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A most unusual tail: Scoliosis in a wild Australian skink, and reported incidences and suggested causes of similar malformations amongst squamates

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Abstract Malformations of vertebrae potentially occur across many taxa, particularly in Testudines, which are susceptible to kyphosis (dorsoventral curvature of the spine). Such malformations may stem from either genetic or environmental origins, and their prevalence and associated impacts on survival remain poorly understood. However, scoliosis (sideways curvature of the spine) is rarely reported and especially so in wild lizards. We report here on the first known case of scoliosis in a wild Australian lizard, the skink *Ctenotus fallens*, from Perth, Western Australia. This occurrence is the first of 805 individuals captured in a natural population monitored annually for the past 11 years. Reporting and monitoring of the frequency of such abnormalities may be a useful indicator of environmental change-induced impacts on populations.

Key words: abnormality, lizard, reptile, scoliosis.

Documenting abnormalities in reptiles is an important contribution to the state of knowledge of this diverse group, given concern over global reptile declines (Gibbons *et al.* 2000). Poor environmental health, including pollution, has been linked to genetic, physiological and physical abnormalities in reptiles (Gibbons *et al.* 2000). We report here on an observed abnormality in the West Coast Ctenotus (*Ctenotus fallens*), a common skink found along the west coast of Western Australia, with a snout-vent length (SVL) ranging from 35 to 95 mm (Storr *et al.* 1999). This species is mostly confined to bushland but tolerates some parks and gardens in the urban matrix (How and Dell 1994, 2000; How 1998; Bamford & Calver 2012). Krawiec *et al.* (2015) suggest that patterns of gene flow in this species show evidence of its dispersal through the urban matrix.

In July 2021, a sub-adult specimen with an estimated SVL of 65 mm was uncovered during garden work near the Biodiversity Conservation Centre in Kings Park, central Perth, WA. The skink's tail was intact, showing no sign of autotomy and regeneration but did demonstrate caudal scoliosis (lateral curves of the spine) with nine distinct lateral curves (Fig. 1). The skink showed no signs of scoliosis in the precaudal vertebrae, nor any signs of kyphosis (vertical displacement or curves of the vertebrae). The skink seemed otherwise active and was promptly released once photographed.

This observation appears to be the first reported case of scoliosis in a wild Australian lizard; however, malformations of vertebrae in reptiles are apparently frequent across many taxa, particularly in Testudines (Rothschild *et al.* 2013), which are susceptible to kyphosis. Amongst the Squamata, kyphosis and scoliosis have been reported from the lizard families Scincidae, Tropiduridae, Iguanidae, Liolaemidae, Agamidae, Lacertidae, Phrynosomatidae, Geckonidae, Dactyloidae and Chamaeleonidae, and from the snake families Colubridae and Viperidae (Table 1).

Such malformations may stem from either genetic or environmental origins. Idrisova (2018) showed that hatchlings of both grass snakes (*Natrix natrix*; Colubridae) and sand lizards (*Lacerta agilis*; Lacertidae) that had been incubated at high and low-temperature extremes were most likely to demonstrate kyphoscoliosis along with other malformations.

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Fig. 1. Sub-adult *Ctenotus fallens* demonstrating scoliosis of caudal vertebrae (photo: R. Benken).

Biochemical substances (pollution) have been implicated (Gray *et al.* 2001), as also in freshwater turtles exposed to polycyclic aromatic hydrocarbons, polychlorinated biphenyls and metals seeping into watersheds from abandoned industrial sites and landfills (Bell *et al.* 2006). Low genetic diversity in some populations is also likely to have an influence (Madsen *et al.* 1992; Olsson *et al.* 1996; Tóth *et al.* 2005). For squamates in captivity, inadequate dietary calcium and lack of UV light are implicated in the onset of nutritional secondary hyperparathyroidism and the development of kyphoscoliosis (Rowland 2009).

It might seem that such malformations would be hugely disadvantageous to the individuals so affected—many of the examples listed in Table 1 show malformations that are far more extensive and dramatic than that of our *Ctenotus*—and Idrisova (2018) and Sant'Anna *et al.* (2013) report that extreme malformations are often associated with death in hatchling lizards and snakes; however, it is worth noting that many of the specimens of lizard reported in Table 1 were adults at the time of capture. The *Iberolacerta cyreni* (Lacertidae) with extreme spinal kyphosis was an adult male with adult coloration (Horváth *et al.* 2021). The *Marisora brachypoda* (Scincidae) with kyphosis from the midpoint of the body to the tail was also an adult male, seen on multiple occasions and described as moving and behaving in a normal way (Arrivillaga & Brown 2019). It had also undergone caudal autotomy at some point and mostly regenerated its tail, perhaps indicating that it had escaped a predatory attack. The *Stenocercus guentheri* (Tropiduridae) adult female with extensive kyphoscoliosis apparently had no difficulties in moving normally (Ramírez-Jaramillo 2018). The highly kyphotic adult male *Podarcis pityusensis* (Lacertidae) was kept in captivity for 9 months, was healthy and had no difficulty in moving or capturing prey (Garin-Barrio *et al.* 2011). Some examples of kyphoscoliosis in Neotropical pit viper (Viperidae) neonates do not prevent further development if they do not preclude the ingestion of prey, even with some associated abnormal locomotion (Sant'Anna *et al.* (2013)). Only Simbotwe (1983) and Gering (2009) respectively, specifically note that the adult female scoliotic *Lygodactylus chobiensis* (Gekkonidae) 'moved with great difficulty' and the juvenile *Furcifer pardalis* (Chamaelonidae) with extensive malformations demonstrated noticeably limited movement.

