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SPECIES OF *GROSPHUS* SIMON, 1880 ASSOCIATED TO *GROSPHUS SIMONI* LOURENÇO, GOODMAN & RAMILIJAONA, 2004 WITH DESCRIPTION OF TWO NEW SPECIES (SCORPIONES: BUTHIDAE)

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Abstract: A reanalysis of the type material of *Grosphus simoni* Lourenço, Goodman & Ramilijaona, 2004, associated with new material of this species from the northeast of Madagascar, has led to the conclusion that the male paratype of *G. simoni* belongs to a new, undescribed species. A large series of specimens collected in the Ambatovy-Analamay-Torotorofotsy humid forests, at around 1000 m, revealed the presence of another new species, also associated to *G. simoni*. Thanks to the supplementary material, with males and females, a new diagnosis is proposed for *G. simoni* and two new species are here described. Some general comments on the biogeography of the two new species and *G. simoni* are also provided.
Key words: Scorpiones, Buthidae, *Grosphus*, new species, Central/ Eastern/Western distributions, Madagascar.

Especies de *Grosphus* Simon, 1880 asociadas con *Grosphus simoni* Lourenço, Goodman & Ramilijaona, 2004 y descripción de dos especies nuevas (Scorpiones: Buthidae)
Resumen: Un nuevo análisis del material típico de *Grosphus simoni* Lourenço, Goodman & Ramilijaona, 2004, a raíz del estudio de material nuevo de esta especie del noreste de Madagascar, ha llevado a la conclusión de que el paratipo masculino de *G. simoni* pertenece a otra especie, por describir. Una serie grande de especímenes recogidos en los bosques húmedos de Ambatovy-Analamay-Torotorofotsy a unos 1000 m. de altitud reveló la presencia de otra especie nueva, también asociada a *G. simoni*. Gracias al material suplementario, que incluye machos y hembras, se propone una nueva diagnosis para *G. simoni* y se describen dos especies nuevas. Finalmente, se aportan comentarios generales sobre la biogeografía de las dos especies nuevas y de *G. simoni*.
Palabras clave: Scorpiones, Buthidae, *Grosphus*, especies nuevas, distribuciones centrales/orientales/occidentales, Madagascar.

Taxonomy / Taxonomía: *Grosphus rakotoariveloi* **sp. n.**, *Grosphus halleuxi* **sp. n.**

Introduction

In several recent publications we call the attention to the considerable number of new species which have been added to the genus *Grosphus* Simon in recent years (Lourenço, 2014; Lourenço & Wilmé, 2015a, b, 2016; Lourenço *et al*., 2016). One of the most reasonable explanations for this is the presence of numerous 'sibling' or vicariant species within this genus. Several of the recently described species showed some strong associations with other members of this genus that in some cases have been previously described. It is well accepted now that the taxonomy of *Grosphus*, one of the most relevant buthid genera endemic to Madagascar, is notably complicated, in particular concerning aspects of species' delimitations. For a more detailed discussion about the characters used in the taxonomy of *Grosphus*, see Lourenço (2014), Lourenço & Wilmé (2015a, b), Lourenço *et al.* (2016).

One recent example which attests the complexity of the *Grosphus* populations was the description of *Grosphus simoni* Lourenço, Goodman & Ramilijaona, 2004, based on two male specimens collected in two totally distinct localities (Lourenço *et al*., 2004): One from the Forêt de Plateau de Makira and the second from the Station Forestière d'Ampijoroa. The first site located in a typical humid forest while the second is located in dry open formations. At the time of the description of the species, the status of the western specimen was unclear but a final decision could not be made due to lack of sufficient material. Five specimens (3 males and 2 females) of *Grosphus simoni*, have been discovered recently in the collections of the museum in Paris; they were collected in the dense humid forests of Torotorofotsy (Region Alaotra-Mangoro). These findings have lead to the clarification of the status of this species and to the description of a distinct species for the specimen from the Station Forestière d'Ampijoroa.

Furthermore, the study of several specimens collected in the Torotorofotsy Forest (Fig. 1) in close vicinity to the lower montane humid forests of Analamay by J.-M. Betsch and other members of the RCP-225 during the 1970s, associated with other specimens more recently collected in the Ambatovy-Analamay forests, lead to the definition of yet another new species associated to *G. simoni*.

Some biogeographical comments are added to contextualize this new case of disrupted distribution among elements of a new defined *Grosphus* group.

Material and methods

Material related with the new species, as well as to *Grosphus simoni* are now deposited in three Museums: MNHN = Muséum national d'Histoire naturelle, Paris. UA = University of Antananarivo. FMNH = Field Museum of Natural History, Chicago.

