Herpetology Notes 19: 51–53, published on 4 February 2026

Caudal regeneration in introduced and native populations of the Italian Wall Lizard, *Podarcis siculus* (Rafinesque-Schmaltz, 1810), in California, USA, and Taormina, Italy, with reports of tail bifurcation

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Caudal autotomy is a predator avoidance strategy used by at least 130 species in the Lacertidae family (Arnold, 1984). Though rates of tail loss can be used to gain insight into prey-predator interactions in this family of lizards (Pafilis et al., 2009; Brock et al., 2015; Fernández-Rodríguez and Braña, 2022), many factors complicate the interpretation of tail loss data. For example, habitat and sex impact the frequency of autotomy with individuals located in more exposed microhabitats having higher instances of tail loss, and in some species, males have more frequent tail loss than females due to greater intraspecific conflict (Bateman and Fleming, 2008). Tail loss as a predator avoidance strategy comes with many costs such as decreases in important aspects of locomotor performance (decreases in running speed, decreased endurance, and increased frequency of pauses while running etc.), the loss of a social signalling tool which can lead to reduced fitness, and the metabolic cost of replacing tissue during subsequent tail regrowth (Vitt et al., 1977; Bellairs and Bryant, 1985; Martin and Salvador, 1993 a, b; Martin and Avery, 1998; Langkilde et al., 2005; Cromie and Chapple, 2012; Eberle et al., 2022). During regrowth, the tail is replaced by a cartilaginous replicate which, in some species such as *Podarcis siculus* (Rafinesque-Schmaltz, 1810), has a distinct visual aspect (e.g., concolor), making it easy to determine where regeneration has occurred along the tail (Barr et al., 2019).

Italian Wall Lizards (*Podarcis siculus*) can autotomise their tails to escape threatening situations. *Podarcis siculus* is a diurnal lizard native to the Italian peninsula and islands in the Adriatic Sea (Corti and Lo Cascio, 2002). This species has been introduced to new ecological and predation regimes across the globe (Kolbe et al., 2012). In 1994, an individual introduced seven lizards from Taormina, Italy to the San Pedro Area in Los Angeles, California (Oskyrko et al., 2022; Gangloff et al., 2025). Since their original introduction, the population has rapidly grown and spread across urban San Pedro (Deitchsel et al., 2010). During data collection for projects in 2013, 2014, and 2022-2025, we opportunistically lassoed lizards in an introduced population in San Pedro, California, and, in 2022 and 2025, from their source population in Taormina, Italy. We noted if adult individuals (snout-vent length, SVL > 50 mm) had experienced an incidence of tail loss and we weighed all individuals to the nearest 0.001 gram using a digital scale. We also determined the sex of all individuals, females were identified by the absence of hemipenes and femoral pores and the presence of slimmer heads, a thinner base of the tail, and egg follicles. In San Pedro, 78.5% of 548 individuals had regrown tails, and in Taormina 73.7% of 133 individuals had regrown tails. Both populations had higher percentages of tail loss as compared to individuals in an introduced population of a closely related species, *Podarcis muralis* (Laurenti, 1768), located in Cincinnati, Ohio (56.6%; Head et al., 2024). This may suggest that both populations of *P. siculus* face more inter- or intra- specific conflict compared to this population of *Podarcis muralis* (Pafilis et al., 2009; Brock et al., 2015; Fernández-Rodríguez and Braña, 2022). This could also suggest differing age structures between populations with these populations of *P. siculus* being made of older lizards who are more likely to have experienced instances of tail loss.

We examined factors influencing rates of autotomy in *P. siculus* located in the introduced population in San

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Figure 1. Image of female *Podarcis siculus* with bifurcated tail captured on 2 May 2025.

