

Description of a new frog species of *Gephyromantis* (subgenus *Laurentomantis*) with tibial glands from Madagascar

(Amphibia, Mantellidae)

Frank Glaw & Miguel Vences

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We describe a new species of frog from Madagascar, assigned to the subgenus *Laurentomantis* in the genus *Gephyromantis*. The new species is known from a single male specimen from about 1300 m elevation in Marojejy National Park in north-eastern Madagascar, and from a second specimen with uncertain locality data. It differs from the other four described *Laurentomantis* species by a combination of its unique life colouration, presence of tibial glands, broad head, and substantial genetic differentiation. In line with the arguments used in the conservation assessments of other potential Marojejy endemics from similar altitude, we suggest a conservation status of Vulnerable for this new species. The possible function of the enigmatic tibial glands is discussed. We also provide new data on *Gephyromantis horridus* from its type locality Nosy Be island suggesting that the type locality of this species is not in error.

Frank Glaw (corresponding author), Zoologische Staatssammlung München, Münchhausenstr. 21, 81247 München, Germany;
e-mail: Frank.Glaw@zsm.mwn.de

Miguel Vences, Division of Evolutionary Biology, Zoological Institute, Technical University of Braunschweig, Mendelssohnstr. 4, 38106 Braunschweig, Germany;
e-mail: m.vences@tu-bs.de

Introduction

The anuran family Mantellidae, endemic to Madagascar and Mayotte island, currently consists of the three subfamilies Mantellinae, Boophinae and Laliostominae (Glaw & Vences 2006). The species of the latter two subfamilies have a generalized reproductive mode: males have nuptial pads and the eggs are laid in open water during an axillary amplexus. In contrast, all representatives of the subfamily Mantellinae seem to lay their eggs outside of water, females not being amplexed during mating. Mantellines show an impressive diversity in species numbers and morphology, and especially in tadpole morphology and reproductive modes.

Several subclades in the mantelline genus *Gephyromantis* reproduce independently from water, and direct development has been assumed for some of them (Blommers-Schlösser 1979, Glaw & Vences 1994). More recently, some *Gephyromantis* have been demonstrated to possess generalized or nidicolous tadpoles (Randrianiaina et al. 2007). *Gephyromantis* is subdivided in five subgenera, *Gephyromantis*, *Duboisimantis*, *Laurentomantis*, *Phylacomantis*, and *Vatomantis* (Glaw & Vences 2006).

The poorly known subgenus *Laurentomantis* was revised by Vences et al. (2002) who recognized a total of four species (*G. horridus*, *G. ventrimaculatus*, *G. malagasius*, and *G. striatus*) but already assumed the existence of further species which, however, were

not described due to the absence of convincing evidence and the small number of specimens available at that time. In the meantime, additional collections of *Laurentomantis* have become available to us, and Vieites et al. (2009) have provided molecular evidence for the existence of further candidate species within this subgenus. We here scientifically name and describe one of the unnamed candidate species listed by these authors which is morphologically distinct and has a strong molecular differentiation to all other nominal species of *Gephyromantis*. We furthermore discuss the possible function of tibial glands in *Laurentomantis* species and provide new data on the related species *Gephyromantis horridus*.

Study site, materials and methods

The holotype of the new species was discovered during a herpetological expedition to the Marojejy National Park, a rainforest massif in northeastern Madagascar that is known to harbour a rich herpetofauna with numerous endemic species (Raselimanana et al. 2000). Three field camps were installed at different altitudes. Around the highest campsite, called Camp Simpona, frogs were searched opportunistically and by localizing calling males, mostly at night, using torches and head lamps. Most individuals were collected near the campsite, along a small trail to the top, and along two streams of c. 50 cm and 3 m in width, respectively. Locality information was recorded with GPS receivers. Morphological measurements (in mm) were taken by MV with a calliper to the nearest 0.1 millimeter.

Morphological abbreviations used are: SVL (snout-vent length), HW (greatest head width), HL (head length), ED (horizontal eye diameter), END (eye-nostril distance), NSD (nostril-snout tip distance), NND (nostril-nostril distance), TD (horizontal tympanum diameter), HAL (hand length), HIL (hindlimb length), TIBL (tibia length, actually referring not to the tibia bone but to the shank), FOL (foot length), FOTL (foot length including tarsus), FORL (forelimb length), RHL (relative hindlimb length), FGL (femoral gland length), FGW (femoral gland width), FGD (distance between femoral glands on opposite thighs), TGL (tibia gland length), and TGW (tibial gland width).

