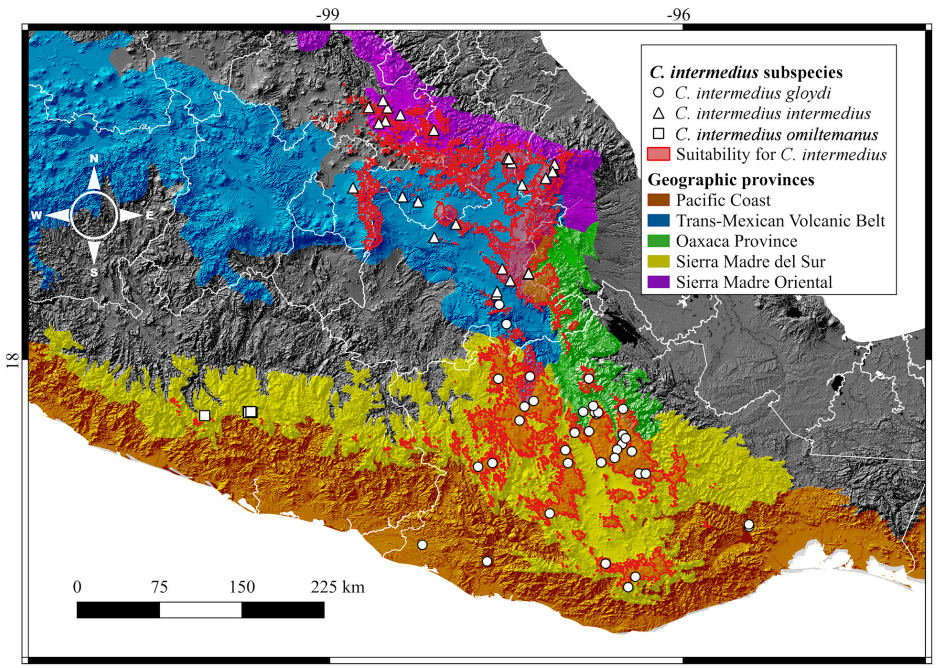

Figure 3. Geographic provinces occupied by *Crotalus intermedius* and the division of its subspecies. The predicted suitability for *C. intermedius* (red polygons) shows distinct areas of occupancy for each subspecies: *C. i. intermedius* (triangles), *C. i. gloydi* (circles), and *C. i. omiltemanus* (squares).

resilience to precipitation variability. The remaining variables showed lower relevance, with the following values: BIO7, temperature annual range (3.2%); BIO19, precipitation of the coldest quarter (2.9%); elevation (1.9%); land use (0.6%); BIO1, annual mean temperature (0.6%); BIO9, mean temperature of the driest quarter (0.3%); slope (0.3%); and aspect (0.3%). Finally, BIO2, mean diurnal range; BIO3, isothermality; and BIO5, maximum temperature of the warmest month, showed 0% permutation importance (Figure 4).

DISCUSSION

Our record and distribution model help to fill the gap in the known distribution of *Crotalus intermedius* towards the central region of the country, specifically 45 km west of Tlaxcala and 65 km south of Hidalgo. The State of Mexico is highly biodiverse, hosting 154 species of amphibians and reptiles, five of which are endemic to the state, which underscores the region's ecological uniqueness (Lemos-Espinal and Smith 2020; Barragán-Reséndiz et al. 2022; Monroy-Vilchis et al. 2024; Solano-García et al. 2025; this study). This record increases the number of venomous reptile species known to be present in the State of Mexico; with the inclusion of *C. intermedius*, the number of venomous species in the federal entity rises to 16: 12 species of Viperidae (Lemos-Espinal and Smith 2020; Monroy-Vilchis et al. 2024; this study), three species of Elapidae (Lemos-Espinal and Smith 2020), and one species of Helodermatidae (Aguilar-Miguel et al. 2003). However, the presence of *Micrurus tener* (Baird & Girard, 1853) appears questionable based on a preliminary distribution model conducted by AGB (unpublished data) which suggests the species may not occur in the State of Mexico. Additionally, *Crotalus atrox* Baird & Girard, 1853, a species listed by Lemos-Espinal and Smith (2020), most probably does not occur naturally in the State of Mexico according to its known distribution (Campbell and Lamar 2004). Rather, we suspect that its presence results from individuals that escaped or were released from captivity. Understanding the diversity of venomous species enhances the effectiveness of responses to envenomation in the State of Mexico, as treatment can vary between species, not only in the choice of the appropriate antivenom, but also in the required dosage and application timing.

