

Deliberate tail loss in *Dolichophis caspius* and *Natrix tessellata* (Serpentes: Colubridae) with a brief review of pseudoautotomy in contemporary snake families

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Abstract. Deliberate tail loss was recorded for the first time in three large whip snakes (*Dolichophis caspius*) and one dice snake (*Natrix tessellata*). Observations were made in different years and in different locations. In all cases the tail breakage happened while snakes were being handled by researchers. Pseudoautotomy was confirmed in one large whip snake by an X-Ray photo of a broken piece of the tail, where intervertebral breakage was observed. This evidence and literature data suggest that many colubrid species share the ability for deliberate tail loss. However, without direct observation or experiment it is not possible to prove a species' ability for pseudoautotomy, as a broken tail could also be evidence of an unsuccessful predator attack, resulting in a forcefully broken distal part of the tail.

Key words: deliberate tail loss, pseudoautotomy, Colubridae, *Dolichophis caspius*, *Natrix tessellata*.

Deliberate loss of the distal portion of the tail is a widespread defense mechanism in representatives of the reptile orders Rhynchocephalia and Squamata (after Benton 2014), with general reviews on this topic including Arnold 1984, Bellairs & Bryant 1985, Brito et al. 2001, Seligmann et al. 2008, Bateman & Fleming 2009 and Pafilis et al. 2009. There are two main types of deliberate tail loss, with and without regeneration of the broken part. The difference in terminology is summarized in Costa et al. (2014), explaining the main differences in "urotomy", which represents any type of tail breakage (both inter- and intra-vertebral), "autotomy" (intravertebral tail breakage followed by the regeneration of the lost part) and "pseudoautotomy" (intervertebral non-spontaneous breakage of the tail, without regeneration). Within Squamata (see Reeder et al. 2015), numerous taxa display various types of tail-breakage ranging from autotomy and pseudoautotomy to intervertebral urotomy with

regeneration; however, in monophyletic group of Serpentes only pseudoautotomy occurs. Costa et al. (2014) listed three families and a number of subfamilies of snakes where species expressed deliberate tail loss. He created an overview of references, going back to Kaufman & Gibbons (1975). The term "autotomy" also has a general meaning as it refers to a specific predator-escape mechanism, recorded in a wide variety of animal taxa, including both invertebrates and vertebrates (see Jagannandan et al. 2014).

According to literature data, pseudoautotomy was described in the snake families Colubridae, Elapidae and Lamprophiidae, occurring in species known for their relatively long tails (see Costa et al. 2014). Here we report the first observation of deliberate tail loss in two Palearctic colubrid species in Europe, namely the large whip snake (*Dolichophis caspius*) and the dice snake (*Natrix tessellata*) (Table 1).

Table 1. List of recorded deliberate tail-loss events in two colubrid species in Serbia and Hungary. Su - sex unknown; L-total length; Lb - length of broken part of the tail; n_{sc} - number of subcaudal scales on broken piece of tail.

Age/Sex	L/Lb (mm)	n _{sc}	Latitude (degrees)	Longitude (degrees)	Altitude (m.a.s.l.)	Date (dd/mm/yyyy)	Country
<i>Dolichophis caspius</i>							
Adult/Su no. 1	>1000/-	-	43.033	21.867	367	22/05/2009	Serbia
Adult/female no. 2	1630/32	16	44.450	22.144	250	20/06/2014	Serbia
Adult/female no. 3	1580/225	52	47.560	18.980	311	14/06/2014	Hungary
<i>Natrix tessellata</i>							
Adult/Su	700 /35	16	43.323	19.675	530	06/07/2011	Serbia