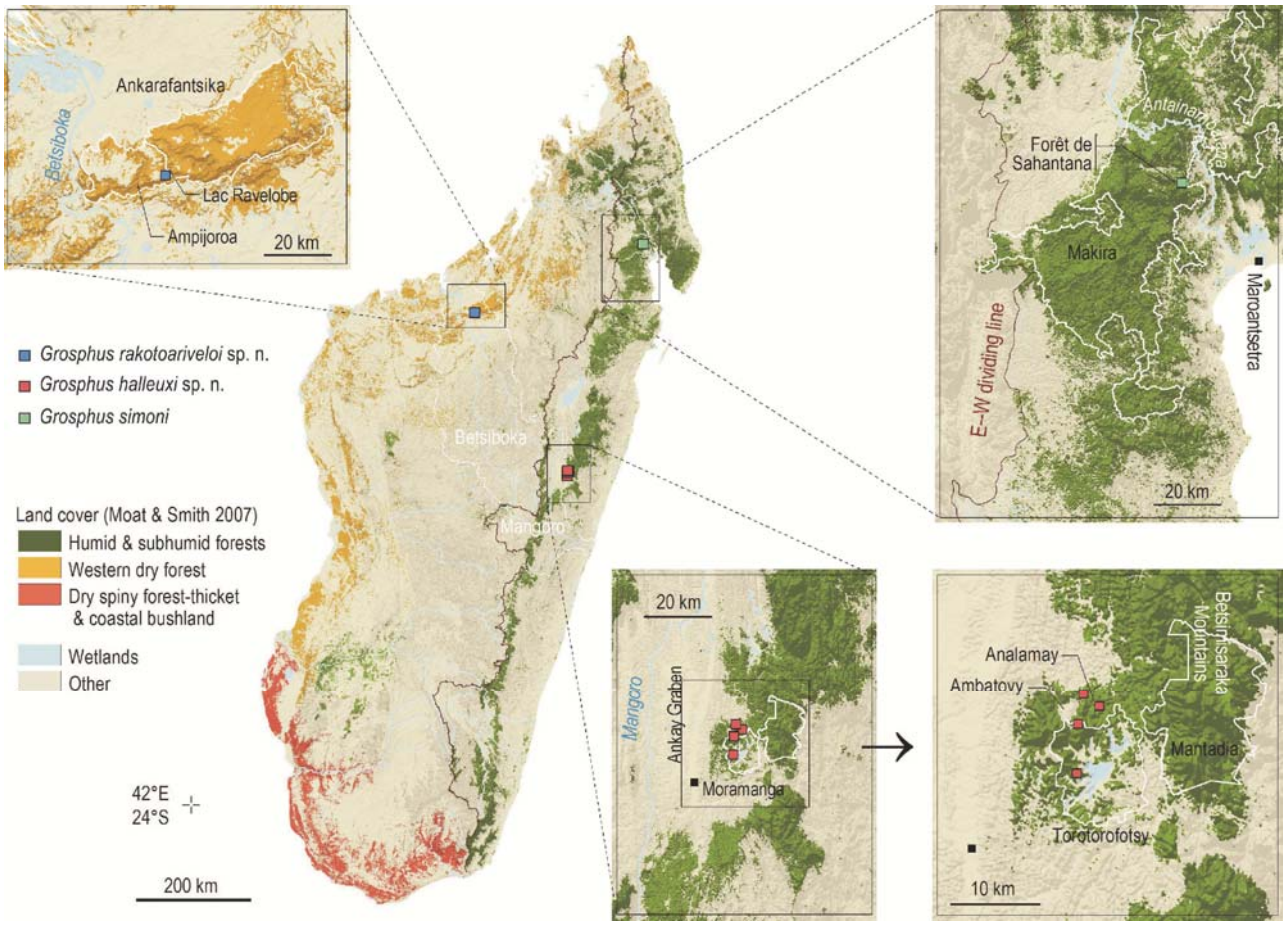


Fig. 1. Distribution of three sister species of *Grosphus* according to forest cover with some major watersheds delineated; *G. simoni* (top right), *G. rakotoarivelol* sp. n. (top left) and *G. halleuxi* sp. n. (bottom right).

Illustrations and measurements were produce using a Wild M5 stereomicroscope with a drawing tube and an ocular micrometer. Measurements follow Stahnke (1970) and are given in mm. Trichobothrial notations follow Vachon (1974) and morphological terminology is after Vachon (1952) and Hjelle (1990).

Taxonomic treatment

Family Buthidae C. L. Koch, 1837

Genus *Grosphus* Simon, 1880

Species considered in the present study

Grosphus simoni Lourenço, Goodman & Ramilijaona, 2004

Grosphus rakotoarivelo sp. n.

Grosphus halleuxi sp. n.

***Grosphus simoni* Lourenço, Goodman & Ramilijaona, 2004** (Fig. 1, 2-5)

Grosphus simoni Lourenço, Goodman & Ramilijaona, 2004: 230.

TYPE SPECIMEN: Madagascar, ex-Province de Toamasina, Region Analanjirofo, Forêt de Plateau de Makira, Forêt de Sahantaha, 7.7 km SW Soanafindra (15° 13.6' S – 49° 31.8' E), 300-1000 m (V. Andrianjakarivelo), 22/I/2003 (SMG-13646), male holotype (FMNH). **New material**: Madagascar, ex-Province of Toamasina, Region Analanjirofo, Forêt de Sahantaha (humid forest), IX/1974 (J.-M. Betsch –RCP-225): 3 males and 2 females (MNHN).

