Nine new emerald species for the fauna of Yemen, with description of two new taxa in the genus *Prasinocyma*

*(Lepidoptera, Geometridae, Geometrinae)*

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In this paper we present a checklist and integrative revision for the genus *Prasinocyma* (Geometridae, Geometrinae, Hemristolini), combining morphological and molecular data, for the Republic of Yemen. Whilst, previously, only one species was recorded, we can now add eight new *Prasinocyma* species to the fauna of Yemen. One species and one subspecies are described as new for the science: *Prasinocyma angolica yemenicola* subspec. nov. and *Prasinocyma saba* spec. nov. Furthermore, *Androzegma tenuis* (Warren, 1898) was recorded for the first time in Yemen. With this, the number of geometrid species recorded from Yemen is raised from 168 to 177 species.

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**Introduction**

The geometrid Fauna of Yemen was subject of several previous papers (Hausmann 1999, 2006, Hausmann et al. 2016a) but not all members of the taxonomically difficult genus *Prasinocyma* Warren, 1897 could be identified properly. Three species had earlier been described from Saudi Arabia, two of them (*P. arabica* Wiltshire, 1982, *P. eremica* Wiltshire, 1980) could be recorded for Yemen in the above cited papers. After the revision of the genus *Prasinocyma* in Ethiopia (Hausmann et al. 2016b) and careful study of almost all congeneric type specimens we can present here a revision of the genus *Prasinocyma* in Yemen.

The 117 so far described species for the Afrotropical fauna (19 of them in Hausmann et al. 2016b) are very similar to each other in their green coloration and the almost entirely lacking wing pattern. Often, males can hardly be attributed to conspecific females and almost no genitalia illustrations are published. This is why even the grand-master of geometridology, Claude Herbulot, just gave a very few identifications in his collection.

With the technique of DNA Barcoding (including old type specimens cf. Hausmann et al. 2016c) and with numerous dissections we were able to overcome these problems and to come closer to a thorough revision of the African/Arabian species of *Prasinocyma*. So far we have gathered more than 550 DNA barcodes for African members of the genus *Prasinocyma* belonging to 170 BINs (barcode index numbers, being a good proxy for species numbers) with 20 additional lineages clearly referring to further *Prasinocyma* species but without BIN assignment (fragment lengths <500 bp). The accumulation curve of African *Prasinocyma* species suggests saturation far beyond 250 species.

**Material and methods**

**Abbreviations**

- **BOLD** Barcode of Life Data System
- **CCDB** Canadian Centre for DNA Barcoding
- **COI** mitochondrial cytochrome c oxidase I (COI) gene, region near the 5’ terminus (barcode fragment, 658 bp)
Sampling and morphological analysis

Sampling in various localities of Yemen is described in Hausmann (1999, 2006). For the codification of the sampling localities see Hausmann (2006). Specimens were pinned, mounted and identified by comparison with collections, type specimens and literature or, if necessary, by genitalia dissection. Dissection and preparation of genitalia slides were performed applying standard protocols (cf. Robinson 1976); the genitalia were embedded in Euparal and mounted on slides. Measurements were done with a reticule in a Wild M3Z microscope.

Specimens are deposited in the entomological collections of the Zoologische Staatssammlung München (Germany).

DNA analysis

DNA sequences were generated for 33 Yemenite Prasinocyma specimens at the Canadian Centre for DNA Barcoding (CCDB, Guelph) following standard high-throughput protocols (Ivanova et al. 2006, deWaard et al. 2008), 30 of them with fragment lengths over 500 bp. PCR amplification with a single pair of primers consistently recovered a 658 bp region near the 5’ end of the mitochondrial cytochrome c oxidase I (COI) gene that included the standard 648 bp barcode region for the animal kingdom (Hebert et al. 2003). DNA extracts are stored at the CCDB. All sequence data are deposited also in GenBank according to the iBOL data release policy. Complete specimen data including images, voucher deposition, GenBank accession numbers, GPS coordinates, sequence and trace files can easily be accessed in the Barcode of Life Data System (Ratnasingham & Hebert 2007) in the public data set DS-PRASIYE (http://dx.doi.org/10.5883/DS-PRASIYE). For comparison, DNA barcodes have been generated from 72...
type specimens from the NHMUK with a special NGS-based protocol (Prosser et al. 2016, Hausmann et al. 2016c).

Data analysis

Sequence divergences for the barcode region were calculated using the Kimura 2 Parameter model, employing the analytical tools on BOLD. Genetic distances between species are reported as minimum pairwise distances, while intraspecific variations are reported as maximum pairwise distances. A neighbour joining tree with all barcoded species of this article and their nearest neighbours is shown in Figure 21. For species delineation we refer to the BIN-system (Barcode Index Numbers) on BOLD (Ratnasingham & Hebert 2013).

