

# Multivariate ratio analysis reveals *Trigonoderus pedicellaris* Thomson (Hymenoptera, Chalcidoidea, Pteromalidae) as a valid species

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**Abstract.** We demonstrate by multivariate ratio analysis (MRA) the validity of two female colour morphs as separate species in what was previously regarded as a single species, *Trigonoderus cyanescens* (Förster, 1841) (Hymenoptera: Pteromalidae). As a result, *T. pedicellaris* Thomson, 1878 **stat.r.**, is resurrected from synonymy under *T. cyanescens* and *T. filatus binubilatus* Erdős, 1960 **syn.n.** is synonymized with *T. cyanescens*. More than 20 characters were measured as part of two MRA dataset analyses. The first analysis excluded all measurements related to the gaster, whereas the second included gaster length, gaster breadth and seventh gaster tergite breadth. The first analysis revealed that the best separating morphometric ratios for the two species are *head breadth:metatibia length* and *OOL:parastigma length*, whereas the second analysis revealed *OOL:gaster length* as the second best separating ratio. The measurement error of all characters was below the admissible level of 30%. Gaster length proved to be a good character for separating the two groups, showed the lowest measurement error, and its percentage coefficient of variation was not greater than for other characters. This indicates that *gaster length* should not be discarded out-of-hand as a morphometric character in Pteromalidae. The variables that gave the best separating ratios included different body parts; therefore we suggest that the body of a specimen should be taken as a whole for use in MRA analyses, where each distance measurement can interact freely with any other. A key, figures and re-descriptions of *T. cyanescens* and *T. pedicellaris* are provided.

## Introduction

In insect taxonomy multivariate morphometrics of distance measurements are widely applied to separate putative species in difficult species complexes (e.g. Sorensen & Footitt, 1992; Kenis & Mills, 1998; Steiner *et al.*, 2010). The most often used methods are principal component analysis (PCA) and linear discriminant analysis (LDA). These methods are usually applied along with conventional analysis of body ratios that are then included in descriptions and identification keys (e.g. Polaszek *et al.*, 2004). Problems may arise concerning the interpretation of data when the two approaches are combined

because different definitions of size and shape are applied (Bookstein, 1989, 1998; Klingenberg, 1998; Richtsmeier *et al.*, 2002; Baur & Leuenberger, 2011). In ratio analysis, usually one character or a combination thereof (such as body length), serves as a measure of size, and ratios are used as descriptors of shape. Size is statistically independent of shape that, on the other hand, reflects differences in the geometry of the objects. In multivariate morphometrics, one linear combination of characters (usually the first component of a PCA) is considered as a size axis and the residual variation defines the shape space (in a PCA the second and following components). In contrast to ratio analysis, the size vector additionally comprises the size-dependent shape variation (allometry) and thus is no longer statistically independent from the geometry of objects (see Baur & Leuenberger, 2011: 823, fig. 6);

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however, size may then be considered biologically independent of shape. Baur & Leuenberger (2011) developed multivariate ratio analysis (MRA), which included a series of new tools for the interpretation of PCA and LDA in terms of body ratios. Using these methods provides not only the power of multivariate analysis, but also the shape values needed for the descriptive part of a taxonomic revision. The newly developed techniques are thus free of pitfalls that may arise through using the different frameworks of size and shape (see, e.g., introduction of Richtsmeier *et al.*, 2002).

*Trigonoderus* Westwood belongs to the tribe Trigonoderini (Peck *et al.*, 1964), which has either been classified in Misco-gasterinae or Pteromalinae of Pteromalidae (Hymenoptera, Chalcidoidea) (Graham, 1969; Bouček, 1988). The last revision of European species was by Graham (1993), preceded by Graham (1969), Kerrich & Graham (1957) and von Novitzky (1955). Ten species are recognized from the Western Palearctic region (Vidal, 2001; Noyes, 2011). Females of *Trigonoderus cyanescens* (Förster, 1841) were separated from other species based on the presence of two fuscous clouds on the forewings. Females of all other Palearctic species either lack fuscous clouds, such as *T. princeps* Westwood, 1832, or have just a single cloud, such as *T. pulcher* Walker, 1836, *T. filatus* Walker, 1836, *T. nobilitatus* Graham, 1993 and *T. sokanowskii* Novitzky, 1955. Another good distinguishing character is the pilosity of the prepectus. *Trigonoderus cyanescens* has a bare prepectus, whereas the prepectus of other Palearctic species have a densely pilose prepectus. However, we encountered unusually large intraspecific variation in morphological features other than the number of fuscous clouds and the pilosity of the prepectus in what was interpreted as *T. cyanescens*. Previously, von Novitzky (1955) had recognized two female colour morphs in *T. cyanescens*: one morph had a darkened pedicel, anelli and first funicular segment (including the type of *T. cyanescens*), whereas the other had these segments pale (including the type of *T. pedicellaris* Thomson, 1878). von Novitzky (1955) considered the latter morph an aberration, for which he proposed the informal name 'flavobasalis' (an unavailable name in the sense of the ICZN).

