

Caudal regeneration in the invasive Common Wall Lizard, *Podarcis muralis* (Laurenti, 1768), in Ohio, USA, with a report of a rare tail trifurcation

Alyssa Head¹, Ali Amer², Emma G. Foster¹, Logan Fraire¹, Ethan H. Livingston¹, Maya M. Moore¹, and Eric J. Gangloff^{1,*}

Caudal autotomy is a strategy employed by numerous lizard species as a predator avoidance mechanism (Arnold, 1984). Therefore, data on rates of caudal autotomy in lizards can give insight into prey-predator interactions. However, interpreting rates of caudal autotomy can be convoluted. For example, tail loss can be due to greater susceptibility to predation, varying predator efficiency, or differing behaviours of the prey species, which may allow escape through autotomy. Additionally, predator avoidance strategies may differ between sexes or among age classes, which further complicates data interpretation (reviewed by Bateman & Fleming, 2009).

Caudal autotomy is used by the Common Wall Lizard, *Podarcis muralis* (Squamata: Lacertidae), a diurnal lizard that originates in Europe. This species is a successful global colonizer that has established populations across the city of Cincinnati, Ohio, USA, over the past 70 years and was recently reported in Columbus, Ohio, USA (Davis et al., 2021). In our ongoing research on these populations, we have captured 500 unique lizards (SVL range 30.5–75.2 mm) since 2020 in these Ohio populations, 56.6% of which exhibited missing or regenerated tails. All statistical analyses were conducted in the Programming Language R (R Core Team, 2022). To test the effect of body size on the probability of an animal having a regenerated tail, we used a generalized linear model, with binomial response and snout–vent length as the predictor. Larger and therefore generally older animals were more likely to have injured (missing

or regenerated) tails (generalized linear model, estimate $\pm$ SE: 0.054 ± 0.011 , $Z = -4.81$, $p < 0.0001$). This observation is concordant with a similar pattern observed in established populations of *P. muralis* on Vancouver Island, Canada, where larger lizards were more likely to exhibit regenerated tails (Allan et al., 2006). Among adult animals (SVL > 50 mm, $n = 424$), the incidence of injured tails did not differ between males and females (59.6% of males vs. 60.2% of females; $\chi^2 < 0.0001$, $p = 0.98$). This observation is counter to previous work on the lizard *Psomophis dorsalis*, whereby males in urban habitats exhibited higher rates of tail loss compared to females (Balakrishna et al., 2021). In the more recently established and isolated population in Columbus, significantly fewer adult individuals exhibited injured tails (63.0% in Cincinnati vs. 21.9% in Columbus; $\chi^2 = 19.17$, $p < 0.0001$), suggesting that either this population is under reduced predation threat or that tail autotomy is a less effective predator-avoidance strategy (that is, lizards being predated are eaten rather than escaping).

During the regeneration process, morphological anomalies can appear, such as the observed polyfurcation of the tail (Fig. 1). Tail bifurcation has been reported in *P. muralis* across their native European range (e.g., Strijbosch, 1999; Pola and Koleska, 2017; Sorlin et al., 2019; Fernández-Fernández, 2020); additionally, there is a single report of a tail trifurcation in a *P. muralis* individual from Croatia (Badiane, 2017). However, outside their historic range, where both anti-predator behaviours and physiological processes of regeneration may have shifted due to novel selective pressures (Balakrishna et al., 2021), there are no previous records of tail bifurcation or trifurcation in populations of *P. muralis*.

We have observed only one incidence of tail bifurcation and one incidence of tail trifurcation in Ohio populations of *P. muralis* (0.4% of the total sample), suggesting that such abnormalities are especially rare.

¹ Department of Biological Sciences, Ohio Wesleyan University, 61 South Sandusky Street, Delaware, Ohio 43015, USA.

² Department of Biological Sciences, Auburn University, 101 Rouse Life Science Building, Auburn, Alabama 36849, USA.

* Corresponding author. E-mail: ejgangloff@owu.edu



Figure 1. The trifurcated tail of a male *Podarcis muralis*, nicknamed “Mike Trison”, in Cincinnati, Ohio, USA on 12 June 2023. Photo by Alyssa Head.

