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Field observations on the salamanders (Caudata: Ambystomatidae, Plethodontidae) of Nevado de Toluca, Mexico

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Abstract. The salamander fauna of Nevado de Toluca, Estado de México, Mexico, is reviewed. Four species of salamanders have been reported from this volcano: *Ambystoma rivulare*, *Pseudoeurycea bellii bellii*, *P. leprosa* and *P. robertsi*. During three excursions in 2000, 2003, and 2006, the presence of all four species was confirmed. Observations on life history and possible intraspecific segregation between larval and adult *Ambystoma rivulare* are provided. *Pseudoeurycea leprosa* seems to have a surprisingly limited distribution on the volcano, possibly due to interactions with the larger *P. robertsi*. *Pseudoeurycea robertsi* revealed a much more variable colour pattern and a slightly larger elevational range than previously reported.

Key words. Amphibia, Ambystomatidae, Plethodontidae, *Ambystoma rivulare*, *Pseudoeurycea bellii*, *P. leprosa*, *P. robertsi*, Mexico, Nevado de Toluca.

Introduction

Regional studies on Mexican salamanders have mainly concentrated on mountain ranges in Veracruz and Oaxaca (e.g., Wake & Lynch 1976, Wake 1987). These areas are generally characterized by great species richness and high levels of endemism. In comparison, the central Mexican plateau is less species-rich and dominated by wide ranging species.

Rising to 4558 m above sea level the stratovolcano Nevado de Toluca, also known by the Nahuatl Indian name Xinantécatl, is the fourth highest peak in Mexico (De la Torre 1971). Located in the central sector of the Trans-Mexican volcanic belt, 22 and 81 km southwest of the cities of Toluca and Mexico, respectively, the volcano dominates the Upper Lerma basin. Nevado de Toluca is presently quiescent, and its latest major eruption has been dated to about 10,500 years B.P. (Arce et al. 2003). Despite easy access and close proximity to the cities of Toluca and Mexico, studies on the salamanders of Nevado de Toluca have been few and mostly anecdotal.

Presently, four species of salamanders are known from Nevado de Toluca. Taylor (1938) described *Oedipus robertsi* (= *Pseudoeurycea robertsi*) from the volcano, thus making it the first species recorded from the area. During the subsequent 45 years another three salamander species were added to the species list: *Pseudoeurycea bellii* by Taylor & Smith (1945), *Rhyacosiredon rivularis* (= *Ambystoma rivulare*) by Brandon & Altig (1973), and *Pseudoeurycea leprosa* by Lynch et al. (1983). Of these, only *P. robertsi* appears to be endemic to Nevado de Toluca.

The aim of the present work is to report new field observations on all four mentioned species and to compare them with already published data

Materials and methods

Study area

The study area comprised the western slopes of Nevado de Toluca extending from the summit in the east to the vicinity of the villages Raices in the north, Mesón Viejo in the