REVISED DIAGNOSIS: Moderate to large scorpions in relation to the average size of the species in the genus, with a total length of 50 to 60 mm. General coloration reddish-yellow to reddish-brown. The coloration is darker than that of *Grosphus rakotoarivelo* sp. n., but paler than that of *Grosphus halleuxi* sp. n. Metasomal granulation and carinae strongly marked, as in the other species of this group. Dorsal carinae of metasomal segments II to IV with several strong posterior spinoid granules. Pectines with 15 to 17 teeth in males and 14 to 15 in females. Basal middle lamellae of female pectines dilated and with an oval shape, what confirms the proximity of the species of this group with those of the *madagascariensis*/*hirtus* group. Fixed and movable fingers of pedipalp chela with 11-12 rows in males and 12-13 rows in females. Chela with a moderate to weak scalloping of the proximal dentate margin of fixed finger.

***Grosphus rakotoarivelol* sp. n.** (Fig. 6-15)

Grosphus simoni Lourenço *et al*., 2004 (in part: male specimen from Station Forestière d'Ampijoroa).

MATERIAL EXAMINED: ex-Province de Mahajanga, Region Boeny, Station Forestière (SF) d'Ampijoroa (16° 19.4' S – 46° 48.4' E), 160 m, in dry deciduous forest on white sand (S. M. Goodman), 18/IV/2003 (SMG 13617). 1 male holotype (previously a paratype of *G. simoni*), deposited in the Muséum national d'Histoire naturelle, Paris.

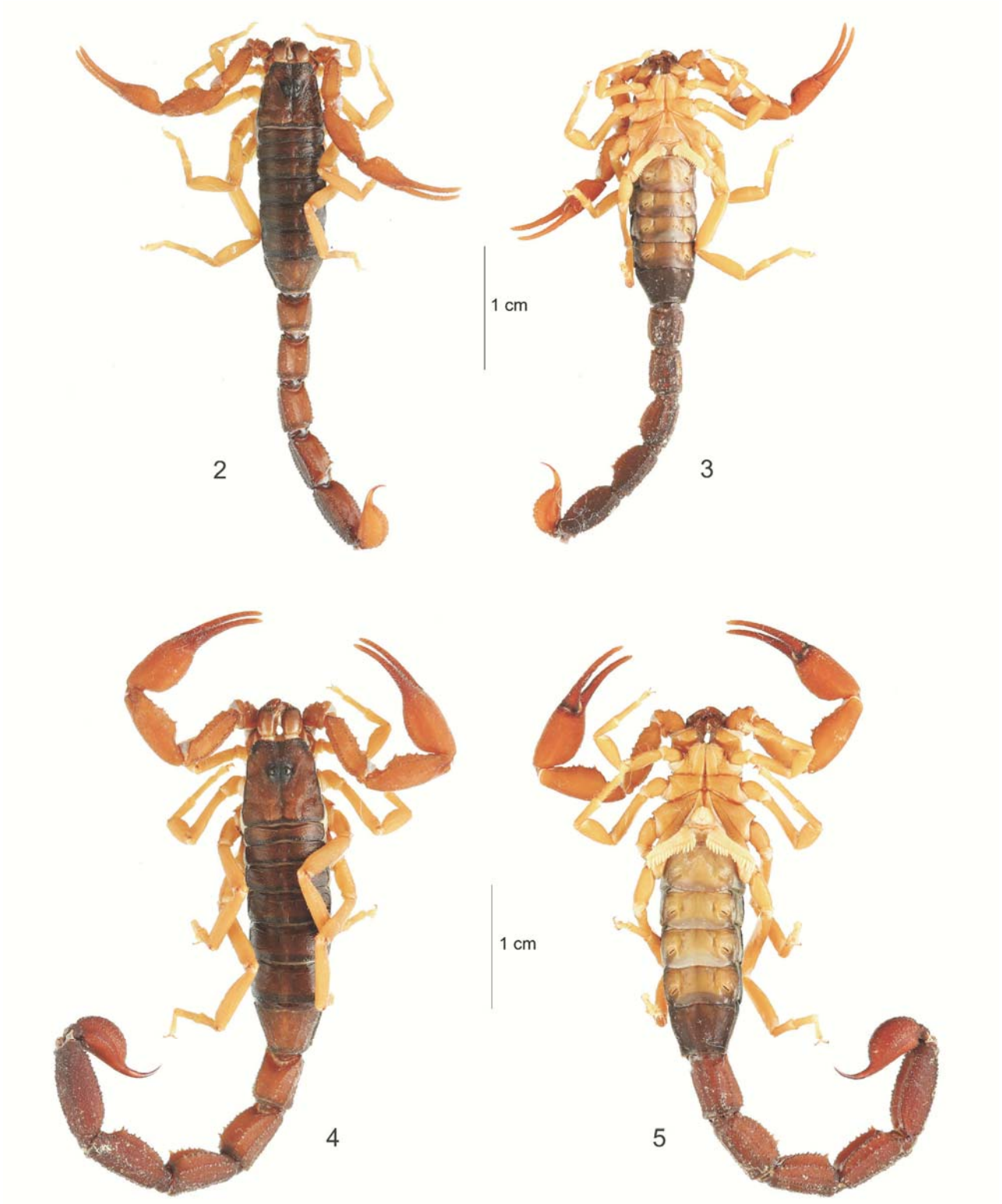


Fig. 2-5 *Grosphus simoni* male (**2-3**) and female (**4-5**) from 'Forêt de Sahantaha'. Habitus, dorsal and ventral aspects.