Institutional abbreviations are as follows: MNHN (Muséum national d'Histoire naturelle, Paris); NMW (Naturhistorisches Museum Wien); ZSM (Zoologische Staatssammlung München). Terminology for the description of femoral glands follows Glaw et al. (2000). The terminology of tibial glands and the scheme of the description of the new species follows Vences et al. (2002).

Taxonomy

Gephyromantis (Laurentomantis) ranjomavo spec. nov.

Fig. 1

Remark. This species has been considered before as *Gephyromantis* spec. aff. *horridus* "Marojejy" by Glaw & Vences (2007) and as confirmed candidate species *Gephyromantis* spec. 11 by Vieites et al. (2009).

Holotype. ZSM 222/2005 (field number FGZC 2843), adult male, from Camp Simpona (14°26.199' S, 49°44.601' E, 1326 m above sea level), Marojejy National Park, northeastern Madagascar, collected on 16 February 2005 by F. Glaw, M. Vences and R. D. Randrianiaina.

Paratype. MNHN 1976.250, adult male, locality and collector unknown, but possibly from the Marojejy massif as well.

Diagnosis. A member of the subfamily Mantellinae based on the presence of intercalary elements between terminal and subterminal phalanges of fingers and toes (verified externally), and on the absence of nuptial pads and presence of femoral glands in males. Assigned to the genus *Gephyromantis* (subgenus *Laurentomantis*) based on the presence of tibial glands; strongly granular dorsum; a single subgular vocal sac, absence of foot webbing, and completely connected lateral metatarsalia. *Gephyromantis ranjomavo* differs from all four hitherto described *Laurentomantis* by its unique life colouration (ground colour of dorsum blackish without vertebral stripe, hindlimbs yellowish, ventral side of thighs and venter without red colour); in addition it differs from *G. ventrimaculatus*, *G. malagasius*, and *G. striatus* by the presence of tibial glands in the male sex; from *G. horridus*, *G. ventrimaculatus*, and *G. striatus* by a lower number of granules in the femoral glands (1 versus 3-9); from *G. horridus* and *G. ventrimaculatus* by less granular dorsal skin; from *G. horridus* by smaller male size (23.5-26 mm versus 26-28 mm SVL). Furthermore, *G. ranjomavo* differs from all four other species in the subgenus *Laurentomantis* by substantial genetic differentiation (see below).

Description of the holotype

Adult male, fixed in ca. 90 % ethanol, preserved in 70 % ethanol, in good state of preservation, muscles from right thigh removed as tissue sample. Body slender; head longer than wide, distinctly wider than body; snout rounded in dorsal and lateral views; nostrils directed laterally, distinctly protuberant, nearer to tip of snout than to eye; canthus rostralis rather indistinct, concave; loreal region concave;



Fig. 1. *Gephyromantis ranjomavo* spec. nov., holotype in life in dorsolateral view (A) and ventral view (B).

tympanum distinct, rounded, 44 % of eye diameter; supratympanic fold recognizable, but superimposed by tubercles; tongue ovoid, distinctly bifid posteriorly; vomerine teeth absent; choanae rounded. No dermal fold is recognizable along the lower jaws (the inflatable parts of the vocal sac). Arms slender, subarticular tubercles single; very poorly developed outer and inner metacarpal tubercle recognizable, respectively; fingers without webbing; relative length of fingers $1 < 2 < 4 < 3$, second finger distinctly shorter than fourth finger; finger disks distinctly enlarged, especially on fingers 3 and 4; nuptial pads absent. Hindlimbs slender; tibiotarsal articulation reaching beyond snout tip when hindlimb is adpressed along body; lateral metatarsalia connected; inner metatarsal tubercle distinct, outer metatarsal tubercle very small but recognizable; webbing between fingers and toes absent; relative toe length $1 < 2 < 5 < 3 < 4$. Toe disks distinctly enlarged. Skin on upper surface strongly granular, with distinctly elevated and irregularly distributed tubercles and ridges on head and eyes, and with less distinct ridges on the back. Ventral skin smooth on throat and limbs, slightly granular on posterior belly. Femoral glands well delimited and distinctly recognizable from external view; from internal view (by dissecting and reflecting the femoral skin, see Glaw et al. 2000) only a single, large, flat, white granule recognizable. Tibial glands very distinct and with many small pores, starting at the anterior part of the tibia and covering about 75 % of the shank.