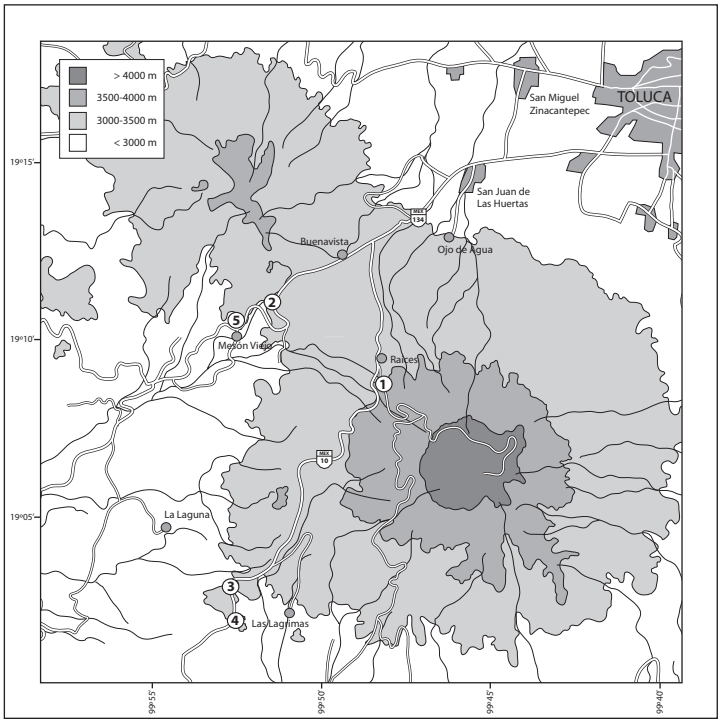

Fig. 1. Map of Nevado de Toluca. Numbers indicate the five localities mentioned in the text.

west, and Sabanillas in the south (Fig. 1). Although several localities were visited on the volcano, only the five localities where the presence of salamanders could be confirmed are included in this paper. With the possible exception of locality 5, all localities lie within the boundaries of the Parque Nacional Nevado de Toluca. They are described in more detail in Table 1.

Sampling methods

Field work was conducted on three excursions to the volcano on 17-18 July 2000, 31 July and 1 August 2003, and 11-12 August 2006, respectively. Salamanders were located by investigating potential cover objects during the day. As no collecting permits were available, no vouchers were collected. Instead relevant individuals were photographed for documentation. Species were identified by external morphology using literature sources (e.g., Taylor 1940, Lynch et al. 1983, Parra-Olea et al. 2005). Locality 2 was visited in 2000, locality 1 in 2000 and 2003, locality 3 in 2003 and 2006, locality 4 in 2003, and locality 5 in 2000 and 2006.

Measurements of living specimens were taken in the field using digital callipers (± 0.02 mm). Snout-vent length (SVL) equals the distance from the tip of the snout to the posterior margin of the vent. Temperature was measured to the nearest 0.1 °C with a digital thermometer fitted with a steel probe. Coordinates for each locality were taken with a Magellan 300 GPS receiver. Altitude was measured with an altimeter, which was calibrated daily. Altitudinal data were confirmed using the GPS coordinates on a topographic map (INEGI, Volcan Nevado de Toluca E14A47, 1:50,000).

Used institutional abbreviation: MVZ – Museum of Vertebrate Zoology, University of California, Berkeley.

Results and discussion

Species accounts

Ambystoma rivulare (Taylor, 1940)

Ambystoma rivulare was originally described from the Méxican side of the México-Michoacán state border. It was first recorded from Nevado de Toluca by Brandon & Altig (1973), who collected eggs, juveniles and adults in a cascading brook at an elevation of about 3500 m. More recently, the species has also been recorded from Michoacán (Moreno-Flores & Sánchez-Núñez 1997). A record from Sierra de Taxco, Guerrero, (Pérez-Ramos et al. 2000, Flores-Villela & Hernández-García 2006) needs to be verified.

In 2003, I observed three adults and numerous eggs and larvae in a small, slow-moving stream at locality 3. The stream was 60-100 cm wide with a water depth of 10-40 cm. The rocky bottom was covered with a layer of mud, varying in thickness from 0-5 cm upstream to 10-30 cm downstream. Only the upstream section had a scarce submersed vegetation. Water temperature was 10.9 °C, pH 6.7 and electric conductivity 69 μS cm^{-1}. The three adults were observed at ca. 17.30 h in a quiet pool in the upstream section of the stream (Fig. 2). All were resting at the bottom, but at the slightest disturbance hid under the stream banks. One of the adults was neotenous, the other two transformed. One reproductively active male measured 87.7 mm SVL and 86.2 mm TL. On land it was uniform coal black dorsally with a greyish venter. In the water, the adults appeared bluish grey. The black spotting and reticulations of the flanks, tail and venter reported by Tay-

Tab. 1. Details of the studied localities mentioned in the text.