ETYMOLOGY: The specific name honors Caleb Rakotoarivelo (Antananarivo) for his constant support and friendship to the second author of this research.

DIAGNOSIS: Large scorpions in relation to the average size of the species in the genus, with a total length of 71.9 mm. General coloration pale yellow to reddish-yellow. Metasomal granulations and dorsal carinae strongly marked with several spinoid granules. Pectines with 18-19 teeth. Cutting edges of chela fingers with 13-14 rows of granules. Chela with a moderate to strong scalloping of the proximal dentate margin of fixed finger. The species can be readily distinguished from the other species of this small group by the following characters: (i) a much paler global coloration, with the appendages yellow to pale yellow, (ii) a higher number of teeth on pectines, (ii) 13-14 rows of granules on cutting edges of pedipalp-chela fingers.

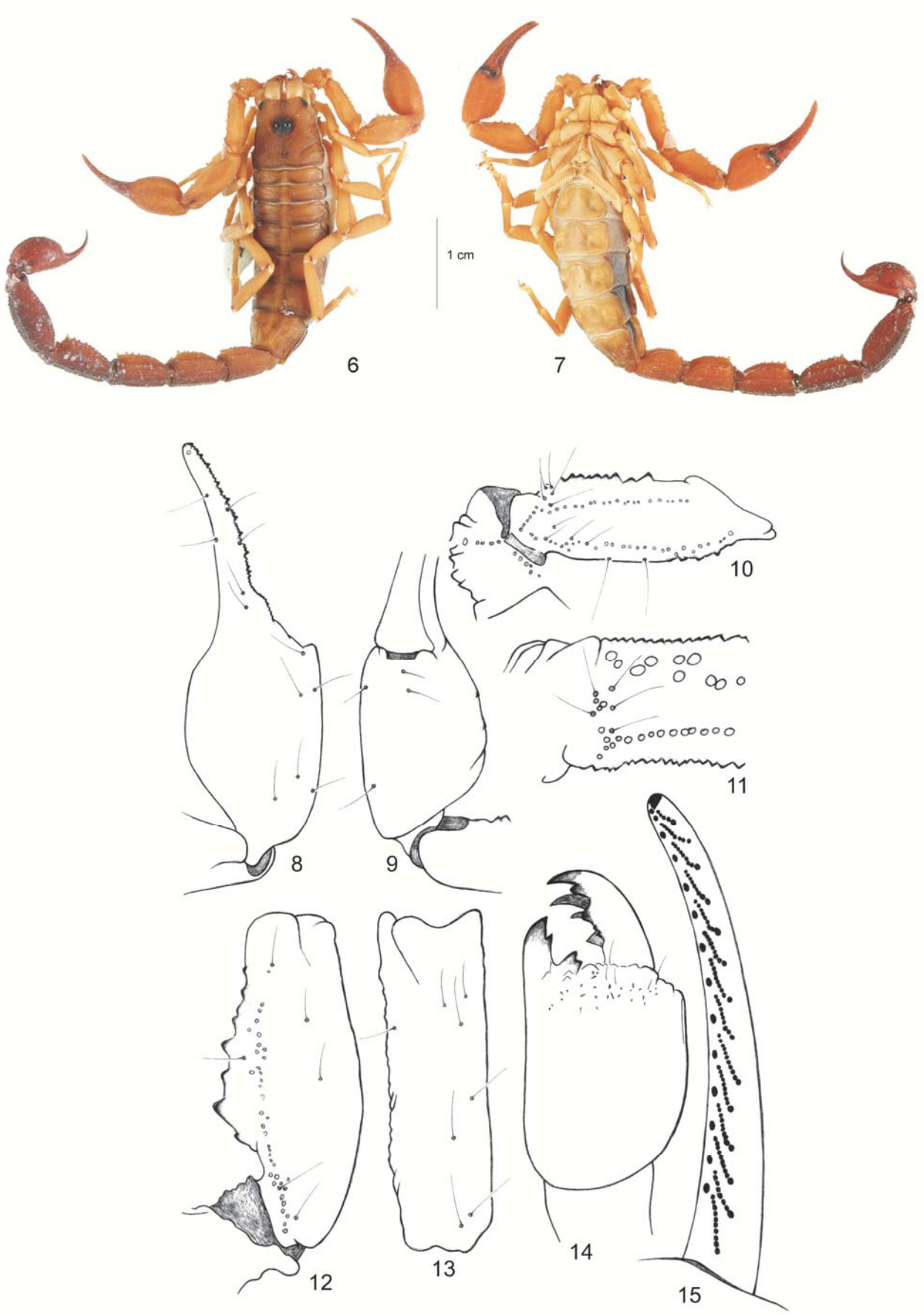


Fig. 6-15. *Grosphus rakotoariveloi* sp. n. Male holotype. **6-7**.Habitus, dorsal and ventral aspects. **8-13**. Trichobothrial pattern. **8-9**. Chela dorso-external and ventral aspects. **10-11**. Femur, dorsal and internal aspects. **12-13**. Patella, dorsal and external aspects. **14**. Chelicera, dorsal aspect. **15**. Cutting edge of movable finger showing rows of granules.

