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Malformations in the critically endangered gecko *Phyllodactylus sentosus* Dixon & Huey, 1970 in Peru

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The scientific documentation of malformations in reptiles has increased in recent years, possibly due to increased reporting effort and growing scientific interest (Dillenburg et al., 2024). Although no causal evidence for these events has been discovered, it is logical to assume that environmental and/or genetic factors play an important role in their incidence (Bellairs, 1981; Gibbons et al., 2000; de Carvalho et al., 2020), thus recording these anomalies should contribute to a better understanding of the conservation status of the affected species (Bateman et al., 2022). Several types of malformations have been reported in the suborder Gekkota, such as tail bifurcation (e.g., Yankanchi and Kumbar, 2016; Maria and Al-Razi, 2018; Koleska, 2018; Bhattarai et al., 2020; Khandakar and Sultana, 2020), which consists of the appearance of at least one additional tail during the regeneration of an affected portion, usually caused by external factors such as predator attacks or fights between individuals (Meyer et al., 2002). Cases of polydactyly (the presence of additional digits, e.g., De Andrade et al., 2015; Chukwuka et al., 2021) and ectrodactyly (the absence of one or more digits, e.g., Sanches et al., 2017) have also been reported (e.g., Rothschild et al., 2012), with improper incubation temperature, embryonic anoxia, or genetic anomalies being possible causes (Bellairs, 1981; Frye, 1991). In other suborders, such as Autarchoglossa and Iguania (e.g., Kolenda et al., 2017; Mora, 2020), cases of ectomelia have been reported, including amelia (complete absence of the limb), hemimelia (defective limbs, especially in their distal parts), and meromelia (total absence of digits) (Rothschild et al., 2012).

The Lima Leaf-toed Gecko, *Phyllodactylus sentosus* Dixon & Huey, 1970, is a small reptile endemic to the Peruvian coastal desert, categorised as Critically Endangered (CR) following criteria of the IUCN Red List of Threatened Species (Pérez and Balta, 2016). This gecko species is nocturnal and is characterised by its low dispersal ability and low reproductive rate (Dixon and Huey, 1970). It inhabits arid environments with sandy substrates lacking vegetation and use shelters usually formed by cracks in the ground or stacked rocks, which allow the gecko to protect itself from the sun, wind, and predators (Fernández-Rodríguez, 2019).

The distribution of *P. sentosus* is restricted to a few localities, mainly within the city of Lima (Dixon and Huey, 1970; Icochea, 1998; Perez and Balta, 2016). These localities act as islands separated by urban development, which prevents the exchange of individuals between populations, leading to positive inbreeding rates, low genetic diversity, and marked population structuring (Esteves-Ramírez, 2022; Arana et al., 2023). Additionally, there are external threats such as waste disposal, which restricts the suitable microhabitat of *P. sentosus*, the presence of predators (Pérez and Balta, 2016), and invasive species like *Phyllodactylus reissii*, which may potentially compete with *P. sentosus* (Arana, 2021). A recent population viability analysis showed the critical state of this species (Arana et al., 2023), indicating some evaluated populations could go extinct within the next ten years.

Here, we report multiple malformations for *Phyllodactylus sentosus* from two localities in the city of Lima, Peru: Universidad Nacional Mayor de San Marcos (UNMSM) (12.0595°S, 77.0860°W, elevation 85 m) and Parque de las Leyendas (PL) (12.0669°S, 77.0927°W, elevation 48 m). As part of a long-term monitoring project for the species, eleven nocturnal sampling events were conducted, at a monthly interval from November 2021 to September 2022, between

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19:00–23:00 hrs at each locality (Fig. 1). Each event consisted of six consecutive sampling nights (three nights per locality), with a sampling effort of 16 man-hours per night. During this time, observed individuals were captured, photographs of the identified malformations and entire individual were taken for posterior analysis, and they were subsequently released. To identify recaptures, individuals were marked by toe clipping following the protocol of Ferner et al. (1979). No individuals were collected.