Pedro and the native population in Taormina. We ran all analyses in RStudio using R version 2024.04.1 (R Core Team, 2024). We found that removing all interactions, and weight as a predictor had non-significant effects on the model (removal of all interactions $p = 0.2159$; removal of weight as a predictor $p = 0.7759$). Our final General Linearised Model (GLM) had a binomial response (regrown/missing or original tail), and SVL, population, and sex as predictor variables. Our final GLM included individuals collected from San Pedro and Taormina, Italy in 2025 ($n = 308$; $n = 63$). We analysed our model using a type III ANOVA from the *car* package to account for the different sample sizes between populations (Fox and Weinberg, 2019). SVL showed a non-significant impact on the probability of tail loss ($\chi^2 = 3.22$, $df = 1$, $p = 0.073$) where larger individuals tended to have higher probability of experiencing tail loss ($\beta = 0.05405$ +/-0.030 SE). The non-significant effect of SVL on the probability of tail loss is similar to data collected in Tuscany, Italy in native populations of *P. siculus*, and counter what has been found in introduced populations of *P. muralis* in Cincinnati, Ohio and on Vancouver Island, Canada (Allan et al., 2006; Biaggini et al., 2009; Head et al., 2024). Individuals from San Pedro showed higher probability of tail loss compared to lizards from Taormina ($\chi^2 = 6.21$, $df = 1$, $p = 0.0127$, $\beta = –1.05 \pm 0.41$ SE). Females had an increased likelihood of tail loss than males ($\chi^2 = 11.24$, $df = 1$, $p = 0.0008$, $\beta = -1.43 \pm 0.44$ SE). Previous work on the agamid lizard *Psammophilus dorsalis* (Gray, 1831) has shown a significant difference in rates of tail loss between sexes, but counter to our findings, males exhibited higher rates of tail loss than females in that study population (Balakrishna et al., 2021). Sex was not a significant predictor of tail loss in populations of *P. muralis* in Cincinnati Ohio and *P. siculus* in Tuscany, Italy (Biaggini et al., 2009; Head et al., 2024).

After an incidence of tail autotomy, abnormalities in the tail regrowth process can lead to the presence of two separate tail tips, called tail bifurcation. Reports of bifurcation are more common in anthropophilic lizards, especially European lacertids compared to other squamate families (Baum and Kaiser, 2024). There have been reports of tail bifurcations and trifurcations in native populations of *Podarcis melisellensis* (Baeckens et al., 2018), *Podarcis erhardii* (Brock and Belasen, 2014), and *Podarcis muralis* (Sorlin et al., 2019) as well as in introduced urban population of *Podarcis muralis* (Head et al., 2024). To our knowledge, there has been only one report of tail bifurcation in a native population of *Podarcis siculus* and no reports in an introduced population (Tofohr, 1905). Conditions faced by species in introduced populations, such as novel selective pressures, may shift anti-predator behaviours and the physiological processes of tail regeneration, which may impact tail autotomy and the rates of tail bifurcation, respectively (Balakrishna et al., 2021).

Because of the relationship between tail autotomy and tail bifurcation, we are also reporting the first incidences of tail bifurcation in the introduced population of *P. siculus* in San Pedro, Los Angeles. On 2 May 2025, we caught an individual with a bifurcated tail in a yard on mulch substrate (33.7147ºN, -118.3087ºW). The individual appeared to be in a good physical state with no obvious injuries. The fact that this individual was gravid suggests that the bifurcation of the tail did not prevent reproduction. The root of the tail was 86.18 mm and the two bifurcated branches were 35.36 mm and 53.53 mm. We caught an additional male individual with a bifurcated tail on 5 August 2025. Including both individuals, the rate of tail bifurcation from 2022 to 2025 seen in captured individuals ($n = 308$) is 0.65%. This is slightly higher than the rate of tail bifurcation and trifurcation reported in an introduced North American population of *Podarcis muralis* which is also located in an urban setting (0.4%; Head et al., 2024). Because reports of tail bifurcation are rare, little is known about potential effects it may have on the

fitness of an individual. Given this gap in the literature, it is unclear if individuals that possess tail regrowth anomalies such as bifurcations suffer a reduction in fitness and are therefore quickly eliminated from the population or if the specific conditions that cause tail bifurcation are rare.

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Accepted by Arnaud Badiane