Our model supports the previously suggested subspecies differentiation within *Crotalus intermedius* (McCraine 1991; Figure 3), the predicted suitability delineates areas of occupancy for each subspecies and reveals distinct ecological and geographic separations. *Crotalus intermedius intermedius* Troschel, 1865 primarily inhabits the Trans-Mexican Volcanic Belt, Sierra Madre Oriental, and the South Altiplano, and corresponds to our record in the State of Mexico. *Crotalus intermedius gloydi* Taylor, 1941 is found in Oaxaca Province, Sierra Madre del Sur, and the Pacific Coast, but both subspecies are most surely connected through the State of Puebla at the high elevations of the Trans-Mexican Volcanic Belt, and concretely in Sierra de Tehuacán, as suitability interruption in the model reveals. *Crotalus intermedius omiltemanus* Günther, 1895 is restricted to the Sierra Madre del Sur in the State of Guerrero. However, the connectivity between *C. i. gloydi* and *C. i. omiltemanus* remains unclear due to a knowledge gap in the distribution of *C. intermedius*, although the most plausible connection route is likely through the Sierra Madre del Sur, but our model does not identify that connection. Our record in the State of Mexico represents a peripheral population of *C. i. intermedius* at

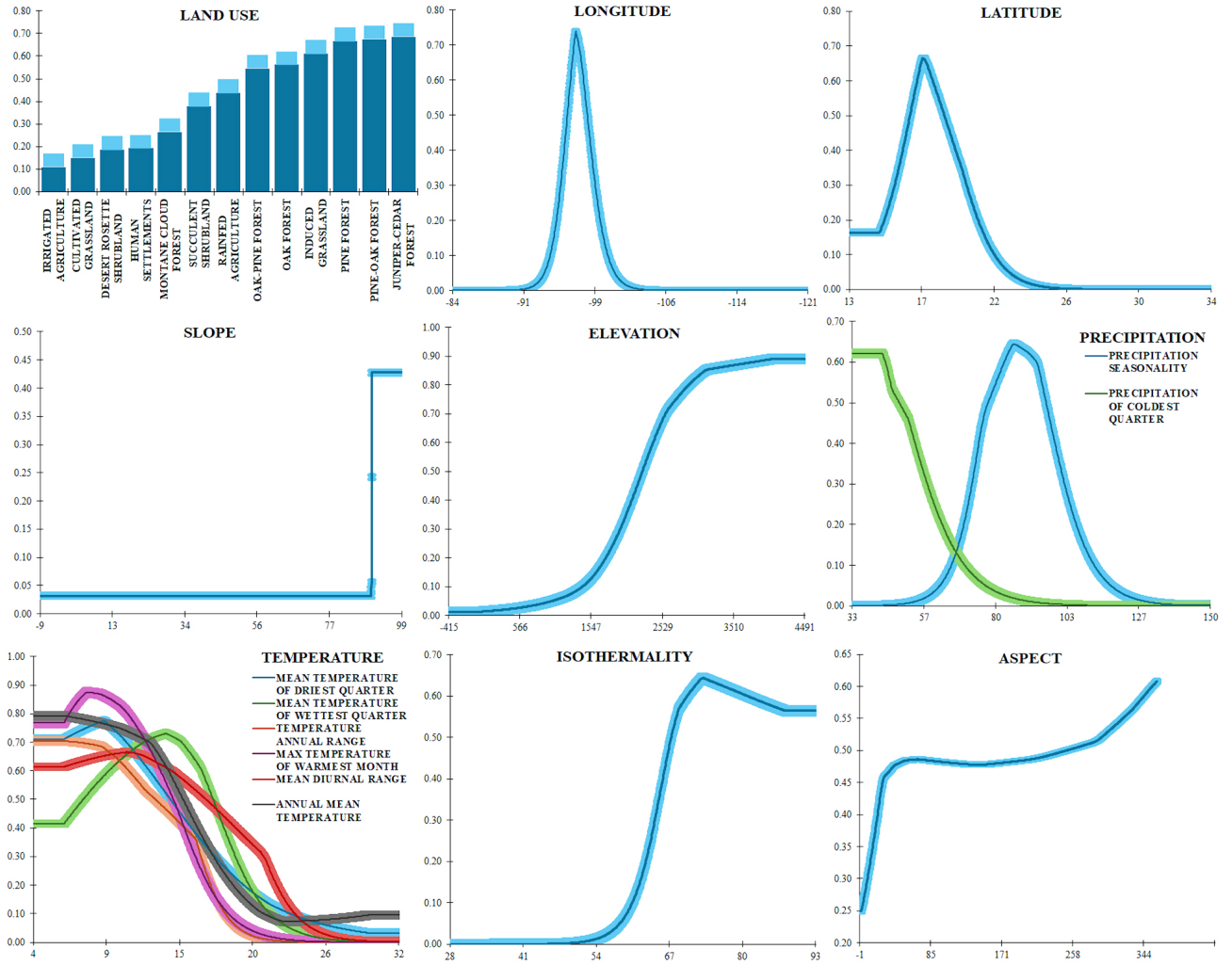

Figure 4. Tolerance curves of the environmental variables used to model the potential distribution of *Crotalus intermedius*. Contours represent the standard error.

the easternmost limit of its distribution. Peripheral populations have been documented in other reptiles in central Mexico, particularly within the Trans-Mexican Volcanic Belt (Hernández-Gallegos et al. 2009). These populations are important because they may possess unique morphologic and genetic characteristics relevant to conservation, as well as potential for speciation (Lesica and Allendorf 1995).