We do not know how kyphoscoliosis may influence breeding success although it seems likely that extreme examples in both sexes will either disrupt the mechanics of mating or of offspring development and delivery (Idrisova 2018). Owens and Knapp (2007) provide an example of a malformed lizard breeding successfully: the female Andros iguana (*Cyclura c. cychlura*; Iguanidae) with kyphoscoliosis of the spine and tail both produced eggs and vigorously guarded her nest during incubation until they hatched. Despite her malformations not being the most extreme example, the eggs she produced were smaller and lighter than that of the population mean and Owens and Knapp (2007) speculate that spinal curvature resulting in a restricted cloacal opening may constrain egg width.

Low prevalence of kyphosis and scoliosis in populations could mean that such pathology is rare, or that most affected individuals die (also noted by others, *e.g.* Garin-Barrio *et al.* 2011). In captive animals, the prognosis for young green iguanas (*Iguana iguana*; Iguanidae) with scoliosis induced by nutritional secondary hyperparathyroidism is apparently poor (Stahl 2003). This would mean that we are seeing the few individual squamates that survive despite their malformations. However, low apparent prevalence may be influenced simply by reporting rate: Barr *et al.* (2020), reviewing abnormal caudal regeneration in lepidosaurs, showed that reporting rate of this phenomenon has been low until the last decade. Of note, however, is that the population being reported on here has been monitored annually for over 11 years (Davis & Doherty 2015) with 805 individuals of *C. fallens* captured to date, but no other examples of kyphosis or scoliosis in this species have been observed.

Kyphoscoliosis may be a useful biomonitoring indicator of reptile susceptibility to pollutants (Gray *et al.* 2001; Bell *et al.* 2006), and in squamates is also linked to variation in incubation temperature extremes (Idrisova 2018). In a time of anthropogenic habitat change, global temperature perturbation and biodiversity loss, we encourage further reporting of examples of kyphosis and scoliosis.

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Table 1. Scoliosis and kyphosis recorded in wild squamates

Species	Malformation	Sex	Age	Suggested cause	Reference
Ctenotus fallens (Scincidae)	Caudal scoliosis with nine distinct lateral curves	-	Subadult	Possible causes discussed, none specifically suggested	This study
Marisora brachypoda (Scincidae)	"Kyphosis…in mid-section of body…to the end of its tail"	Male	Adult	Possible causes discussed, none specifically suggested	Arrivillaga and Brown (2019)
Iberolacerta cyreni (Lacertidae)	"vertical curvature of six vertebrae, two behind the head in the thoracic region, one over the pelvic girdle and three along the base of the tail"	Male	Adult	Possible anthropogenic-induced habitat deterioration	Horváth *et al.* (2021)
Podarcis pityusensis (Lacertidae)	Severe malformation…arched in five places in spine and tail (kyphosis)	Male	Adult	Possible suboptimal incubation as a cause	Garin-Barrio *et al.* (2011)
Podarcis bacagei (Lacertidae)	Torsion (scoliosis) in anterior spinal column, turning body slightly to left; associated change in dorsal coloration.	Male	Subadult	Either an accident (*i.e.* wound) or genetic issue	Sillero *et al.* (2011)
Liolaemus koslowskyi (Liolaemidae)	"…exhibited two vertical curvatures on the spine (kyphosis), one behind the head in the pectoral girdle and one over the pelvic girdle. In addition, the tail had nine alternating lateral curves (scoliosis)"	Female	Adult	None suggested	Ávila *et al.* (2013)
Liolaemus petrophilus (Liolaemidae)	Scoliotic deformation over the pelvic girdle	Male	Adult	None suggested	Frutos *et al.* (2006)
Stenocercus guentheri (Tropiduridae)	Malformation of entire vertebral column, kyphosis in dorso-cervical region, pelvis and middle of tail. Scoliosis in lumbar region and end of tail	Female	Adult	None specifically suggested but agrochemicals and habitat stress were ruled out as this was only specimen found with malformations in an area where 143 healthy individuals were captured	Ramírez-Jaramillo (2018)
Sceloporus formosus (Phrynosomatidae)	Kyphosis from forelimbs to pelvis, with associated scoliosis. Tail with four lateral curves (scoliosis)	Female	Subadult	Likely to be undetermined congenital factors, perhaps metabolic dysfunction in the mother	Castillo Juárez *et al.* (2020)
Sceloporus u. undulatus (Phrynosomatidae)	"two vertical curvatures of the spine (kyphosis), one behind the pectoral region and one over the pelvic girdle. The anterior one … curved to the left and the posterior … curved to the right. In addition, her tail had three, alternating lateral curves near the base (scoliosis)"	Female	Juvenile	None suggested; developmental malformation inferred	Mitchell and Georgel (2005)
Sceloporus vandenburgianus (Phrynosomatidae)	"…one vertical curvature of the spine (kyphosis) in the thoracic region…Scoliosis…over the pelvic girdle and six throughout the length of the tail."	Male	Subadult	Possible causes discussed, none specifically suggested	Valdez-Villavicencio *et al.* (2016)