Overall, a total of 480 sampling hours were conducted per locality. During this period, 297 individuals of *Phyllodactylus sentosus* were recorded at Universidad Nacional Mayor de San Marcos (UNMSM), of which three individuals showed malformations (1.01%). At Parque de las Leyendas (PL), 212 individuals were recorded, among which two exhibited malformations (0.94%). In total, six cases of malformations were observed: two cases of tail bifurcation, two of hemimelia, one of ectrodactyly, and one of polydactyly, with one individual presenting two malformations (Table 1, Fig. 2). The prevalence of malformations in *P. sentosus* populations (1.01% at UNMSM and 0.94% at PL) is higher than that reported for other lizards like *Ctenotus fallens* and *Tropidurus etheridgei*, which showed rates of 0.12% and 0.5%, respectively (Pelegrin, 2007; Bateman et al., 2022). However, these levels are likely underestimated, as studies examining the prevalence of malformations from birth in *Crotalus durissus* and *Bothrops jararaca* have reported much higher rates, reaching up to 11.1% (Sant'Anna et al., 2013). This suggests that malformations may negatively affect the survival of newborns, which is particularly concerning given that *P. sentosus* clutches contain a maximum of two eggs (Sánchez et al., 2022).

The origin of recorded malformations in reptiles could be varied (de Carvalho et al., 2020). For example, it is likely that tail bifurcation is mediated by poor tail regeneration caused by inter or intraspecific aggression (Meyer et al., 2002), as has been recorded for *P. sentosus* by Valdez and Cossios (2017). The likelihood of intraspecific aggression within the studied *P. sentosus* populations might be higher considering that this species is territorial and the high population densities at studied populations in restricted areas with limited resources (J. Ormeño unpubl. data), similar to what has been documented in insular species such as *Podarcis*

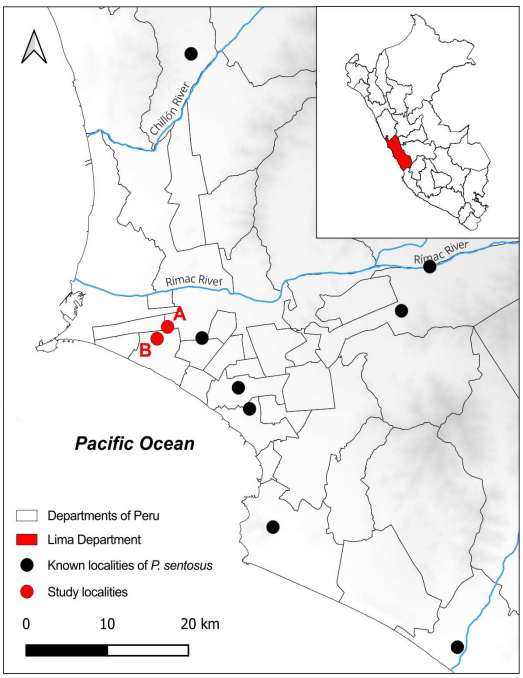

Figure 1. Distribution of *Phyllodactylus sentosus* in Lima, Peru, represented by black circles, with the localities evaluated in this study highlighted in red: (A) Universidad Nacional Mayor de San Marcos (UNMSM); and (B) Parque de las Leyendas (PL).

Table 1. Characteristics and malformations recorded in five individuals of *Phyllodactylus sentosus*. Abbreviations: SVL: Snout-vent length; UNMSM: Universidad Nacional Mayor de San Marcos; PL: Parque de las Leyendas.

Stage	Sex	Locality	SVL (mm)	Body weight (g)	Malformation	Observations
Adult	Male	UNMSM	52.0	3.6	Tail bifurcation	Regenerated tail
Adult	Female	UNMSM	53.1	3.0	Hemimelia in the right hind limb	-
Juvenile	-	UNMSM	28.5	0.4	Polydactyly in both forelimbs	-
Adult	Female	PL	50.3	3.2	Hemimelia in the right forelimb, Ectrodactyly in the left hind limb	-
Adult	Female	PL	61.1	5.8	Tail bifurcation	Regenerated tail