This value is comparable to the number of animals with bifurcated tails reported from populations in the native range in France ($< 0.2\%$; Sorlin et al., 2019). Oddly, both individuals we encountered were found on the same day, 12 June 2023, in Cincinnati, Ohio, USA. At 12:19 h, we caught an adult male (SVL 55.0 mm, head length 16.7 mm; weight 6.9 g) that exhibited a tail trifurcation at the caudal extremity (as opposed to a pronounced tail split at the base of the tail; Fig. 1). The individual appeared to be in good physical state with no obvious injuries. The lizard was caught using a looped filament at a site along a busy road characterized by rocky walls behind mixed vegetation (39.0927°N, 84.5620°W, elevation 158 m). Later that afternoon, at 15:46 h, we caught an adult male (SVL 55.7 mm, head length 15.0 mm, weight 5.3 g) with a bifurcated tail at a nearby city park (39.0933°N, 84.5642°W, elevation 244 m). Again, this individual appeared to be in good health. After processing the animals, both were released at the location of initial capture. Almost nothing is known about the effects of supernumerary tails; it is possible the rare presence of supernumerary tails could be a result of affected individuals being eliminated from the population due to detrimental effects (Barr et al., 2020). Alternatively, the specific conditions that cause tail bi- or trifurcation could be rare (Henle and Grimm-Seyfarth, 2020).

Acknowledgements. All research was conducted under Ohio Division of Wildlife Wild Animal Permit (SC220002) and all procedures were approved by Ohio Wesleyan University IACUC

(12-2020-02). This material is based upon work supported by the National Science Foundation under Award No. 2217826 (BRC-BIO to EJG).

References

- Allan, G.M., Prelypchan, C.J., Gregory, P.T. (2006): Population profile of an introduced species, the common wall lizard (*Podarcis muralis*), on Vancouver Island, Canada. *Canadian Journal of Zoology* **84**(1): 51–57.
- Arnold, E.N. (1984): Evolutionary aspects of tail shedding in lizards and their relatives. *Journal of Natural History* **18**(1): 127–169.
- Badiane, A. (2017): Trifurcation caudale chez le lézard des murailles *Podarcis muralis* (Laurenti, 1768) (Squamata: Lacertidae). *Bulletin de la Société Herpétologique de France* **163**: 106–107.
- Balakrishna, S., Amdekar, M.S., Thaker, M. (2021): Morphological divergence, tail loss, and predation risk in urban lizards. *Urban Ecosystems* **24**(6):1391–1398.
- Barr, J.I., Somaweera, R., Godfrey, S.S., Gardner, M.G., Bateman, P.W. (2020): When one tail isn’t enough: abnormal caudal regeneration in lepidosaurs and its potential ecological impacts. *Biological Reviews* **95**(5): 1479–1496.
- Davis, J.G., Ferner, J.W., Krusling, P.J. (2021): Common Wall Lizard, *Podarcis muralis* (Laurenti 1768). In: *Reptiles of Ohio*, p. 317–334. Davis, J.G., Lipps, G.J., Jr., Wynn, D., Armitage, B.J., Matson, T.O., Pflingsten, R.A., Caldwell, C., Eds., Columbus, Ohio, USA, Ohio Biological Survey.
- Fernández-Fernández, D. (2020): Cola bífida en *Podarcis muralis* (Laurenti, 1768) *Boletín de la Asociación Herpetológica Española* **31**(1): 26–282.
- Henle, K., Grimm-Seyfarth, A. (2020): Exceptional occurrences of double, triple and quintuple tails in an Australian lizard community, with a review of supernumerary tails in natural populations of reptiles. *Salamandra* **56**(4): 373–391.

- Pola, L., Koleska, D. (2017): Tail bifurcation in Common Wall lizard (*Podarcis muralis* Laurenti, 1768) from Liguria, Italy. In: 9th Workshop on Biodiversity, July 8–9 2017, p. 93–97. Minář, J., Litvinec, A., Eds., Prague, Czech Republic, Czech University of Life Sciences Prague.
- R Core Team (2022): R: A language and environment for statistical computing. Vienna, Austria, R Foundation for Statistical Computing.
- Sorlin, M., Gangloff, E.J., Kouyoumdjian, L., Cordoer, G.A., Darnet, E., Aubret, F. (2019): Natural history notes. *Podarcis muralis* (Common wall lizard). Tail bifurcation. Herpetological Review **50**(2): 377.
- Strijbosch, H. (1999): Doppelschwänze bei europäischen Lacertiden. Die Eidechse **10**: 1–7.