Number	Locality	Habitat description
1	West facing slope along the dirt road to Parque de los Venados and the summit, ca. 1.5 km (by road) south of Raices, 3580 m elevation. 19°08'51" N, 99°48'06" W.	Open pine forest consisting exclusively of *Pinus hartwegii*, with a dense ground cover dominated by various bunchgrasses (*Muhlenbergia* spp.).
2	East facing slope along Highway 134 to Tejupilco de Hidalgo, ca. 4 km (by road) northeast of the village of Mesón Viejo, 3000 m elevation. 19°11'04" N, 99°52'01" W.	Dense forest dominated by fir (*Abies religiosa*) and with scattered stands of alder (*Alnus jorullensis*). Ground either bare or with a loose cover of grasses and ferns.
3	Narrow valley with a northwest-southeast orientation along the road between Raices and Sultepec de Pedro, ca. 0.5 km (by road) south of the village of Cajones. 2970 m elevation. No GPS data.	Mixed forest dominated by fir (*Abies religiosa*) but with a relatively high density of alder (*Alnus jorullensis*) and pines (*Pinus hartwegii* and *P. pseudostrobus*). Ground either bare or with dense patches of grasses and ferns.
4	A continuation of the valley of locality 3, here with a north-south orientation, along the road between Raices and Sultepec de Pedro, ca. 0.3 km (by road) south of the village of Sabanillas, 2930 m elevation. 19°02'09" N, 99°52'39" W.	Similar to locality 3.
5	South facing slope along Highway 134 to Tejupilco de Hidalgo, ca. 1 km (by road) north of the village of Mesón Viejo, 2890 m elevation. 19°10'35" N, 99°52'43" W.	Open forest dominated by fir (*Abies religiosa*) and alder (*Alnus jorullensis*) and with scattered stands of pine (*Pinus pseudostrobus*) and various oaks (*Quercus* spp.). Ground either bare or with a loose cover of grasses and ferns.

Fig. 2. Pool in the upstream section of the stream at locality 3. Adult *Ambystoma rivulare* were hiding under the stream banks. Eggs were scattered throughout the pool attached to submerged twigs and decomposing pine needles.

Fig. 3. Downstream section of the stream at locality 3. Larvae of *Ambystoma rivulare* were abundant on the muddy stream bottom. Eggs were found attached to the stream banks and to submerged twigs.

Fig. 4. Eggs of *Ambystoma rivulare* attached to pine needles at locality 3.

lor (1940), could not be discerned in any of the observed adults.

Larvae were only observed downstream (Fig. 3) from the adults. For each metre of the stream 1-3 larvae were seen resting on the muddy stream bottom, into which they would disappear, if disturbed. The larvae had a total length of ca. 6-8 cm. Dorsally the ground colour was pale to dark brown with varying extension of yellow spotting, from almost spotless to the spots being arranged into two distinct rows on each sides of the body. Ventrally the larvae were either uniform pale grey or with faint light spotting.

While adults and larvae appeared to be restricted to the upstream and downstream sections, respectively, eggs were distributed evenly throughout the stream. They were found to be in varying stages of devel-

Fig. 5. Juvenile *Pseudoeurycea bellii bellii* from locality 5.

Fig. 6. Portrait of adult *Pseudoeurycea leprosa* from locality 3.

opment, ranging from freshly laid to stages 41-42 (after Harrison 1969). The eggs were attached singly or in clusters of 3-7 to submerged twigs and pine needles (Fig. 4) or to the rocky stream banks just below the waterline. Eight eggs in the neurula stage had an outer diameter of 9.73 mm ± 0.29 (mean ± S.E.). The substantial variation in size was due to the highly variable gelatinous capsules surrounding the ova.

In 2006, neither adults nor larvae could be found in the stream. In the upstream section eggs were again found to be numerous and over all in slightly more advanced stages of development (stages 28-32, after Harrison 1969). Twelve eggs had an outer diameter of 9.91 mm ± 0.12 (mean ± S.E.). There was no significant difference between the medians of the outer egg diameter in the samples from 2003 and 2006, despite the difference in development ($U = 39.5$; $P > 0.05$, Mann-Whitney U-test).