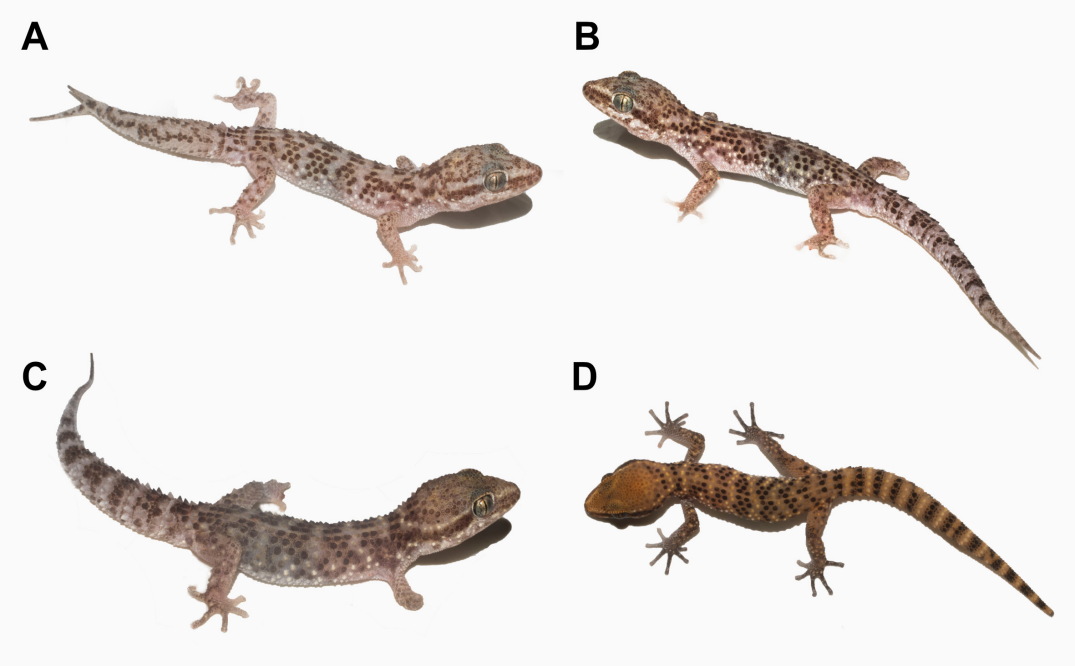

Figure 2. Individuals of *Phyllodactylus sentosus* with malformations: (A) bifurcation of the tail, (B) hemimelia in the right hind limb, (C) hemimelia in the right forelimb accompanied by ectrodactyly in the left hind limb, and (D) polydactyly in both forelimbs. Missing toes on the right limb of individual A and on the left fore-and hind limbs of individual B resulted from the marking methodology. Photos by Jesús R. Ormeño.

gaigeae and *Mediodactylus kotschyi* (Cooper et al., 2015; Itescu et al., 2017).

The individuals of *P. sentosus* recorded with ectomelia, ectrodactyly, and polydactyly did not show any signs of external origin (e.g., no presence of scar tissue or completely regenerated tails), leading to the suspicion that these malformations may have a genetic origin, likely stimulated by elevated levels of inbreeding and low genetic diversity within both populations (Esteves, 2022; Arana et al., 2023). It is important to mention that inbreeding is a key factor contributing to the occurrence of malformations in reptiles (Olsson et al., 1996). The impact of malformations on the fitness of reptiles, and in particular on *Phyllodactylus sentosus*, has not been evaluated. The tail, toes, and limbs play vital roles in locomotor performance in geckos (Marcellini, 1977; Medger et al., 2008; Bateman and Fleming, 2009), and the recorded malformations significantly change the structure of these body parts, which would likely have detrimental effects on the survival of the affected individuals. However, the fact that five individuals were found actively moving and in good health, with weights proportional to their size (Table 1), suggests otherwise.

Only two cases of tail bifurcation have been formally documented in Peru, for *Caiman crocodilus* and *Stenocercus ornatissimus* (Henle and Grimm-Seyfarth, 2020; Baum and Kaiser, 2024). Additionally, an ocular malformation has been reported in *Corallus batesii* (Reyes-Lizárraga et al., 2024). This study adds *Phyllodactylus sentosus* as an additional species, increasing the number of species with reported malformations in Peru to four. Additional studies (e.g., ecological, molecular, and physiological) are recommended to precisely identify the factors contributing to the occurrence of these anomalies and to assess their impact on the survival and performance of *P. sentosus*. Understanding the origin and effect of malformations is not only essential to improve conservation strategies for this critically endangered species, but also provide valuable insights into the overall health of reptile populations in similar environments.

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