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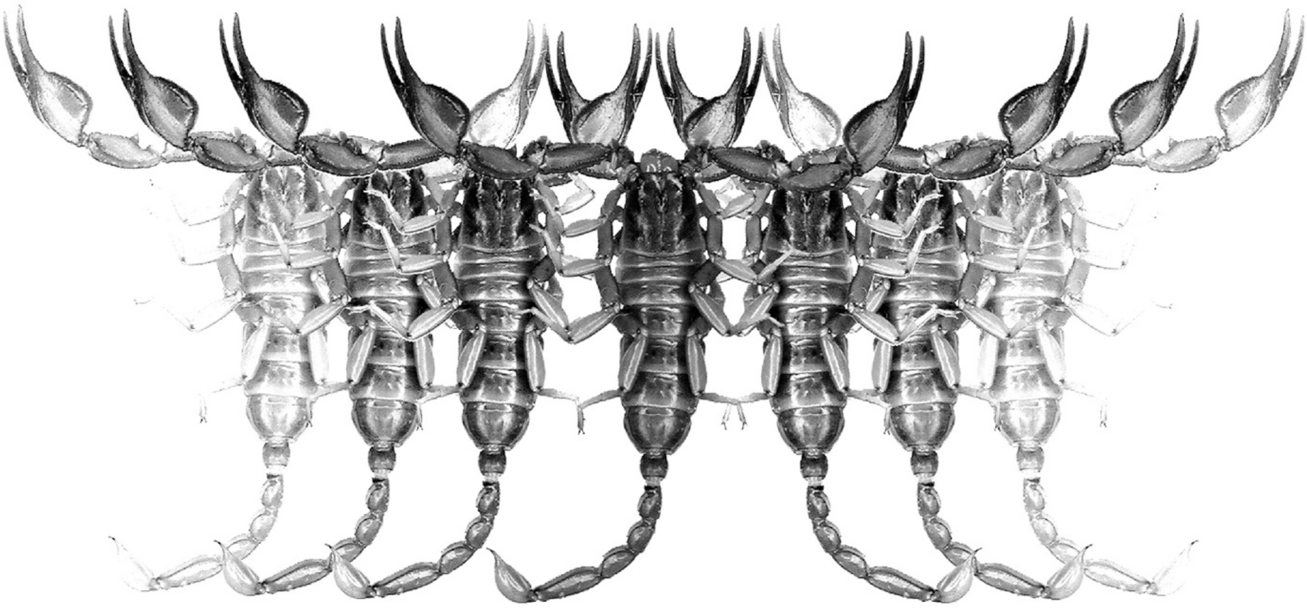

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Martin Watz & Jason A. Dunlop

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Observations on regeneration of the pedipalp and legs of scorpions

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Summary

Two examples of scorpion limb regeneration following unsuccessful molts are documented based on material held in captivity. An *Opisthacanthus asper* (Peters, 1861) (Hormuridae) shows a relatively rare example of pedipalp regeneration in which the lost tibia and tarsus was replaced by a smaller, curved element of uncertain homology to either the fixed or free finger. A comparable abnormal palp described in the literature hints that pedipalps can only regenerate a structure of this form, regardless of the site of amputation. An *Olivierus caucasicus* (Nordmann, 1840) (Buthidae) is described in which claws (pretarsus) of leg III regenerated directly at the distal end of the tibia, while in leg IV the claws regenerated at the end of a truncated section of the metatarsus. This supports previous observations that scorpions can only regenerate the pretarsus of the leg, again irrespective of where on the limb the original breakage occurred.