Finally, our record and distribution model will contribute to the conservation of *C. intermedius*, a highly threatened species. We recorded *C. intermedius* on Monte Tláloc, part of Iztaccíhuatl-Popocatépetl National Park, a natural protected area (NPA). Our model suggests that the species could be distributed throughout the mountains in this area, underscoring the crucial role of NPAs in protecting *C. intermedius*, although only 11.4% of its potential distribution overlaps with NPAs, 10.1% in federal NPAs and 1.3% in state NPAs. Despite its ecological importance, Monte Tláloc faces significant environmental threats, including visitor overload, waste pollution, erosion, and increased fire risk (Lugo-Sandoval et al. 2020), all of which threaten *C. intermedius* habitat. This highlights the urgent need for collaboration with the government of the State of Mexico on a conservation project focused on the species, a process facilitated by its presence within NPAs. Identifying this rattlesnake in a protected zone reinforces the importance of ongoing efforts to preserve its habitat and mitigate threats, while emphasizing the need for continuous biodiversity monitoring on a national scale.

ACKNOWLEDGEMENTS

We thank Gregorio Monter Pozos for assistance with the fieldwork and photography, Leonardo Fernández Badillo for his comments on the manuscript and verification of the species, Jonatan Torres Pérez Coeto for verifying the species and for facilitating the registration of the photographs in the Collection of the Universidad Michoacana de San Nicolás de Hidalgo, and the Consejo Mexiquense de Ciencia y Tecnología for the funding for AGB.

ADDITIONAL INFORMATION

Conflict of interest

The authors declare that no competing interests exist.

Ethical statement

No ethical statement is reported.

Funding

This study was partially funded by the Consejo Mexiquense de Ciencia y Tecnología, which provided funding for AGB's research, moreover, was partially supported by Universidad Autónoma del Estado de México, grant number 7037/2024CIB for OHG.