DESCRIPTION BASED ON MALE HOLOTYPE.

Measurements in Table I.

Coloration. Basically reddish yellow to pale yellow. Prosoma: carapace yellow with the posterior and lateral margins dark; eyes surrounded by black pigment. Mesosoma: yellow with dark strips on the posterior margins of tergites. Metasoma: all segments reddish-yellow with some vestigial dark pigmentation on the ventral carinae; segment V darker than the others. Telson reddish-yellow without spots; aculeus with reddish-yellow base and dark reddish tip. Venter: coxapophysis, sternum, genital operculum and pectines yellow to pale yellow; sternites pale yellow; VII slightly darker. Chelicerae yellow with a pale variegated pigmentation over the anterior portion; fingers and teeth reddish. Pedipalps: reddish-yellow. Legs yellow without spots.

Morphology. Carapace moderately granular; anterior margin with a weak median concavity. All carinae weak; furrows moderately developed. Median ocular tubercle anterior to the centre of the carapace; median eyes separated by about one ocular diameter. Three pairs of lateral eyes. Sternum subtriangular in shape. Mesosoma: tergites with thin poorly intense granulation. Median carina moderately developed in all tergites. Tergite VII pentacarinate. Venter: genital operculum consisting of two semi-oval plates. Pectines: pectinal tooth count 18-19; basal middle lamellae of each pecten not dilated in male. Sternites smooth, with elongated stigmata; VII with four vestigial carinae. Metasomal segments I to III with 10 carinae, crenulate; segment IV with 8 carinae, crenulate. Segment V with 5 carinae; intermediate carina incomplete on II. Dorsal carinae on segments II to IV with several strong posterior spinoid granules. Intercarinal spaces strongly granular. Telson moderately granular over latero-ventral and ventral surfaces; its dorsal surface smooth; aculeus moderately curved and shorter than the vesicle; subaculear tooth absent. Cheliceral dentition characteristic of the family Buthidae (Vachon, 1963); two distinct basal teeth present on the movable finger; ventral aspect of both fingers and of manus with dense, long setae. Pedipalps: femur pentacarinate; patella with a dorsointernal carina and with several strong spinoid granules on the internal face; dorsal carina weak; chela smooth, without carinae. Fixed and movable fingers with 13-14 oblique rows of granules. Trichobothriotaxy; orthobothriotaxy A-α (Vachon, 1974, 1975). Legs: tarsus with numerous short thin setae ventrally. Tibial spurs present on legs III and IV; pedal spurs present on legs I to IV; all spurs strong.

Female unknown.

***Grosphus halleuxi* sp. n.** (Fig. 16-25)

MATERIAL EXAMINED: Madagascar, ex-Province of Toamasina, Region of Alaotra-Mangoro, District of Moramanga, Torotorofotsy Forest (dense humid forest), 1060 m, XI/1974 (J.-M. Betsch –RCP-225): 1 male holotype, 8 male paratypes (MNHN).

Other paratypes. Madagascar: ex-Province of Toamasina, Region Alaotra-Mangoro, District of Moramanga, Analamay Forest, 10 km E of Ambohimanarivo Village, Dense humid forest, 15-31/I/ 2009 (V. Soarimalala): (18°48'20.8"S-48°21' 38.1"E), 1006 m: 8 males (MNHN); (18°49'25.9"S-48°20' 18"E), 1045 m: 3 males (FMNH); (18°49'25.9"S-48°20' 18"E), 1045 m: 4 males (UA); (18°47'36.1"S-48°20'37"E), 1105 m: 1 male (FMNH).

Table I. Comparative morphometric values (in mm) of the male holotypes of the *Grosphus* species associated with *G. simoni*

Grosphus	*simoni*	*rakotoariveloi* sp. n.	*halleuxi* sp. n.
Total length(*)	61.9	71.9	54.8
Carapace:			
-length	6.4	7.6	6.1
-anterior width	4.8	5.5	4.4
-posterior width	6.9	8.5	6.8
Mesosoma length	18.2	21.8	15.9
Metasomal segment I:			
-length	4.5	5.0	3.7
-width	3.4	3.8	3.4
Metasomal segment II:			
-length	5.3	5.9	4.3
-width	3.2	3.6	3.3
Metasomal segment III:			
-length	5.6	6.4	4.8
-width	3.2	3.5	3.2
Metasomal segment IV			
-length	6.5	7.5	5.5
-width	3.2	3.4	3.2
Metasomal segment V:			
-length	7.7	8.6	6.7
-width	3.2	3.4	3.1
-depth	3.3	3.7	3.2
Telson length	7.7	9.1	7.8
Vesicle:			
-width	2.8	3.8	3.0
-depth	2.9	3.8	2.8
Pedipalp:			
-Femur length	6.2	6.9	5.8
-Femur width	1.9	2.3	1.8
-Patella length	7.1	8.2	6.8
-Patella width	2.7	3.2	2.5
-Chela length	11.9	13.6	11.8
-Chela width	3.1	4.2	3.2
-Chela depth	2.8	3.6	3.0
Movable finger:			
-length	6.8	7.7	6.8

(*) including telson

ETYMOLOGY: The specific name honors Dominique Halleux, an ornithologist who opened many localities to the knowledge of naturalists in Madagascar.