Introduction

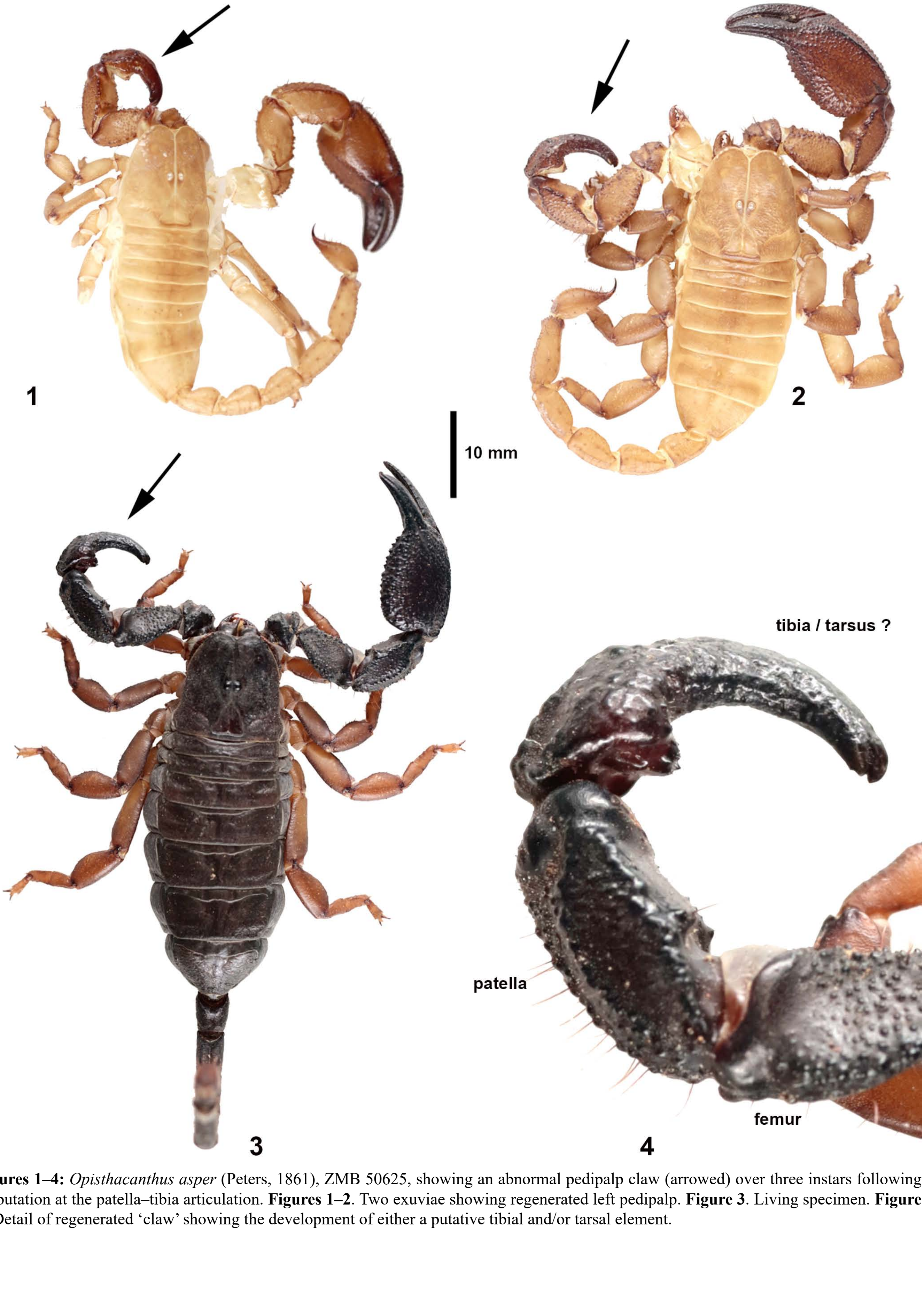
Morphological anomalies in scorpions have long been documented in the literature. Useful summaries include Teruel (2004) and Mattoni (2005: table 1), with a more recent overview in Alqahtani & Badry (2021, and references therein). Some of these may be teratologies, i.e. developmental abnormalities usually arising at an early stage of life history such as the duplication of the metasoma. Another potential source of malformation is the (incomplete) regeneration of structures lost through traumatic injury. Potential sources of damage include attacks by predators, or problems arising during molting (see below). Scorpions, like many other arachnids, can survive the loss of appendages or even parts of the metasoma (García-Hernandez & Machado, 2020, 2021), although it should be stressed that the mesosomal segments and/or telson do not regenerate and loss of the anal region means that the animal eventually dies as it becomes constipated and can no longer feed properly. For wider reviews of arthropod regeneration, see Maruzo et al. (2005) and Maruzo & Bortolin (2013).

In scorpions at least the appendages can be regenerated during subsequent molts (Vachon, 1957; Rosin, 1964), although the replacement limb is usually less complete than a normal one. Scorpions maintained in captivity are potentially a useful source of data here. Injuries and abnormalities arising, for example, during molting can be documented, regeneration can be followed over subsequent molts and both the animals and their exuviae can be maintained as voucher specimens in natural history collections. Here, we present two brief case studies of regeneration observed in scorpions in captivity relating to the pedipalp and legs.