Our observations indicated that the range of variation in continuous characters other than colour clearly exceeded typical species limits. We therefore conducted a morphometric analysis to describe intraspecific variation in *T. cyanescens* based on females to determine whether there was really only a single species with two colour morphs. We searched for powerful statistical methods in an attempt to find the most important differential characters, and applied MRA because ratios are commonly used as descriptors of shape in Chalcidoidea (see Graham, 1969; Bouček, 1988; among many others) and insect taxonomy in general. The results of our morphological analyses are summarized below in the key and descriptions (File S1).

Characters may pose problems in morphometric analyses if the structure measured is subdivided into units whose exact configuration may change. For example, in Chalcidoidea the gaster is composed of telescopically arranged tergites and sternites (e.g. Gibson, 1997). Because of this, the gaster usually

shrinks when air dried after being stored in ethanol, but may inflate quite considerably when critical-point dried or put in lower percentage ethanol (80% or less). Such artefacts may prevent reliable measurements of important characters of the gaster for morphometric separation because of the increased variation due to the differential drying. As part of our analyses we tested whether the inclusion of *gaster length*, *gaster breadth* and *seventh tergite breadth* improves or reduces success in separating putative species correlated with the two colour morphs of *T. cyanescens* females. We predict that gaster length should be the only reliably useable morphometric gaster character because, for example, contrary to gaster breadth, it may be much less strongly altered by the dilatation of segments during storage and drying. We thus assumed that the telescopic change of gaster length compared with the gaster breadth is smaller due to anatomic characteristics of the gaster.

Measurement error (ME) is a vital part of morphometric analyses because it gives the variability of different measurements on the same character of a specimen. However, ME is usually not evaluated, partly due to the lack of coverage in popular morphometric books (see Bailey & Byrnes, 1990) and the huge effort required to determine it. The significance of ME is the comparison of the amount of the relative variation between repeated measures of the same individual compared to the measurement of variation among individuals (Bailey & Byrnes, 1990). In this way it is possible to test the usefulness of a character in an identification key.

## Material and methods

The study is based on the analysis of 76 dry-mounted females (Appendix 1, see Files S1) of *Trigonoderus cyanescens* from a total of 86 measured specimens. We do not know the preservational and mounting history of many specimens, especially those which originated from museum collections. Some characters could not be measured on all specimens because of missing body parts and specimens with missing data were not included in the analysis. The examined material originated from the Hungarian Natural History Museum, Budapest, Hungary (HNHM), Zoological Museum, Lund University, Sweden (LUZN), Natural History Museum Vienna, Austria (NHMV), Gérard Delvare, Montpellier, private collection (GD), and Natural History Museum in Bern, Switzerland (NMBE).

Gibson (1997) is followed for terminology of morphological structures. The list of morphometric characters used is given in Table 1. The selected characters correspond to those used in taxonomy of Pteromalidae for calculating typically used ratios (e.g. Graham, 1969). Measurements were made with an Olympus SZ51 stereo microscope (objective: 110AL2X; eyepiece: WHSZ10X) under 60× magnification using a calibrated eye-piece micrometer (2.5 mm subdivided into 100 units). For all measurements we ensured that the points of reference were equidistant from the objective of the microscope. Because the quality of museum specimens varied, characters were measured from the side that was in better

**Table 1.** Measured characters for identification of *Trigonoderus*, abbreviations used, and their description.

Abbreviation	Character	Definition
<i>eye.b</i>	Eye breadth	Greatest length of eye breadth in lateral view
<i>eye.h</i>	Eye height	Greatest length of eye height in lateral view
<i>fu1.l</i>	First funicle length	Length of first funicular segment in dorsal view
<i>gst.l</i>	Gaster length	Length of gaster along median line from anterior edge of first tergite to posterior edge of seventh gastral tergite
<i>gst.b</i>	Gaster breadth	Greatest breadth of gaster, distance between the outermost lateral edges of the gaster
<i>gt7.b</i>	Seventh gastral tergite breadth	Greatest breadth of the seventh gastral tergite, greatest distance between the outermost lateral edges of the seventh gastral tergite
<i>hea.b</i>	Head breadth	Greatest head breadth in dorsal view
<i>hea.h</i>	Head height	Distance between lower edge of clypeus and lower edge of anterior ocellus
<i>hea.l</i>	Head length	Head length in dorsal view (Graham, 1969), distance between anterior and posterior margin of the head, measured laterally
<i>msc.b</i>	Mesoscutum breadth	Breadth of mesoscutum in dorsal view
<i>msh.l</i>	Malar space	Distance between the point where malar sulcus enters mouth margin and malar sulcus enters lower edge of eye (Graham, 1969)
<i>mss.l</i>	Mesosomal length	Length of mesosoma along median line from anterior edge of neck to posterior edge of nucha
<i>mv.l</i>	Marginal vein	Length of marginal vein (Graham, 1969), distance between the point at which the submarginal vein touches the leading edge of the wing to the point at which the stigmal vein and postmarginal vein unite
<i>ool.l</i>	OOL	Minimal distance between posterior ocellus and eye margin (Graham, 1969)
<i>pd.l</i>	Pedicel length	Length of pedicel in dorsal view
<i>pmv.l</i>	Postmarginal vein	Length of postmarginal vein (Graham, 1969), distance between the point at which the stigmal vein and postmarginal vein unite, apically to where the vein appears to end
<i>pol.l</i>	POL	Distance between posterior ocelli (Graham, 1969)
<i>ppd.b</i>	Propodeum breadth	Distance between inner margins of propodeal spiracles
<i>ppd.l</i>	Propodeum length	Length of propodeum measured along median line from anterior edge to posterior edge of nucha
<i>pst.l</i>	Parastigma	Length of parastigma (Graham, 1969), distance between the point at which the submarginal vein touches the leading edge of the wing to the point at which the basal vein meets the submarginal vein
<i>scp.l</i>	Scape length	Length of scape in ventral view exclusive of radicle (Graham, 1969)
<i>stv.l</i>	Stigmal vein	Length of stigmal vein (Graham, 1969), distance between the point at which the stigmal vein and postmarginal vein unite, apically to where the vein appears to end
<i>tb3.l</i>	Metatibia	Greatest length of metatibia, measured along midline
<i>upf.l</i>	Upper face	Distance between lower edge of torulus and lower edge of anterior ocellus