DIAGNOSIS: Scorpions of medium size in relation to the average size of the species in the genus, with a total length of 54-55 mm for an average male. General coloration reddish-yellow to reddish-brown. Metasomal granulations and dorsal carinae strongly marked with several spinoid granules. Pectines with 16 to 19 teeth (mode = 17-18). Cutting edges of chela fingers with 11-12 rows of granules. Chela with a moderate to weakly marked scalloping of the proximal dentate margin of fixed finger. The species can be readily distinguished from the other species of this small group by the following characters: (i) a much darker global coloration, with the body and appendages reddish-yellow to reddish-brown (ii) a smaller global size, (iii) a higher number of teeth on pectines compared to *G. simoni*, (iv) 11-12 rows of granules on cutting edges of pedipalp-chela fingers, (v) a less marked scalloping of the proximal dentate margin of fixed finger

DESCRIPTION BASED ON MALE HOLOTYPE AND MALE PARATYPES.

Measurements in Table I.

Coloration. Basically reddish-yellow to reddish-brown. Prosoma: carapace reddish-brown with the posterior and lateral margins dark; eyes surrounded by black pigment. Mesosoma: reddish-yellow to reddish-brown with dark strips on the poste-

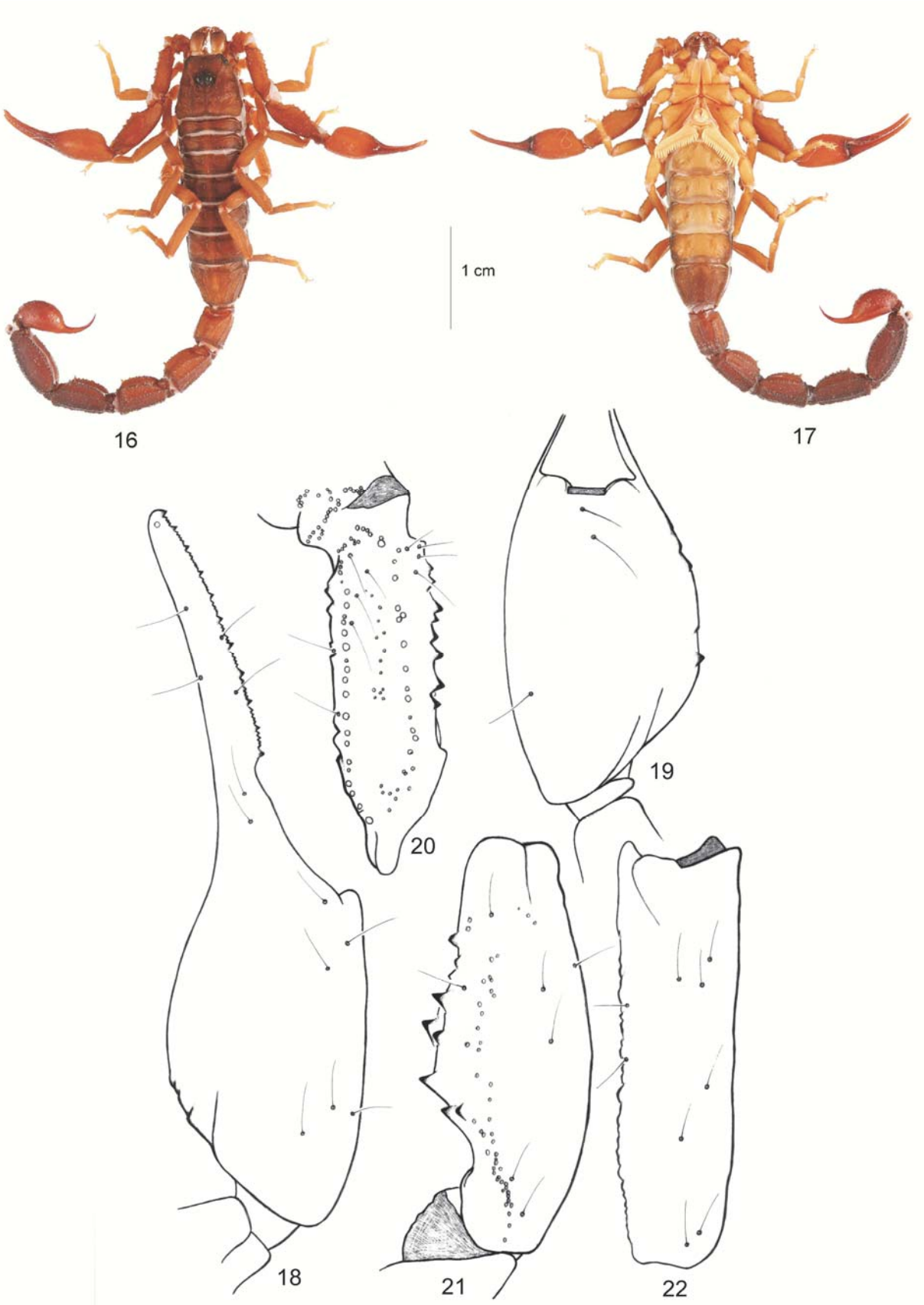


Fig 16-22. *Grosphus halleuxi* sp. n. Male holotype. **16-17**. Habitus, dorsal and ventral aspects. **18-22.** Trichobothrial pattern. **18-19**. Chela, dorso-external and ventral aspects. **20**. Femur, dorsal aspect. **21-22**. Patella, dorsal and external aspects.