Measurements (in mm) are as follows: SVL, 23.5; HW, 9.1; HL, 10.0; ED, 3.4; TD, 1.5; END, 2.6; NSD, 2.0; NND, 2.5; HAL, 8.9; FORL, 19.6; HIL, 41.9; FOL, 11.9; FOTL, 18.5; TIBL, 12.8; FGL, 3.4; FGW, 1.5; FGD, 0.8; TGL, 7.0; TGW, 2.0; length and height of inner metatarsal tubercle, 1.3 and 0.8; length of first toe, 2.6.

After five years in preservative, dorsal colouration of head and body (including the cloacal region) dark grey, with two small whitish spots situated on elevated tubercles on head and beige mottling on back, most distinct in the middle of dorsum. Hindlimbs cream-white with several irregularly shaped dark and light brown flecks, one distinct dark brown band on thigh, one on shank at posterior border of tibial gland and two on tarsus. Dorsal surfaces of arms, hands and feet with several dark and light brown crossbands. Ventrally, throat dark brown with a series of grey spots along the lower jaw. Belly dark brown, chest and ventral surfaces of limbs light brown, with darker femoral glands.

In life (Fig. 1), colour on head and dorsum similar to that in preservative, but dorsal surfaces of arms and especially of hindlimbs orange-golden instead

of cream-white. Iris grey-brown with a dark marking ventrally. Throat brown with a series of silvery flecks along upper jaw and in center, and a larger greyish area laterally. Belly grey-brown with indistinct silvery spots laterally. Ventral sides of arms and hindlimbs orange-brown; femoral glands not darker than surrounding limb surfaces.

Variation. Measurements of the single male paratype were given in Vences et al. (2002, tab. D). SVL (25.8 mm) is greater than in the holotype. However, the general morphology and especially the colouration agree very well with those of the holotype.

Distribution. Only known from the type locality in the Marojejy National Park, c. 1300 m altitude.

Natural history. The holotype was collected in the early evening, calling from the vegetation about 1 m above the ground, at about 2–3 m distance from a small stream (width c. 50 cm) in a mountainous rainforest, only few meters from the cleared campsite. This calling site suggests that the reproduction of this *Laurentomantis* species is associated with running water, although only a single observation is available. The calls consisted of series of unharmonious, distinctly pulsed notes, but unfortunately could not be recorded. By subjective impression to the human ear, they were similar to calls of *G. striatus* which occurs at lower altitudes (c. 300–500 m a.s.l.) in the Marojejy reserve, and also similar in general structure to calls of *G. klemmeri* which occurs syntopically with *G. ranjomavo*.

Molecular differentiation. No molecular study was performed for this paper, but based on phylogenetic analyses of partial sequences of the mitochondrial 16S rRNA gene (Vieites et al. 2009), *G. ranjomavo* (as *G. spec.* 11) was the sister group of *G. horridus* from the Tsaratanana Massif with high node support values. This relationship is also supported by additional, unpublished datasets (Kaffenberger et al. submitted) that contain sequences of several mitochondrial and nuclear genes. In the 16S rRNA gene, the differentiation (uncorrected pairwise p-distances) of *G. ranjomavo* from *G. horridus* (from Tsaratanana) is substantial and amounts to 5.1 % (Vieites et al. 2009); it is differentiated by divergence values of >5 % from all other *Gephyromantis* species and other undescribed candidate species assigned to this genus. The Genbank accession number of the 16S sequence of the holotype of *G. ranjomavo* is FJ559188.

Etymology. The specific name consists of the two Malagasy words ranjo (= leg) and mavo (= yellow). It refers to the yellow hindlegs in life and is used as an unlatinized, invariable noun in apposition.

