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Systematic revision of the Malagasy chameleons *Calumma boettgeri* and *C. linotum* (Squamata: Chamaeleonidae)

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Abstract

We revise the taxonomic status of two species of Madagascan chameleons in light of a recent molecular phylogenetic study on the *Calumma nasutum* group. The investigation of morphological and osteological characters led to a clear delineation between two species within the *C. boettgeri* complex, *C. boettgeri* and *C. linotum*. *Calumma linotum* has been considered either a synonym of *C. boettgeri* or a dubious, poorly defined taxon. So far it has only been known from the male holotype with the imprecise locality ‘Madagascar’. Based on pholidosis, morphological measurements and characters of the skull that were analyzed using micro-X-ray computed tomography (micro-CT) scans, we ascribe the population of chameleons from Montagne d’Ambre, formerly assigned to *C. boettgeri*, to *C. linotum*. *Calumma linotum* differs from *C. boettgeri* in the larger size of tubercle scales on the extremities and rostral appendage, the larger diameter of the extremities relative to the body size, the presence of a parietal crest as well as the form of the nasal bones and the anterior tip of the frontal. The life colouration of the males is also characteristic, with a blue rostral appendage and greenish turquoise extremities. The body and rostral appendage of *C. boettgeri* in contrast are inconspicuously yellowish brown coloured. All confirmed distribution records of *C. boettgeri* are confined to the biogeographic Sambirano region whereas *C. linotum* is only known from Montagne d’Ambre and a locality at the base of the Tsaratanana massif. Additional literature records of *C. boettgeri* and *C. linotum* from northeastern Madagascar are in need of confirmation. We also confirm the synonymy of *Chamaeleo macrorhinus* (described from a female holotype with an unknown locality) with *Calumma boettgeri*. The use of micro-CT exposed further characteristics for species delimitation in an integrative taxonomic approach. In addition to the skull, we also micro-CT scanned the hemipenes of *C. boettgeri* and *C. linotum*, using an iodine-based tissue stain, and provide 3D PDF models of these organs. This method enables detailed illustration and the detection of variation in particular characters, and might be an important tool in further taxonomic studies on the *C. nasutum* group and other squamate reptiles.

Key words: *Calumma boettgeri*, *Calumma linotum*, Chamaeleonidae, micro-computed tomography, hemipenis morphology, skull structure, Madagascar

Introduction

The island of Madagascar is one of the most valuable natural resources on the planet. In addition to an impressive number of animal and plant species, endemism reaches 85% for vascular plants, 84% for land vertebrates (Goodman & Benstead 2005), 92% for non-marine reptiles (Glaw & Vences 2007), and 100% for species in the chameleon genus *Calumma* (Townsend *et al.* 2011). Description of the island’s species level diversity is far from complete, and modern molecular methods have contributed to an increase of species descriptions in recent years. Molecular analyses enable the discovery of cryptic species that show few or no external morphological differences (Bickford *et al.* 2007). Among Malagasy reptiles, cryptic diversity and microendemism is presumed to be widespread, but the level of these phenomena has not been rigorously explored (Gehring *et al.* 2012; Glaw *et al.* 2012).

The chameleon genus *Calumma* currently comprises 33 species, many of them described in the last 10 to 15 years (Tilbury 2014; Glaw 2015). Small *Calumma* species with a soft dermal appendage on the snout tip are clustered into the *Calumma nasutum* group, which includes the seven described species *C. boettgeri*, *C. fallax*, *C.*