Fig. 23-25. *Grosphus halleuxi* sp. n. Male holotype. **23**. Chelicera, dorsal aspect. **24**. Metasomal segments III-V and telson, lateral aspect. **25**. Cutting edge of movable finger showing rows of granules.

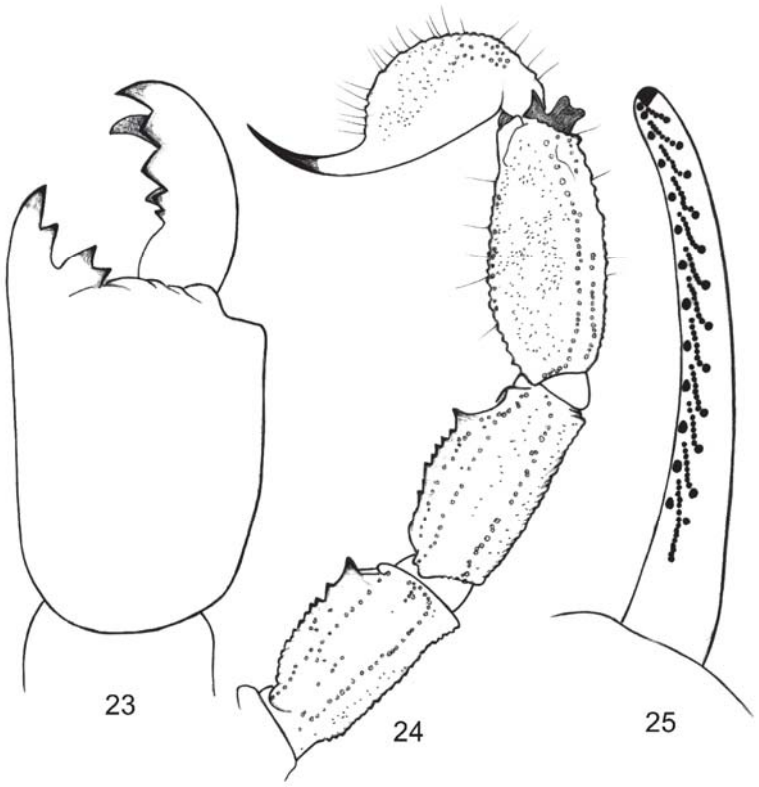


Table II. Variation of the number of male pectinal teeth of *Grosphus halleuxi* sp. n.

N-Teeth	N-Pectines
16	5
17	29
18	12
19	2

rior margins of tergites. Metasoma: all segments reddish to reddish-brown with some vestigial dark pigmentation on the ventral carinae. Telson reddish without spots; aculeus with reddish yellow base and dark reddish tip. Venter: coxapophysis and sternum reddish-yellow, genital operculum and pectines pale yellow; sternites yellow; VII dark. Chelicerae yellowish with dark variegated pigmentation over the entire surface; fingers and teeth reddish. Pedipalps: reddish-yellow with dark carinae. Legs reddish-yellow without spots.

Morphology. Carapace moderately granular; anterior margin with a weak median concavity. All carinae weak; furrows moderately developed. Median ocular tubercle anterior to the centre of the carapace; median eyes separated by one ocular diameter. Three pairs of lateral eyes. Sternum sub-triangular in shape. Mesosoma: tergites with thin poorly intense granulation. Median carina moderately developed in all tergites. Tergite VII pentacarinate. Venter: genital operculum consisting of two semi-oval plates. Pectines: pectinal tooth count 18-19 in male holotype (see table II); basal middle lamellae of each pecten not dilated in males. Sternites smooth, with elongated stigmata; VII with four vestigial carinae and granulations. Metasomal segments I to III with 10 carinae, crenulate; segment IV with 8 carinae, crenulate. Segment V with 5 carinae; intermediate carinae incomplete on II. Dorsal carinae on segments II to IV with several strong posterior spinoid granules. Intercarinal spaces moderately to strongly granular. Telson strongly granular over latero-ventral and ventral surfaces; its dorsal surface smooth; aculeus moderately curved and as long as the vesicle; subaculear tooth absent. Cheliceral dentition characteristic of the family Buthidae (Vachon, 1963); two distinct basal teeth present on the movable finger; ventral aspect of both fingers and of manus with dense, long setae. Pedipalps: femur pentacarinate; patella with a moderate dorsal carina and a strong dorsointernal carina; presence of several strong spinoid granules on the internal face; chela smooth, without carinae, only the internal face with a few granules. Fixed and movable fingers with 11-12 oblique rows of granules. Trichobothriotaxy; orthobothriotaxy A-α (Vachon, 1974, 1975). Legs: tarsus with numerous short thin setae ventrally. Tibial spurs present on legs III and IV; pedal spurs present on legs I to IV; all spurs strong.

Female unknown.