Taxonomy and nomenclature

The systematic order of species and species-groups is based on Hausmann (2016b); the nomenclature follows Scoble (1999), Scoble & Hausmann (2007) and Hausmann et al. (2016b).

Systematic part

Geometrinae
Tribe Hemistolini Inoue, 1961

Genus Prasinocyma Warren, 1897

Type species: Thalassodes vermicularia Guenée, 1858 (South Africa: Northern Cape, Namaqualand) by original designation.

For systematic position of the genus and differential characters within the “Thalassodes group of genera” see extensive discussion in Hausmann (2016b). The aforementioned publication raised the species number of described African and Arabian species from 94 to 117 by the description of 19 new species and the transfer of four other species from genus Eretmopus to Prasinocyma. With several new samples, recently arrived at the ZSM from various African countries, just six months after the publication of Hausmann et al. (2016b), the estimated species number for African Prasinocyma as revealed from DNA barcoding and dissections (restricted to material of the ZSM, so far) has raised from 140 to more than 200 species. Saturation is expected far beyond the mark of 300 species.

The immaculata species-group

Prasinocyma angolica Prout, 1930

Prasinocyma angolica Prout, 1930: 22. Locus typicus: Angola, Bihi (Syntypes 5 ♀ NHMUK, examined).

Prasinocyma angolica pseudopedicata Hausmann, Sciarretta & Parisi, 2016: 13. Locus typicus: S. Ethiopia, Oromia, 7 km NW Yabello (Holotype ♂ ZSM, examined, dissected and barcoded). Validated at subspecies rank.

Prasinocyma angolica yemenicola, subspec. nov.

Figs 1, 2, 13


Description

The new subspecies – like the nominotypical subspecies and subspp. pseudopedicata – is medium-sized (wingspan 24–26 mm), frons ochreous to pale brown, male hindtibia with pencil and four spurs, covering first tarsomere, discal spots absent or vague, hind-wing round. For differential diagnosis from other congeneric species see Hausmann et al. (2016b).

Male genitalia. Without differences from P. angolica and subspp. pseudopedicata, except for sternum A8: posterior processes in P. angolica yemenicola subspec. nov. stouter and much stronger curved outside.

Genetic data. BIN: BOLD:AAF8220. Nearest genetic neighbour: P. angolica (examined in subspp. pseudopedicata from Ethiopia and subspp. angolica from Sao Tomé) at a distance of 2.2 % but BIN-sharing; P. pedicata aethiopica Hausmann et al., 2016 from Ethiopia BIN-sharing, too (cf. Hausmann et al. 2016) and even closer, but genitalia clearly assign the Yemenite populations to P. angolica. Six DNA barcodes from Yemen (see Fig. 21), two of them dissected: ZSM G 19859, 20172.

Prasinocyma eremica Wiltshire, 1980

Figs 3, 14


Description and differential diagnosis see Wiltshire (1980).

Genetic data. Two constant BINs (both with 0 % variation) at a distance of 1.5 %: (1) BOLD:ACE4388 with four barcodes from Yemen, provinces Sana’a and Ibb (one dissected: ZSM G 19857); (2) BOLD:AAF0062: two barcodes from Yemen, both from Sana’a city (see Fig. 21). Nearest neighbour: P. hailei from Ethiopia (3.8 %).

The nereis species-group

Prasinocyma saba Hausmann & Wildfeuer, spec. nov.

Figs 4, 15

Description

Adult (Fig. 3). Wingspan. Male 23–24 mm. Ground colour comparatively pale green, very densely irrorated with white striigae. Forewing without spot at the inner termen. On fore- and hindwing, terminal and discal dots absent. Hindwing termen round. Male palpi short, length 0.8–1.0 times diameter of eye, tip and upperside reddish. Frons red-brown. Antennae bipecate in male. Male frenulum developed up to weak. Male hindtibia narrow, with four spurs and white pencil.

Differential diagnosis. Closely related to Prasinocyma shoa yabellensis Hausmann et al., 2016, described from southern Ethiopia. Differing in the male genitalia in the broader valva, dorsally straight whilst strongly curved in P. shoa shoa Herbulot, 1993 and P. shoa yabellensis. Ventral part of valva in P. saba spec. nov. with spinose saccus, projection straight rather than inwards curved, basal thorn slightly longer. Aedeagus shorter. No difference from P. shoa in the shape of sternum A8. DNA barcode suggesting certain relationships with P. corrugata Fletcher, 1958 (see below) but the latter larger, hindwing angled, in male genitalia clearly differing in the shape of the (narrow) harpe, aedeagus with two cornuti, processes of sternum A8 tapered (cf. Hausmann et al. 2016b).