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Table 1. *Continued*

Species	Malformation	Sex	Age	Suggested cause	Reference
Sceloporus torquatus (Phrynosomatidae)	One specimen with cervical kyphotic deformation between vertebrae 7 and 8, the other specimen with thoracic kyphotic deformation between vertebrae 12 and 13	Females	Adults	Suggested to be either congenital and/or the effect of agrochemicals used nearby	Pérez-Delgadillo *et al.* (2015)
Anolis cybotes (Dactyloidae)	… kyphoscoliosis, both vertical and lateral curvature of the spine… also a tail rolled into a corkscrew shape	-	Subadult	Possible causes discussed, none specifically suggested	Tiburcio *et al.* (2021)
Norops (Anolis) sericeus (Dactyloidea)	"vertical curvature of the spine (kyphosis) … in the thoracic region…, [&] curvature on the base of the tail (scoliosis)"	Female	Adult	Possible causes discussed, none specifically suggested	Dominguez-De la Riva and Carbajal-Márquezm (2016)
Agama anchietae (Agamidae)	"… the spinal column makes an abrupt turn to the left at the third vertebra, then a sharp turn to the right at vertebra nine, and another left turn at the sixteenth vertebra. The caudal vertebrae continue twisting counter-clockwise throughout the length of the tail for three complete turns"	Male	Adult	"This deformity is probably congenital and apparently did not prevent development"	Grogan (1976)
Calotes versicolor (Agamidae)	"The trunk was highly deformed with two humps at the beginning of the thorax and the end of the pelvic region… The tail… was stiff and spirally twisted along its entire length"	-	-	Possible causes discussed, none specifically suggested	Datta and Hasan (2020)
Cyclura c. cychlura (Iguanidae)	"convex curvature of the spine… anterior to the pelvic girdle, and a concave spinal curvature over the pelvic girdle. Multiple lateral curvatures…spanned the entirety of the tail"	Female	Adult	None suggested	Owens and Knapp (2007)
Lygodactylus chobiensis (Gekkonidae)	"…scoliosis… spinal column and caudal vertebrae were twisted into three complete turns"	Female	Adult	Possible causes discussed, none specifically suggested	Simbotwe (1983)
Furcifer pardalis (Chamaeleonidae)	"…spinal column … frontocaudally highly deformed with a hump at the end of the thorax and a kink in the lumbar spine and the pelvis. The tail had an "accordion"-like shape and was twisted on itself. Only the tip of the tail was flexible"	-	Juvenile	Possible causes discussed, none specifically suggested: inbreeding rejected due to high population; also pesticides and herbicides not used in the area	Gering (2009)
Bothrops jaracara & *Crotalus durissus* (Viperidae)	"Spinal abnormalities were the most common in both species" Kyphosis, scoliosis & lordosis	Both	Neonates	95 malformations recorded from 4087 births. Possible causes discussed, none specifically suggested	Sant'Anna *et al.* (2013)
Thamnophis s. sirtalis (Colubridae)	Multiple malformations of various sorts including kyphoscoliosis in a wild population	Both	Neonates to adults	Suspected to be partly due toxic pollution of site, though kyphosis can be of genetic origin	Gray *et al.* (2001)

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AUTHOR CONTRIBUTIONS

Philip W Bateman: Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); resources (equal); software (equal); supervision (equal); validation (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). **Robyn Benken:** Data curation (equal); investigation (equal); methodology (equal); writing – review and editing (equal). **Ryan Glowacki:** Conceptualization (equal); project administration (equal); writing – original draft (equal); writing – review and editing (equal). **Robert A. Davis:** Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); resources (equal); software (equal); supervision (equal); validation (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal).

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