In all four cases, deliberate tail loss happened in the field while a researcher was measuring the snake, handling it by the distal portion of the tail. In both species, deliberate tail loss was preceded by a particular type of behavior, which consisted of fast circular body movements along the longitudinal axis, already described in Sharma (1980), Cooper & Alfieri (1993), Marco (2002) etc. and elaborated also in Costa et al. (2014) on the basis of extensive literature and personal experience. These fast spinning movements led to cracking of the distal part of the tail while the snake was being handled by the researcher, and this was followed by the successful escape of the snake. Both species are sexually dimorphic, males having larger tails than females. Unfortunately, incomplete data (see Table 1) made comparison of the relation between the relative length of the broken piece of the tail and total relative tail length in different sexes impossible. In *D. caspius* specimens no. 1 and 2 and in the *N. tessellata*, only measurements of the total length were done, as researchers did not expect their snakes to escape. In *D. caspius* no. 3, all available measurements were taken from photos made on site and done by SnakeMeasurer 1.0 software. The number of caudal vertebrae in the broken piece of tail was countable only in *D. caspius* no. 3 (N=54), thanks to the opportunity of taking an X-ray photo (Fig. 1). Additionally, the free movements of the broken piece of the tail in the same individual were recorded by Panasonic Lumix DMC- FT2 camera by the third author (B.H.).

Examined *D. caspius* individuals no. 2 and no. 3 were adult females of almost the same size but the lengths of their broken tails differed apparently (1:7). Weight of the broken piece of tail in snake no. 3 was 4.5 g. Occurrence of intervertebral tail breakage was confirmed by the X-ray photo (Fig. 1). Moreover, before the incident the tail length in no. 3 was estimated as 415 mm, which indicates that more than 50% of the tail was deliberately lost in a single pseudoautotomy event. In all cases, less than 8 minutes passed from the start of handling to the moment of the tail breaking and the consequent escape of the snake. Only in large whip snake no. 3 did B. H. have the opportunity to observe the broken part of the tail moving freely on the surface for about 2 min, changing direction from left to right and *vice versa*. In the other three reported cases the authors did not check the ability of the broken tail to twitch autonomously after breakage.

Looking at the list of published occasions of snake tail breakage collected from Google Scholar (Table 2), the majority of reports referred to the Colubridae family (46 reported species from 34 genera), followed by Lamprophiidae (4 reported species from 2 genera), Viperidae (2 reported species from 2 genera) and Elapidae (1 reported species). Pseudoautotomy was witnessed in 41% and 25% of listed colubrid and lamprophiid snake species, respectively. In colubrids, it was recorded in large, fast, mainly arboreal species (Sheehy 2006), and/or in those having active foraging behaviour



Figure 1. X-Ray photo of broken piece of tail of *Dolichophis caspius* from Hungary.

(Pleguezuelos et al. 2010). The phenomenon of pseudoautotomy was also detected in the semi-aquatic Natricinae subfamily (see Table 2 for species' list and references) and our report on *N. tessellata* implies that pseudoautotomy could also occur in two other members of the genus *Natrix*. Records of tail injuries and tail breakage were already documented in both *N. natrix* (Nagy 2001, Borczyk 2004, Bakiev 2005, Gregory & Isaac 2005) and *N. maura* (Santos et al. 2011). Apart from Natricinae, the other European colubrid species from the list mainly occur in open (including altered) habitats, while South American colubrids are associated with forests.

While collecting evidence of pseudoautotomy in snake species, we separated direct observations of deliberate tail loss (bolded species' names in Table 2, for elaboration see Clause & Capaldi 2006 or Bateman & Fleming 2009) from simple evidence that part of tail is missing. The latter could be the result of either pseudoautotomy or injury (in terms of forced severance of the distal part of the tail) by a predator. The reports on broken tails available to us were acquired either from analyses of museum specimens (specimens with broken tails that were noticed during measurements for various taxonomic or natural history purposes) or from intentional inspections of frequency of broken tails in particular populations (elaborated also in Costa et al. 2014). Twitching of the detached tail, confirmed here in one of four witnessed cases, was recorded also in other snake species (see for example Savage & Slowinski 1996, Marco 2002, Todd & Wassersug 2010), but c.f. Hoogmoed & Avilla-Pires (2011).