New data on *Gephyromantis horridus*. The historically first discovered species of the subgenus *Laurentomantis*, *G. horridus*, was described based on a juvenile holotype specimen from the Malagasy offshore island Nosy Be, in the northern Sambirano region. Afterwards, the species has been reliably recorded from Manarikoba forest in the Tsaratanana massif, and from Montagne d'Ambre, both located in northern Madagascar as well (Vences et al. 2002). However, despite intensive herpetological survey work at the type locality Nosy Be (e.g. Andreone et al. 2003), the species has not been recorded from this island again. This left doubts on the correctness of the type locality, especially since Nosy Be was historically an important locality for stock turnover which might have led easily to confusion about collecting locality and sender address. We could recently find in the historical collections of the Vienna museum an adult female of *Gephyromantis horridus* (NMW 3643) that had been collected by Brancsik at "Nossi Be" in 1890. Morphologically this specimen is very similar to female specimens from Montagne d'Ambre in all respects, and thus constitutes a further confirmation for the probable occurrence of *G. horridus* on Nosy Be. We here provide measurements (all in mm) of this specimen, and (in parentheses) of a second female of *G. horridus* from Montagne d'Ambre (ZSM 2243/2007, collected in March–April 2007 by P. Bora and A. Knoll) that has not been included in previous accounts (Vences et al. 2002): SVL 33.7 (33.0), HL 14.0 (13.9), HW 13.9 (13.9), TD 2.1 (2.3), ED 4.4 (4.6), END 3.7 (3.5), NSD 2.3 (2.3), NND 3.3 (3.4), HAL 10.9 (10.4), FORL 25.0 (23.0), HIL 50.2 (51.2), FOTL 22.2 (22.9), FOL 14.4 (15.0), TIBL 15.8 (15.5), tibiotarsal articulation reaches anterior corner of eye when hindlimb is adpressed along body (reaches between eye and nostril).

Discussion

For over 60 years, i.e. between 1935 and 2001, only three nominal species in the subgenus *Laurentomantis* (*G. horridus*, *G. ventrimaculatus* and *G. malagasius*) were recognized, although Glaw & Vences (1994) already noticed the existence of a further candidate species that was eventually described by Vences et al. (2002) as *G. striatus*. Besides the new species, *G. ranjomavo*, described herein, we are aware of the existence of at least one additional confirmed candidate species (*G. spec. 13*) and two unconfirmed candidate species (*G. spec. 12* and *G. spec. 14*) of *Laurentomantis* which are related to *G. malagasius* (see Vieites et al. 2009). However, despite this taxonomic progress, *Laurentomantis* continues to be one of the least known lineages of the Malagasy anuran fauna,

with very few specimens in collections and almost no data available on their ecology, behaviour and reproductive mode. Virtually nothing is known about the function of one of the unique features of *Laurentomantis*, the tibial glands seen in several species of this subgenus. In many amphibians, besides the typical multicellular mucous and granular glands, specific macroglands occur which typically are agglomerations of granular (also called serous or poison) glands (Duellman & Trueb 1986, Lenzi-Mattos et al. 2005, Crook & Tyler 1981). These often have a function in toxin secretion or are involved in production of pheromones or other compounds relevant in the context of reproduction (Vences et al. 2007). Such a function can be assumed in all cases where glands are sexually dimorphic, usually restricted to or better developed in males. In Madagascar, hyperoliid frogs (genus *Heterixalus*) are characterized by gular glands on the vocal sac of the males (Blommers-Schlösser 1982) and in various genera of mantellid frogs of the subfamily Mantellinae, males have femoral glands on the ventral side of the thigh that can occur as a rudiment also in females (Glaw et al. 2000, Vences et al. 2007). Furthermore, some species of *Gephyromantis* have gland-like structures on the forearm (Vences & Glaw 2001). Tibial glands, in Madagascar, occur only in the microhylid *Rhombophryne guentherpetersi* (own, unpublished observations) and in some species of *Laurentomantis*. In *R. guentherpetersi* these glands do not appear to be sexually dimorphic and might serve predominantly to secrete toxins, similar to the tibial glands of some species of *Limnodynastes* (Crook & Tyler 1981). In *Gephyromantis* species of the subgenus *Laurentomantis*, according to present knowledge (Vences et al. 2002 and data herein), tibial glands occur in the males of *G. ranjomavo* (females unknown), in males and females of the central eastern population assigned to *G. malagasius* (*G. spec. 13* according to Vieites et al. 2009), and in males of *G. horridus*. In the latter species, however, the situation is convoluted. Tibial glands were observed in a population from Tsaratanana from where, however, no females are known. Females without tibial glands are known from Montagne d'Ambre from where, however, no males have been collected. One DNA sequence from Montagne d'Ambre (from Genbank; not referring to specimens examined by us) differs substantially from the Tsaratanana specimens (and was considered to be an unconfirmed candidate species, *G. spec. 12*, by Vieites et al. 2009). According to data presented here, also one *G. horridus* female from the type locality Nosy Be, geographically and biogeographically closer to Tsaratanana, lacks tibial glands, but from this locality no molecular data are available. In conclusion, since it is not certain whether the Montagne d'Ambre and Tsaratanana populations

assigned to *G. horridus* are conspecific, the assumed sexual dimorphism in the presence of tibial glands in this species is in need of confirmation.