Male genitalia (Fig. 15). Uncus short. Short socii present. Valva broad, with dorsolateral corners and with a large subapical ventral membranous lobe. Saccus sclerotized, broad, straight towards tip, terminally round and spinulose. Dorsobasal margin of saccus with thorny process. Aedeagus with a very narrow proximal stalk, length 1.5 mm, without cornuti, vesica weakly granulated. Sternum A8 with two poorly sclerotized prominent lobes and deep invagination between.

Genetic data. BIN: BOLD:AAL0595. One barcode from Yemen (see Fig. 21). Nearest neighbours: P. corrugata (3.1 %) and P. shoa yabellensis (3.8 %). Distance to P. shoa shoa 6.4 %.

Genetic data. BIN: BOLD:ABW1385. One barcode from Saudi Arabia, two barcodes from Yemen (see Fig. 21). The latter genetically somewhat diverging (1.7 %) from populations from Saudi Arabia. Nearest genetic neighbours (three fragmentary barcodes from type specimens): P. leucopsis exilior Fletcher, 1958 from Tanzania (4.5 %), P. edwardsi Fletcher, 1958 from Kenya (4.5 %) and P. stictinargo Warren, 1902 from Kenya (5.3 %). P. robusta Hausmann et al., 2016 from Ethiopia diverging by 6.5 %, though morphologically being close to P. acutipennis.

Prasinocyma arabica Wiltshire, 1982
Figs 6, 7, 17


Description and differential diagnosis see Wiltshire (1982).

Genetic data. BIN: BOLD:AAF0061: five barcodes at high but continuous genetic variation (maximum pairwise distance 1.4 %; see Fig. 21). Nearest neighbours: an unidentified species from Zambia (6.0 %) and P. edwardsi Fletcher, 1958 from Kenya (6.3 %).

Prasinocyma magica Hausmann, Sciarretta & Parisi, 2016
Figs 8, 18


Description and differential diagnosis see Hausmann et al. (2016b).

Genetic data. BIN: BOLD:ABA7613. Two barcodes from Yemen (see Fig. 21). Genetically well matching the nominotypical populations from Ethiopia.
Nearest neighbours: *P. batesi distans* Hausmann et al., 2016 (3.8 %) and *P. germinaria* (Guenée, 1858) (4.9 %), both described from Ethiopia.

**Prasinocyma sanguinicosta** Prout, 1912

*Prasinocyma sanguinicosta* Prout, 1912: in Wytsman, Genera Insectorum 129: 156. Locus typicus: Sudan, Kartum (Holotype M, NHMUK, examined, dissected and barcoded: BMNH (E) 1377543).


**Description** see Prout (1912).

**Differential diagnosis.** Forewing costa bicolorous, pale creamy-white with reddish margin. All wings with a fine, black discal dot. Frons pale brown. Male palpi comparatively long (1.4 times diameter of eye). Frenulum very weak. Male hindtibia with four spurs, without pencil.


**Genetic data.** BIN: BOLD:ACV2622. Five barcodes from Yemen (see Fig. 21), three of them dissected. Intraspecific variation low (maximum pairwise distance 0.3 %). Nearest neighbour: *P. germinaria* (Guenée, 1858) from Ethiopia (5.6 %).

**The bifimbriata species-group**

**Prasinocyma bilobata** Fletcher, 1978


Description

Adult (Fig. 6). Wingspan. Male 18–20 mm. Ground colour bluish green, not irrorated with white strigulae. Forewings sometimes with minute spot at the inner termen. On fore- and hindwings, a minute black discal dot present but variable in intensity. Terminal line fine, black, slightly undulate, at vein endings marked by whitish dots distally from terminal line. Hindwing termen angled at M3. Male palpi long, length 1.4–1.6 times diameter of eye, last segment elongate and narrow, ochreous. Frons brown with slight greenish tinge. Antennae bipectinate in male. Male frenulum very weak, almost absent. Male hindtibia narrow, with four spurs, without pencil.

Differential diagnosis. The closest related species, *P. albisticta* (Warren, 1901), shares with *P. bilobata* the following features: gnathos well developed, socii developed though remaining short, saccus elongate digitiform, valva with dorsal projection, aedeagus with a long lateral appendage. *P. albisticta* differs from *P. bilobata* in the larger wingspan (22–26 mm), longer male palpi (1.7 times diameter of eye), in male genitalia in the shorter dorsal process of valva, ventral margin of valva less concave, transtilla with long dorsal projection, aedeagus longer (1.4 mm) and curved at tip, paired lobes of sternum A8 rounded.

Male genitalia (Fig. 20). Uncus of medium length. Socii short. Gnathos well developed. Transtilla developed as a large, sub-oval sclerite. Saccus projecting, digitiform. Valva with a long, sclerotized, tapering dorsal projection, ventral margin deeply concave at centre. Aedeagus straight, comparatively short (1.05–1.15 mm), with very thin lateral appendage, as long as the rest of the aedeagus. Sternum A8 sclerotized, with two triangular projections.
Genetic data. BIN: BOLD:ADB1216. One barcode from Yemen (BC ZSM Lep 98940, see Fig. 21). Nearest neighbour: P. albisticta (Warren, 1901) from Ethiopia (3.8 %).