Moreover, our data showed a difference in length of the broken tail between two individuals of the same species, sex, and approximate size, which is concordant with the statements of Clause & Capaldi (2006) on "inner control" of the process. It could be the result of different amounts of

Table 2. Evidence of tail loss in various snake families, following phylogeny by Pyron et al. (2011). Latin names of species where deliberate tail loss was directly observed, are denoted by bolded font.

Species	Family	Reference
Europe		
<i>Hierophis viridiflavus</i>	Colubridae	Capula et al. (2010)
<i>Dolichophis caspius</i>	Colubridae	This study
<i>Hemorrhois hypocrepis</i>	Colubridae	Marco (2002)
<i>Natrix maura</i>	Colubridae	Santos et al. (2011)
<i>Natrix natrix</i>	Colubridae	Nagy (2001); Borczyk (2004); Bakiev (2005); Gregory & Isaac (2005)
<i>Natrix tessellata</i>	Colubridae	This study
North America		
<i>Agkistrodon piscivorus</i>	Viperidae	Kauffman & Gibbons (1975);
<i>Coluber constrictor</i>	Colubridae	Kauffman & Gibbons (1975);
<i>Crotalus horridus</i>	Viperidae	Kauffman & Gibbons (1975);
<i>Drymobius sp.</i>	Colubridae	Mendelson (1991)
<i>Elaphe obsoleta</i>	Colubridae	Kauffman & Gibbons (1975);
<i>Heterodon plathyrinos</i>	Colubridae	Kauffman & Gibbons (1975);
<i>Lampropeltis getula</i>	Colubridae	Kauffman & Gibbons (1975);
<i>Masticophis flagellum</i>	Colubridae	Kauffman & Gibbons (1975);
<i>Nerodia erythrogaster</i>	Colubridae	Hampton (2007)
<i>Nerodia sipedon</i>	Colubridae	Kauffman & Gibbons (1975); Fitch (1999); Bowen (2004); Lockhart & Amiel (2011)
<i>Nerodia taxipilota</i>	Colubridae	Kauffman & Gibbons (1975); White et al. (1982)
<i>Ophedryas aestivus</i>	Colubridae	Gritis (1992)
<i>Rhadinaea sp.</i>	Colubridae	Jayne & Bennett (1989)
<i>Tamnophis butleri</i>	Colubridae	Willis et al. (1982)
<i>Tamnophis sauritus</i>	Colubridae	Willis et al. (1982); Todd & Wassersug (2010)
<i>Tamnophis sirtalis</i>	Colubridae	Willis et al. (1982); Cooper & Alfieri (1993); Fitch (2003); Placyk & Burghardt (2005)
South America		
<i>Alsophis sp.</i>	Colubridae	Seidel & Franz (1994)
<i>Coniophanes fissidens</i>	Colubridae	Zug et al. (1979); Mendelson (1991)
<i>Dendrophiidum brunneum</i>	Colubridae	Cadle (2010)
<i>Dendrophiidum dendrophis</i>	Colubridae	Martins (1996); Prudente et al. (2007); Hoogmoed & Avila-Pires (2011); Dourado et al. (2013); Santos-Costa et al. (2015)
<i>Dipsas catesbyi</i>	Colubridae	Zug et al. (1979)
<i>Drymobius sp.</i>	Colubridae	Mendelson (1991)
<i>Drymoluber brasili</i>	Colubridae	Costa et al. (2014)
<i>Drymoluber dichrous</i>	Colubridae	Costa et al. (2014)
<i>Echinanthera undulata</i>	Colubridae	Gomes & Marques (2012)
<i>Enulius sp.</i>	Colubridae	Savage & Slowinski (1996)
<i>Imantodes cenchoa</i>	Colubridae	Zug et al. (1979)
<i>Mastigodryas bifossatus</i>	Colubridae	Leite et al. (2009); Dourado et al. (2013)
<i>Mastigodryas boddaerti</i>	Colubridae	Roberto (2011); Siqueira et al. (2013)
<i>Mastigodryas heathii</i>	Colubridae	Cadle (2012)
<i>Pliocercus elapoides</i>	Colubridae	Liner (1960)
<i>Rhadinaea sp.</i>	Colubridae	Jayne & Bennett (1989)
<i>Scaphiodontophis sp.</i>	Colubridae	Taylor (1954); Savage & Crother (1989); Slowinski & Savage (1995); Savage & Slowinski (1996)
<i>Urotheca sp</i>	Colubridae	Savage & Crother (1989)
Africa		
<i>Natriciteres variegata</i>	Colubridae	Broadley (1987)
<i>Gastrophyscis sp./Hapsidophrys sp.</i>	Colubridae	Spawls et al. (2002)
<i>Grayia sp.</i>	Colubridae	Spawls et al. (2002)
<i>Mehelya sp.</i>	Lamprophiidae	Spawls et al. (2002)
<i>Rhinechis scalaris</i>	Colubridae	Pleguezuelos et al. (2010)
<i>Psammophis notostictus</i>	Lamprophiidae	Broadley (1987)
<i>Psammophis 'phillipsii'</i>	Lamprophiidae	Broadley (1987); Akani et al. (2002)
<i>Psammophis similans</i>	Lamprophiidae	Broadley (1987)