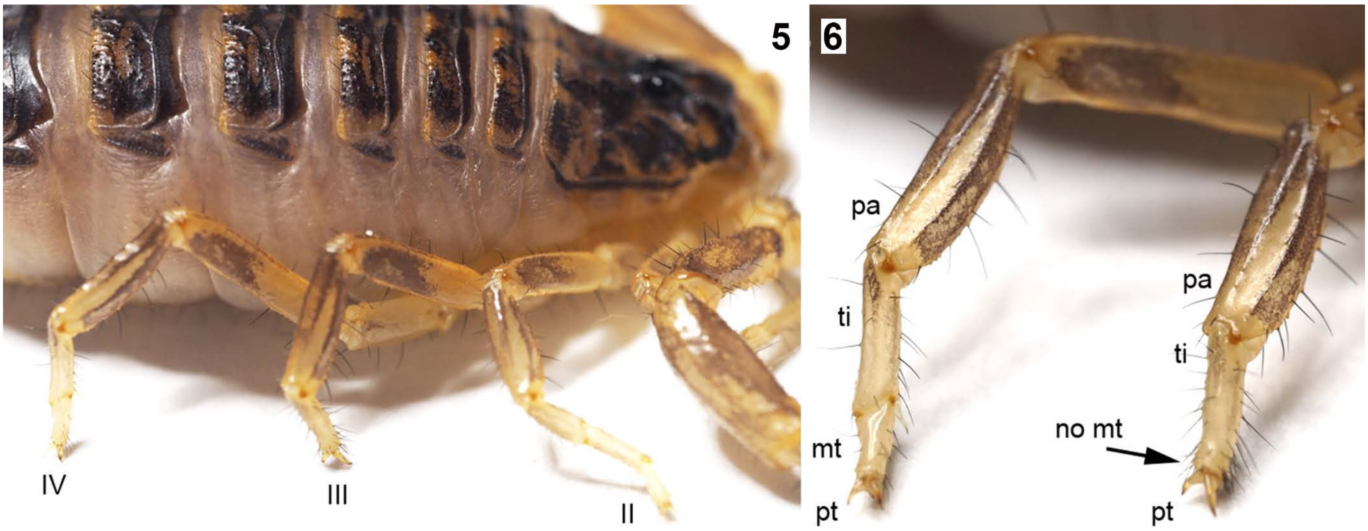
Material and methods

The first specimen is an *Opisthacanthus asper* (Peters, 1861) (Hormuridae) from the private collection of the first author. During a molting attempt the entire exuvium was left hanging on the pedipalp claw which remained trapped within the original cuticle. The old exuvium was removed with tweezers. The animal, however, could no longer move its claw, thus the decision was made to amputate the distal podomeres of the pedipalp at the patella–tibia articulation. The animal survived the procedure, and from the next molt onwards a replacement claw-like morphology appeared (see Results). The *O. asper* specimen is still alive, but will be deposited as voucher material (together with its exuviae) in the Museum für Naturkunde Berlin under the repository number ZMB 50625.

The second specimen is a fifth instar of *Olivierus caucasicus* (Nordmann, 1840) (Buthidae) which was acquired in exchange from a Russian collector and comes from Novo-Filya village, Magaramkent, Dagestan, Russia. It is now maintained in captivity in the collection of Stefan Olsson. This specimen again lost appendages, in this case the tips of two of its legs, through becoming trapped in the old cuticle during an unsuccessful molt from the second to the third instar.



Figures 1–4: *Opisthacanthus asper* (Peters, 1861), ZMB 50625, showing an abnormal pedipalp claw (arrowed) over three instars following amputation at the patella–tibia articulation. **Figures 1–2**. Two exuviae showing regenerated left pedipalp. **Figure 3**. Living specimen. **Figure 4**. Detail of regenerated 'claw' showing the development of either a putative tibial and/or tarsal element.



Figures 5–6: *Olivierus caucasicus* (Nordmann, 1840). **Figure 5**. Overview of the living specimen in lateral view showing abnormal right posterior limbs III and IV. **Figure 6**. Details of the abnormal limbs. In leg III pretarsal claws have regenerated directly at end of the tibia. By contrast, in leg IV they have regenerated at the end of a truncated metatarsus. Abbreviations: mt = metatarsus, pa = patella, pt = pretarsus, ti = tibia

Results

The *Opisthacanthus asper* specimen presents a normal left pedipalp down to the patella, but in all three instars documented here (Figs 1–4) the claw, i.e. the manus and fixed finger (tibia) plus the movable free finger (tarsus), is replaced by a strongly curved element about the same length as the patella. It has a broader base where it articulates against the patella, but is not expanded into a typical manus as in a normal pedipalp (Fig. 3). The regenerated structure is granulate and setose like a typical pedipalp element (Fig. 4) and terminates in a bluntly rounded tip with a slight hook and several distinct granules in the tip region. There is no fundamental change in the structure of this limb element across all three instars recorded, but in later instars it becomes proportionally slightly longer. Behavioural observations of the specimen in life suggest that the regenerated structure is not actively used in prey capture. Otherwise, the scorpion appears to have suffered no adverse effects, was successfully mated in captivity and produced offspring. For species which are relatively uncommon in hobby circles, this reiterates the value of rescuing ‘invalids’ and facilitating their availability for captive breeding.