Author contributions

Conceptualization: EARV, AGB. Formal analysis: AGB. Investigation: AMP. Visualization: EARV. Validation: OHG. Methodology: AMP, EARV, AGB. Writing – original draft: AMP, EARV, AGB. Writing – review and editing: AGB, OHG.

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Data availability

All data that support the findings of this study are available in the main text and appendix 1.

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APPENDIX

Table A1. Occurrence records used to model the potential distribution of *Crotalus intermedius* in Mexico. The record in bold denotes a new occurrence reported in this study from the State of Mexico.

Latitude	Longitude	State	Latitude	Longitude	State
17.5237	−100.0624	Guerrero	17.2307	−097.0000	Oaxaca
17.5507	−099.6668	Guerrero	17.2359	−096.5613	Oaxaca
17.5507	−099.6601	Guerrero	17.2820	−096.5184	Oaxaca
17.5574	−099.6701	Guerrero	17.2820	−096.5184	Oaxaca
17.5583	−099.6920	Guerrero	17.3313	−096.4873	Oaxaca
17.5583	−099.6750	Guerrero	17.3322	−096.4874	Oaxaca
17.5583	−099.6917	Guerrero	17.3633	−096.5109	Oaxaca
17.5583	−099.6917	Guerrero	17.3794	−096.9207	Oaxaca
20.0047	−098.5844	Hidalgo	17.3906	−096.7991	Oaxaca
20.0256	−098.5279	Hidalgo	17.4827	−097.3891	Oaxaca
20.0775	−098.4009	Hidalgo	17.5368	−096.7350	Oaxaca
20.1368	−098.5099	Hidalgo	17.5508	−096.7208	Oaxaca
20.1406	−098.6701	Hidalgo	17.5528	−096.7508	Oaxaca
20.1996	−098.5487	Hidalgo	17.5531	−096.7356	Oaxaca
19.4584	**−098.8035**	**State of Mexico**	17.5571	−096.8489	Oaxaca
16.0675	−096.4667	Oaxaca	17.5807	−096.5100	Oaxaca
16.1559	−096.4050	Oaxaca	17.6003	−097.3464	Oaxaca
16.2675	−096.6584	Oaxaca	17.6062	−096.7635	Oaxaca
16.2865	−097.6650	Oaxaca	17.6486	−097.2694	Oaxaca
16.4271	−098.2144	Oaxaca	17.8364	−097.5694	Oaxaca
16.5808	−095.4400	Oaxaca	17.8375	−096.8008	Oaxaca
16.6008	−095.4417	Oaxaca	17.8559	−097.3005	Oaxaca
16.6939	−097.1330	Oaxaca	18.3007	−097.5001	Puebla
17.0311	−096.3173	Oaxaca	18.4654	−097.5616	Puebla
17.0328	−096.3734	Oaxaca	18.5534	−097.5862	Puebla
17.0897	−097.7413	Oaxaca	18.5773	−097.5801	Puebla
17.1211	−096.9777	Oaxaca	18.6709	−097.4690	Puebla
17.1216	−097.6194	Oaxaca	18.7701	−097.5362	Puebla
17.1274	−096.6950	Oaxaca	19.0366	−098.1133	Puebla
17.1646	−096.5809	Oaxaca	19.1500	−097.9300	Puebla
17.2200	−096.4356	Oaxaca	19.4829	−097.3678	Puebla
17.2200	−096.4356	Oaxaca	19.6721	−097.4565	Puebla

Latitude	Longitude	State
19.7029	−097.4971	Puebla
19.7066	−097.4808	Puebla
19.9465	−098.1171	Puebla
19.3400	−098.2500	Tlaxcala
19.3826	−098.3826	Tlaxcala
18.7265	−097.3179	Veracruz
18.7324	−097.3117	Veracruz
19.5389	−097.1663	Veracruz
19.5950	−097.1083	Veracruz
19.5997	−097.0990	Veracruz
19.6583	−097.0917	Veracruz