Brandon & Altig (1973) found eggs of *A. rivulare* in March and May, which, combined with the observations reported here, suggests an extended breeding season. *Ambystoma rivulare* appears to select its egg deposition sites rather indiscriminately. Brandon & Altig (1973) reported eggs of *A. rivulare* attached individually but in a single cluster to the underside of a large rock and in water beneath a small overhanging bank where they were attached to rootlets. This is consistent with the observations made here, although loose rocks were not present in the stream at locality 3. Brandon & Altig (1973) did not provide measurements of the outer egg diameter, but the egg size reported here for *A. rivulare* resembles that of the two stream-breed-

Fig. 7. Adult *Pseudoeurycea robertsi* from locality 1 with a well-defined, brick red dorsal stripe.

ing Mexican ambystomatids *A. ordinarium* and *A. rosaceum*, i.e., 8.8-11.5 mm and 10-15 mm, respectively (Anderson & Worthington 1971, Anderson & Webb 1978).

Most remarkable is the apparent spatial segregation between adults and larvae, i.e., adults present only upstream and larvae only downstream. Lemos-Espinal et al. (1999) reported that when both large and small larvae of this species were kept for a short period of time in a small container the small larvae were preyed upon by the larger ones. A study of the canal, from which the larvae were taken, showed that large and small larvae occupied different areas, suggesting that cannibalism could be an important factor in the spatial distribution of larvae. Similarly, cannibalism might be the force segregating the larvae from the adults at locality 3. The presence of eggs throughout the stream contradicts this hypothesis, though, as adults must be present alongside the larvae at least for the duration of egg deposition. Adults might just prefer the upstream section during the day due to the superior cover of the overhanging stream banks compared to the mud of the downstream section but forage widely in the stream at night. The presence of larvae in only the downstream section might be attributable to larval drift.

Pseudoeurycea bellii bellii (Gray, 1950)
Pseudoeurycea bellii is one of the largest and most widespread Mexican salamanders occurring from the states of Sonora and Tamaulipas in the northwest and northeast, respectively, through central Mexico to Puebla and Guerrero in the east and southeast. Two subspecies are recognised, of which the nominate subspecies occurs at Nevado de Toluca (Parra-Olea et al. 2005).

A single specimen collected by H.M. Smith on 2 October 1939 from »Nevado de Toluca, Mexico« and mentioned by Taylor & Smith (1945) represents the first record of *P. bellii* on the volcano. Although *P. bellii* has subsequently been collected on Nevado de Toluca, few specimens are present in collections. The most recent specimens (MVZ 137865-137873, 137875-137876, 143803) were collected in 1976.

On 18 July 2000, I discovered a juvenile *P. bellii* (Fig. 5) underneath loose bark on a fir stump at locality 5. It had a SVL of 22.3 mm and a tail length of 11.5 mm. Dorsally it was coal black with two rows of small brick red spots and a red chevron shaped mark on the neck. Occipital spots were present. The spotting did not extend to the tail. The venter was uniform dark grey. Despite intensive effort, the juvenile of locality 5 was the only individual of *P. bellii* I was able to find on Nevado de Toluca.

Although *Pseudoeurycea bellii* has suffered a substantial decline in recent years (Stuart et al. 2008), the species is easily found where it is still common (pers. obs.). *Pseudoeurycea bellii* should be present at all five localities visited but as no additional individuals could be found, I consider it to be rare on the volcano. Due to the lack of data there are no grounds for talking about a population decline of the species, though.

Pseudoeurycea leprosa (Cope, 1869)
Pseudoeurycea leprosa is a wide-ranging species, known from western Estado de México and east to western Puebla and central Veracruz. It has had a confusing taxonomic history, which is not yet resolved (e.g. Lynch et al. 1983, Highton 2000). So far, no taxonomic review has included populations from Nevado de Toluca.