Remarks. P. bilobata was described from Malawi, but so far, no DNA barcode could be generated for a south-eastern African specimen. Currently, the species identification is based on the very high similarity with the genitalia of the type specimen. The holotype, however, is differing from populations from Yemen by the lacking discal dots, by its yellow fringe, separated from the uniform green ground colour of wings and by the straight, fine black terminal line. The minute white dots distally from the terminal line at the vein endings are almost invisible. Further study is needed to investigate if these differences are constant and if they are, potentially, correlated with divergences in the DNA barcode.

The lateral projection of aedeagus, the missing subapical lobe on the ventral margin of valva, the dorsal projection of valva and the sclerotization of juxta are reminiscent of genus Thalassodes, but the very short socii and the genetic similarity with the bifimbriata species-group support a position in Prasinocyma as proposed by Prout (1930) and Scoble (1999).

Genus Androzeugma Prout, 1913
Type species: Androzeugma hapala Prout, 1913 (junior synonym of A. tenuis Warren, 1898) (northern Nigeria: Zungeru); by original designation.

Androzeugma tenuis (Warren, 1898)
Fig. 11


Genetic data. BIN: BOLD:AAD6950 (n=24 from Ethiopia, Cameroon, Gabon, Gambia, Ghana, Guinea, Liberia, Mali). One submitted specimen from Yemen (BC ZSM Lep 91637) not successful in DNA barcoding.

Remarks. Secure discrimination from similar species of Prasinocyma is possible when based on the lamellate male antennae (bipectinate in Prasinocyma). One dissected male from Yemen confirms the species identification as Androzeugma tenuis.

Checklist of the Hemistolini of Yemen

Subfamily Geometrinae
Tribe Hemistolini Inoue, 1961
Genus Prasinocyma Warren, 1897
The immaculata species-group
Prasinocyma angolica yemenicola Hausmann & Wildfeuer, subspec. nov.
Prasinocyma eremica Wiltshire, 1980
The nereis species-group
Prasinocyma saba Hausmann & Wildfeuer, spec. nov.
Prasinocyma acutipennis Wiltshire, 1994
Prasinocyma arabica Wiltshire, 1982
Prasinocyma magica Hausmann, Sciarretta & Parisi, 2016
Prasinocyma sanguinicosta Prout, 1912
The bifimbriata species-group
Prasinocyma bilobata Fletcher, 1978
Genus Androzeugma Prout, 1913
Androzeugma tenuis (Warren, 1898)
Genus Thalassodes Guenée, 1858
Thalassodes quadraria Guenée, 1858 (cf. Hausmann 2006, confirmed by DNA barcodes)
Genus Celidomphax Prout, 1912
Celimdomphax analiplaga (Warren, 1905) (cf. Hausmann 2006, confirmed by DNA barcodes)
Genus Victoria Warren, 1897
Victoria fifensis Wiltshire, 1994 (cf. Hausmann 2006, confirmed by DNA barcodes)

Acknowledgements
We thank Hermann H. Hacker, Hans-Peter Schreier (Staffelstein), and Bernd Müller (Berlin) who collected numerous geometrids from Yemen Republic and provided information on the collecting localities. For mounting of moths, dissections, tissue sampling and databasing (DNA Barcoding) we are grateful to Eckhard Wierig and Mei-Yu Chen (Munich). We thank John Chainey (London) for access to NHMUK collections and kind help in digitizing the genitalia slides. The genetic analyses have received considerable support from Paul D. N. Hebert and the Biodiversity Institute of Ontario (BIO) and the Canadian Centre for DNA Barcoding (CCDB University of Guelph). For supporting the DNA barcoding of type specimens we thank John Chainey and Geoff Martin (NHMUK, London), Sean Prosser and Jeremy deWaard (BIO, Guelph). The data management and analysis system BOLD was provided by Sujeevan Ratnasingham (BIO, Guelph). The work was financially supported by Genome Canada (Ontario Genomics Institute) in the framework of the iBOL program, WG 1.9.
Fig. 21. Neighbour Joining Tree of 67 specimens of the genus *Prasinocyma* with representatives of their genetically nearest species and with conspecific specimens from Ethiopia and Saudi Arabia, if available (> 500 bp, BOLD alignment, Kimura 2 parameter, pairwise deletion, constructed with MEGA 6, Tamura et al. 2013). All sequence records, trace files and images are available and accessible on BOLD as a single citable dataset (http://dx.doi.org/10.5883/DS-PRASIYE).
References