The *Olivierus caucasicus* specimen (Fig. 5) presents a visible truncation of two legs (Fig: III and IV on the right side of the body. Leg III is has a normal morphology down to the tibia, but the tibia is immediately followed by the pretarsus (Fig. 6) in the form of a normal-looking pair of claws. Leg IV is also normal down to the tibia, but this is followed by a truncated metatarsal podomere, approximately half its expected length compared the left metatarsus IV, which again terminates in a normal-looking pair of pretarsal claws (Fig. 6). In both cases the truncated legs are held in life in such a way that the pretarsus rests on the substrate and the limbs can still contribute to walking.

Discussion

Abnormalities previously documented for scorpion pedipalps include Mattoni’s (2005) report of a poorly-developed secondary sexual apophysis in a specimen of *Bothriurus araguayae* which implied an intersexual condition, Graham’s (2006) observation of malformed dentition on the moveable finger in a specimen of *Superstitionia donensis*, and Karataş & Kürtüllu’s (2006) remarkable example of duplicated pedipalp segments in a specimen of *Androctonus crassicauda*. These morphologies are, however, unlikely to be the results of regeneration. The present specimen of *Opisthacanthus asper* offers an unequivocal example of pedipalp regeneration after traumatic injury and reveals that the scorpion can regenerate a hook-like structure distal to the patella, but this is a single element (i.e. there is no opposing fixed and free finger) and it is noticeably smaller than a normal pedipalp claw.

Most published accounts of scorpion regeneration relate to the walking legs, although the chelicerae can regenerate its dentition and the tip of the aculeus (sting) can also be replaced during subsequent molts (e.g. Rosin 1964). Examples of pedipalp regeneration in the literature are extremely rare. A possible comparison is with two abnormal pedipalps described by Jahanifard et al. (2008: figs 1–2) in buthid scorpions from Iran. An *Orthochirus* sp. was figured with a normal coxa and trochanter, but the rest of the pedipalp replaced by a small, short, curved element again reminiscent of either a small fixed or free finger. An *Orthochirus* was figured with a more complete pedipalp, but in which the fixed finger of the tibia was strongly truncated and only about a quarter of the length of the opposing free finger. Whether these are teratologies or regenerations after injury is difficult to determine in wild-caught specimens.

As noted below for the scorpion legs, there is a fairly fixed pattern of regeneration in these limbs in which only the most distal element reappears. Our *Opisthacanthus* specimen raises some interesting questions for the pedipalps, which are difficult to resolve at this stage. First, is the small regenerated element homologous with the tibia or the tarsus? It lacks an obvious basal expansion into a manus and is similar in length to the corresponding tarsus in the undamaged right pedipalp (Figs. 1–3). However, its detailed morphology (Fig. 4) cannot be matched unequivocally to either the fixed (tibial) or free (tarsal) finger of a normal claw. Second, are there constraints on pedipalp regeneration comparable to those on the legs? Again, we note the specimen figured by Jahanifard et al. (2008) in which a small, curved element, similar to what we observed in *Opisthacanthus*, emerged directly from the trochanter. A possible explanation would be that the pedipalps can only regenerate this curved, tibial/tarsal structure regardless of where on the limb the original breakage occurred. Given that the legs can only regenerate their most distal part, we may have grounds for interpreting the regenerated element in the pedipalps as the tarsus.

The *Olivierus caucasicus* showing two truncated legs, in which both legs end in normally developed tarsal claws (Figs 5–6), is consistent with previous reports that scorpions are only able to regenerate the pretarsus (or apotele) (Rosin, 1964; Maruzo & Bortolin, 2013), irrespective of where on the limb the original amputation took place. The only example of a scorpion regenerating more than the pretarsus is Vachon's (1957) observation of a scorpion with a limb amputated during the larval stage in which a regenerated pretarsus subsequently differentiated into a tarsus and pretarsus at the second molt after injury. More typical are observations such as those of Armas (1977, fig 2) who figured a pretarsus emerging from the end of the patella and from a small limb element distal to the femur in *Centruroides anchorellus* (Buthidae). More recently, Ayrey & Myers (2020, figs 14–15) figured an example of a pretarsus emerging directly from the tibia in *Wernerius mumai* (Vaejovidae). We suspect that these could also be cases of regeneration after injury. What is particularly interesting to observe in the present *Olivierus* specimen is the fact that two adjacent legs were presumably broken at different points along the limb axis and that regeneration began at the distal end of the next available podomere (or part thereof); see also comments in Rosin (1964). Thus the third leg regenerated the pretarsus directly at the end of the tibia, but the fourth leg shows the pretarsus regenerating in a slightly more distal position in which about half of the metatarsus was also still available (Fig. 6).

Acknowledgements

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