Biogeographical aspects

The type localities and only known localities for the three species considered here are several hundred km apart. The Ankarafantsika National Park, type locality of *Grosphus rakotoariveloi* sp. n., lies on the western slope of Madagascar, in the lower portion of the Betsiboka watershed (Fig. 1). The type of forest habitat is classified as 'Western Dry Forest' (Moat & Smith, 2007), at altitudes ranging from ca. 20 m (mainly above 50 m) to 350 m for the national park, and ca. 20 m to 250 m for the Forest Station of Ampijoroa, the western portion of the Ankarafantsika National Park (Fig. 1). At some 200 m to the Northeast of the collection locality lies the Ravelobe lake. The underlying geology of Ankaranfantsika National Park is of Cretaceous marl and clay. The mean annual rainfall is between 1000 and 1500 mm falling mainly between November and April. The dry season is lasting several months, at least from May to October (Alonso & Hannah, 2002).

The forests of Torotorofotsy and Ambatovy-Analamay are situated in the central eastern portion of Madagascar (Fig. 1). Torotofotsy is renowned for its marshlands surrounded by humid forests at elevation ranging from ca. 920 m to 1180 m; an area of some 10,000 ha has been proposed as a New Protected Area (Fig. 1). The forests of Analamay are located to the north of Torotorofotsy in the region of the Ambatovy mine, with elevations between 930 and 1200 m. The Torotorofotsy and the Ambatovy-Analamay forests lie along the Southeastern border of the Alaotra-Ankay Graben, a rift val-

ley with high seismic activity (Kusky *et al*., 2010; Raharimahefa *et al*., 2013), and are in the rain shadow of the Betsimisaraka Mountains (Lourenço & Wilmé, 2015b). Torotorofotsy and Ambatovy-Analamay forests receive less orographic rainfall than the windward Betsimisaraka Mountains, e.g., Analamazaotra or Mantadia reserves (Fig. 1). The soil substrates in Ambatovy-Analamay are largely igneous in origin with low concentrations of silica and high concentrations of magnesium, nickel, and iron (Melluso *et al*., 2005). The mean annual rainfall was 1504 mm for Moramanga, a city located at an elevation of 912 m to the East of the mining site of Ambatovy, and of 1713 mm in Analamazaotra at an elevation of 928 m (Cornet, 1974).

The humid forests of the Makira Natural Park, where the *Grosphus simoni* Lourenço, Goodman & Ramilijaona, 2004 has been located, lies at elevations spanning from ca. 100 m to 1450 m. The forest of Sahantaha is located in the northern part of the Makira park, in the Antainambalana watershed (Wilmé *et al.,* 2006, 2012, Fig. 1). The forest bear the same name as the geological group of the region, the Sahantaha shelf sediments which are only well preserved in this region (Windley *et al*., 1994; De Waele *et al*., 2011). The Sahantana group is dominated by quartzites, gneiss, pelitic schist, and some veins of calcareous schist or cipolin (Ishwar-Kumar *et al*. 2013) including at the place of the collection of *G. simoni*. Quaternary volcanism is present just to the east of the Sahantana group. The lower part of the site at elevation below 500 m has also been referred as Lohanisahantaha (Rakotomalala *et al*., 2007). The mean annual rainfall in Maroantsetra was 3703 mm in a per-humid bioclimate with no dry season (Cornet, 1974).

This group of scorpions is distributed in the per-humid, humid and dry bioclimates. *Grosphus rakotoariveloi* sp. n. is found in the dry forest of Ankarafantsika, at a distance of some 18 km from the Betsiboka river, and ca. 40 km from its estuary. The type locality is at a short distance of Lake Ravelobe which belongs to a permanent river, tributary of the Betsiboka River, with a confluence at a close distance from the estuary. The Ampijoroa Forest Station offers some humid conditions for species; this region in the sedimentary basin of Mahajanga could have served as refugia (cf. Wilmé *et al*., 2006) where some mesic conditions were maintained during the driest periods of the paleoclimate oscillations (cf. Mercier & Wilmé, 2013).

The narrow-ranged species *Grosphus halleuxi* sp. n. in the Torotorofotsy and Analamay forests is best explained by the localized conditions present in the rainshadow of the Betsimisaraka Mountains. The Analamay and Torotorofotsy forests occur in the Rianila watershed to the East of the Northern portion of the Mangoro watershed (Wilmé *et al*. 2006, 2012). The species occurs in humid forests but in a drier setting than most of the other forests of the Betsimisaraka Mountains. Other species of *Grosphus* occur in the humid forests of these mountains, including *G. madagascariensis* (Gervais, 1843); a local adaptation to a micro-climate as in the Analamay and Torotorofotsy forests occurring in the rainshadow of the Betsimisaraka Mountains has also been proposed to explain the distribution of *Grosphus voahangyae* Lourenço & Wilmé 2015 in these forests (Lourenço & Wilmé 2015b).

The two new sister species of *Grosphus simoni* occur in localities that are a lot drier than the forests of Makira. Due to the patchy distribution of these three sister species, it can be expected that future collections should reveal more individuals from one of these three species or new sister species in Northern Madagascar.

Acknowledgements

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(*) Available on www.sea-entomologia.org