Table 2. (continued)

Species	Family	Reference
Asia		
<i>Amphiesma stolata</i>	Colubridae	Sharma (1980)
<i>Boiga</i> sp.	Colubridae	Whitaker & Captain (2004)
<i>Sibynophis</i> sp.	Colubridae	Taylor & Elbel (1958)
<i>Xenochrophis piscator</i>	Colubridae	Ananjeva & Orlov (1994)
Australia		
<i>Boiga</i> sp.	Colubridae	Whitaker & Captain (2004)
<i>Notechis ater occidentalis</i>	Elapidae	Aubret et al. (2005)

strength used by researchers to secure large whip snakes no. 2 and no. 3 by the tail during handling (also, no. 2 was held by the end of its tail while no. 3 was held by the mid-section of its tail).

To our knowledge, no case of pseudoautotomy was recorded in vipers, although cases of broken tail were documented in some species (for two of them see the reference above). We often hold vipers by the tail (where it is not possible to catch them safely by the head and when we are without proper handling equipment) but deliberate tail loss has never happened. The tail also has a defensive role in those relatively short-tailed and slow-moving snakes, through tail displaying behaviour (Greene 1973) although this is not exclusive to vipers (see Martins 1996 and Parellada & Santos 2002 for review). We observed tail display of *Vipera ammodytes* in laboratory conditions in the presence of prey, and this type of behavior, called "caudal luring", has been extensively reported elsewhere (Parellada and Santos 2002). Perhaps the same behavior is applied to attract a predator's attention to the peripheral part of the snake's body (as described in Sheehy 2006) in order to be more effective in biting or escaping. In some snake species there is also "passive misdirection" of the predator by simply positioning the tail towards it without a particular display (Gritis 1992). All these defensive tactics result in evidence of broken tails in snake species, but do not necessarily confirm pseudoautotomy. The fact that vipers have relatively short tails implies that deliberate tail loss could be more costly for them and thus ineffective.

In conclusion, our observations contribute to the growing evidence of snake species being capable of pseudoautotomy. In this respect, we would consider as perhaps premature the statement that pseudoautotomy evolved independently several times within various snake taxa (see Costa et al. 2014) as the field researcher's opportunity to record this type of behavior depends largely on chance, if not applied intentionally (which could

be considered unethical). It further suggests that the list of the snake species capable of pseudoautotomy is still open (as commented also in Sheehy 2006) and implies that we could expect the establishment of more coherent insights into the evolution of this defense behavior in the future.

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