The presence of *P. leprosa* on Nevado de Toluca was mentioned in a figure legend in Lynch et al. (1983). The record was based on specimens now in the collection of the Academy of Sciences of Philadelphia, but the notes with the exact catalogue numbers are now, unfortunately, lost (D. Wake, pers. comm.). Apparently, the specimens were never officially recorded as *P. leprosa* and no specimens of *P. leprosa* from Nevado de Toluca are on record in the collection of the Academy of Sciences of Philadelphia (N. Gilmore, pers. comm.). No reports of *P. leprosa* from Neva-

do de Toluca have appeared since Lynch et al. (1983) and it has apparently not since been collected on the volcano.

Seven individuals of *P. leprosa* were found at locality 4 on 1 August 2003. No *P. leprosa* could be found at locality 3 in 2003, but on 11 August 2006 six individuals (Fig. 6) were discovered. All were hiding underneath loose bark on fallen logs and stumps often together with individuals of *P. robertsi*. At both localities, *P. robertsi* outnumbered *P. leprosa* by about 5:1. Coloration was markedly consistent in the seven individuals. Dorsally they were blackish brown with purplish to rusty brown vermiculate markings. Ventrolaterally they had a greyish silvery band. The venter was uniform greyish black with a light grey chin region. This easily separated them from syntopic *P. robertsi*, a species in which the chin is always dark. Additionally, *P. leprosa* is smaller and more slender than the robust *P. robertsi*.

The apparently very limited distribution of *P. leprosa* on Nevado de Toluca is surprising, as this is usually a very abundant and ubiquitous species throughout its range. The most obvious explanation is exclusion by the larger *P. robertsi*. It is notable that the localities at which *P. leprosa* was discovered are also the lowest localities at which *P. robertsi* was found. These localities must, therefore, lie near the lower limit of the elevational range of *P. robertsi*. If exclusion is the factor limiting its elevational range on Nevado de Toluca, *P. leprosa* would be expected to occur only at elevations below ca. 3000 m.

Pseudoeurycea robertsi (Taylor, 1938)

This is the only salamander species endemic to Nevado de Toluca. It is most closely related to *Pseudoeurycea altamontana* and *P. longicauda* (Parra-Olea 2002) but its habits remain poorly known.

Of the four salamander species occurring on Nevado de Toluca, *P. robertsi* (Fig. 7) is by far the most abundant. I found it at all included localities except the lowest, i.e., locality 5. Individuals were found under rocks and logs as well as under loose bark of fallen logs and stumps. At most localities it was very common. An exception was locality 1. Here it was relatively common in 2000 but despite favourable conditions I was unable to find any individuals there in 2003.

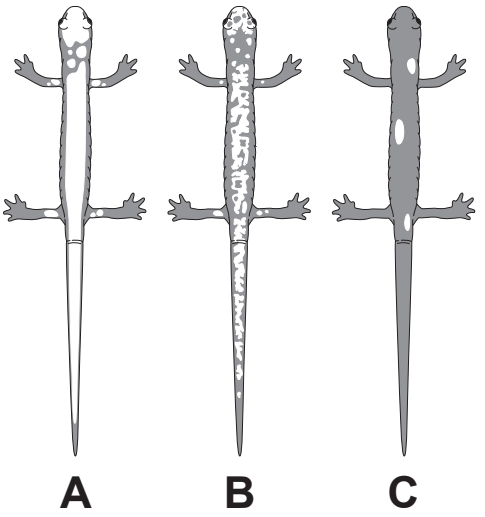

Fig. 8. Schematic drawings of the variation in dorsal pattern of *Pseudoeurycea robertsi*. (A) Well-defined dorsal stripe. Predominant pattern on locality 1 and 2. (B) Dorsal mottling. Predominant pattern on locality 3 and 4. (C) Almost patternless with few scattered spots. Rare pattern on locality 4.