The presence and distinctness of the tibial glands in *Laurentomantis* suggest a special function of these enigmatic structures. At first glance, it seems plausible to assume that they are involved in the mating behaviour as it is known for the femoral glands of mantelline frogs, to which also the genus *Gephyromantis* belongs. However, sexual dimorphism clearly is more consistently expressed in femoral glands, i. e. all *Gephyromantis* species in the subgenus *Laurentomantis* have distinct femoral glands in males but these are always absent in females (Vences et al. 2002). Mantelline frogs are unusual among anurans in lacking a strong amplexus during the mating. Instead males are usually positioned above the female during the egg deposition (in some groups in a vertical position in the vegetation), and obviously in this position the femoral glands of the males get in contact with the dorsal skin of the female (Blommers-Schlösser 1975, own observations). It appears plausible to assume that in this position the secretion of the glands serves as a signal in the context of reproduction. In contrast to the femoral glands which are positioned on the ventral side of the thigh, tibial glands are positioned and directed dorsally on the lower leg. If the mating behaviour of the species of *Laurentomantis* is similar to that of the other mantellines, tibial glands of the males would not get in direct contact with the female during mating. This, together with the presence of tibial glands in females of at least one species (*G. spec. 13*; Vences et al. 2002) justifies seeking for alternative functions of these morphological structures. Given that other *Gephyromantis* (e. g. in the subgenus *Vatomantis*, which is the phylogenetic sister group of *Laurentomantis*) show parental care, it would be plausible – though speculative – to assume a function of the tibial glands in protecting eggs with secretions, and a secretion of toxins connected to an antipredator function also cannot be ruled out at present. Tibial glands are also known from several insects but their function is poorly known as well (Billen et al. 2000).

Preliminary phylogenetic data from a DNA barcoding dataset of the 16S rRNA gene (Vieites et al. 2009) indicates the existence of one clade within *Laurentomantis*, containing *G. malagasy* and the morphologically similar *G. spec. 13*, *G. spec. 14* and *G. striatus*, and the less similar *G. ventrimaculatus*. A second clade contains *G. horridus*, *G. ranjomavo*, and *G. spec. 12*. These relationships were also retrieved by a yet unpublished multigene dataset which we have recently completed, although several nodes were not strongly supported (Kaffenberger et al. submitted). Because the species with tibial glands

(*G. horridus*, *G. ranjomavo*, *G. spec. 13*) did not form a monophyletic group, the data suggest homoplasy in the evolution of tibial glands, either their convergent origin in several *Laurentomantis* or (more likely) their secondary reduction in some of the species. However, more data on the sexual dimorphism of these glands in all *Laurentomantis* species and a strongly supported phylogenetic hypothesis are necessary to understand the evolution of tibial glands in these frogs in more detail.

Gephyromantis ranjomavo is only known by the holotype and a second specimen without locality data. Attempts to find more specimens of *G. ranjomavo* at the type locality by searching for calling and non-calling specimens along the stream where the holotype was discovered, and in adjacent rainforest areas, were unsuccessful. Furthermore, we could trace only one additional specimen in the historical collections, and extensive recent surveys of other teams in Marojejy (Raselimanana et al. 2000) apparently failed to record this distinctively coloured species as well. This might indicate that *G. ranjomavo* is either very seasonal and cryptic, or that the species is indeed rare or restricted to special habitats at least in Marojejy National Park. The presence of *G. ranjomavo* in this reserve might hopefully assure its survival for at least the near future. Because this species is rather conspicuous in morphology and especially in colouration and has not been recorded during our surveys in other regions of Madagascar, it might be a regional mid to high altitude endemic of north-eastern Madagascar or even be restricted to the Marojejy massif. In line with the arguments used in the conservation assessments of other potential Marojejy endemics from similar altitude, namely *Gephyromantis tandroka*, *G. schilfi*, and *G. tahotra* (Glaw et al. 2011), we propose for *G. ranjomavo* a conservation status of Vulnerable based on IUCN (2001) criteria B1ab(iii), i. e. because it is known from less than 10 locations and because there is continuing decline in the extent and quality of its habitat.

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