Pseudoeurycea robertsi is generally thought to possess a relatively constant colour pattern. In his diagnosis Taylor (1938) simply notes that it has »a broad, orange stripe on the back and tail«. Later, his description got slightly more detailed, adding that the »broad dorsal stripe varies from dull orange to orange-brown« (Taylor & Smith 1945). Even Lynch et al. (1983) concurred that »a striking tan to red-brown dorsal stripe is invariably present«. My observations on *P. robertsi* show a much more variable pattern than indicated by these authors, especially at lower elevations. Not only did colour pattern vary much more than previously reported, however, it was apparently also correlated with elevation, i.e., individuals from high elevations possessed a very constant pattern, whereas

individuals from lower elevations exhibited a high degree of variability.

At locality 1 all individuals possessed a broad orange-red to brick red dorsal stripe (Fig 8A). A few lateral spots of varying size were present in most individuals. Somewhat lower, at locality 2, the pattern was consistent with that of locality 1, but the colour of the dorsal stripe and the lateral spots was much more variable, ranging from a dirty yellow to tan, orange and brick red. At locality 3 and 4 the colour remained variable but here even the pattern began to break up. This was most pronounced at locality 4 where the pattern ranged from a broad, unbroken dorsal stripe through dense dorsal mottling (Fig. 8B) to almost patternless with just 3-4 spots scattered on the dorsal and lateral surfaces (Fig. 8C).

Although present in more open areas, *P. robertsi* appears to reach its highest abundance in dense, humid forest. Its elevational range was observed to be slightly larger than previously reported, i.e., ca. 2900-3600 m a.s.l. Within these limits it is expected to occur throughout the volcano where forest is still present.

Concluding remarks

Continued and more detailed studies of the salamanders of Nevado de Toluca than has been presented here are necessary to extend our knowledge of these fascinating and possibly threatened animals. Collecting has mainly focused on the upper northwestern slope of the volcano and the distributional patterns of the four salamander species elsewhere on the volcano remain completely unknown. Additionally, the segregation observed between adults and larvae of *Ambystoma rivulare* and the interspecific interactions between *Pseudoeurycea leprosa* and *P. robertsi* deserve scientific attention.

Two other salamander species might occur on Nevado de Toluca, but their presence has yet to be confirmed. No records of *Ambystoma altamirani* have ever been published. Nevertheless, four specimens in the collections of the Museum of Vertebrate Zoology (MVZ 36609-36612), collected by Seth B. Benson in 1940 from »Ojo de Agua, NW slope Nevado de Toluca«, indicate, at least, a previous occurrence on the volcano. Although I had no opportunity to visit the village of Ojo de Agua, it seems unlikely that *A. altamirani* still persists here. Almost all of the northern and eastern slopes of the volcano are completely deforested, leaving little chance for a continued existence of salamanders. As the volcano is in close proximity to its known distribution elsewhere the presence of *A. altamirani* on the northern slopes of Nevado de Toluca would not be surprising, though, and should be expected, if suitable habitat can be found.

Ambystoma ordinarium has been reported from localities both to the west, east and north of Nevado de Toluca (Matias-Ferrer & Murillo 2004). It is most likely that this species also occurs in the southern portions of the volcano and it should be searched for in these areas.

Like most Mexican national parks Nevado de Toluca is not well protected. The main threat is logging and subsequent conversion of the forest to agriculture. Signs of this appear throughout the park, most notably on the northern and eastern slopes which are now almost completely deforested. Although all the salamander species occurring there appear to tolerate some degree of disturbance, the impact and its effect on these populations should be monitored closely. Also, a real effort should be made to reduce or possibly stop logging within the confines of the park. The overall decline observed in Latin American salamanders has apparently not yet affected the species of Nevado de Toluca, but particular care should be taken to ensure their continued existence. Nevado de Toluca and its surroundings were declared a national park in 1936 and have remained so ever since. The opportunity to conserve this valuable area, so close to the capital cities of Mexico and Toluca, seems to be an obtainable goal and should not be missed.

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