condition and/or most accessible. All measurements were repeated three times, nonconsecutively.

Measurement error as we measured it here is a relative measure, because it is the sum of squares of intra- or interspecimen variation compared with intra- and interspecific variation. Hence the ME is relatively higher for more similar species, even if the precision of taking measurements is always the same.

Measurement errors (ME) were estimated by the common measure of repeatability R (Nakagawa & Schielzeth, 2010; Wolak *et al.*, 2012). To calculate R we used the function 'rpt' from package 'rptR version 0.6.404' (Nakagawa & Schielzeth, 2010). We then calculated %ME as  $(1 - R) \times 100$ , because the difference between unity and repeatability can be interpreted as measurement error (Nakagawa & Schielzeth, 2010). There is no general consensus regarding an acceptable level of ME because the scheme used to describe correlation coefficients may serve as an informal guideline only, when the results are significant (Martin & Bateson, 1986; Harper, 1994). Nevertheless, Harper (1994), Martin & Bateson (1986), Nakagawa & Schielzeth (2010) and Wolak *et al.* (2012)

proposed an admissible level of 30% ME, that is adopted here.

Two datasets of morphometric measures were created. One excluding and one including gastral measurements (gaster breadth and length, and the breadth of the seventh gastral tergite). Specimens that had initially been stored in ethanol were also measured; thus, in many cases the gaster was inflated or otherwise deformed. So, based on the shrinkage or inflation due to the preserving methods of the specimens we predicted that only gaster length would be highly informative from the gastral measurements. We consider a 'normal' form of the gaster when the specimens were directly mounted and air dried without prior preservation in ethanol.

We applied the recently developed multivariate ratio analysis (MRA) of Baur & Leuenberger (2011), which comprises a shape PCA, a PCA ratio spectrum, an allometry ratio spectrum and an LDA ratio extractor. The PCA ratio spectrum is a graphical tool that aims to interpret principal components of shape in terms of body ratios. In a similar manner, the allometry ratio spectrum reveals the allometric behaviour of ratios. The LDA ratio extractor reveals the best ratios

to separate two or more groups with the help of linear discriminant analysis (LDA). The measure  $\delta$ , also introduced by Baur & Leuenberger (2011: 818, formula 14), was calculated to see how much of the total difference was due to size and how much was due to shape. These methods allow the interpretation of the results of the frequently used PCA and LDA by body ratios, which can then be directly incorporated in species descriptions and identification keys.

In order to determine whether the morphometric data really supported the existence of two species and to avoid any circular reasoning, we applied the above-mentioned methods in a two-step procedure. First, we performed a PCA in MRA shape space (as defined by Baur & Leuenberger, 2011: 815) and then labelled the specimens according to either their darkened or yellowish coloration of the pedicel, anelli and first funicular segment. This constitutes a rather conservative approach for exploring group differences because for a PCA all specimens are considered as belonging to a single group and the resulting scatterplot shows the unconstrained variation of that group (e.g. Pimentel, 1979). If delimitation of groups based on colour characters is congruent with nonoverlapping morphometric variation as revealed by the PCA, this would usually provide persuasive support for the existence of separate taxa. However, in the case of significant allometric variation, the differences found by a shape PCA might be attributable mainly to a size effect. We therefore plotted the relevant shape PCs against isometric size (defined as the geometric mean of all variables, see Baur & Leuenberger, 2011: 816) and visually inspected the correlation of shape with size. Once there was strong evidence for separate groups by the shape PCA, the LDA ratio extractor (where groups have to be defined beforehand) was applied to find the best body ratios to discriminate the indicated taxa. Each of these ratios was finally compared with the allometry ratio spectrum for again checking allometric behaviour.

The R (R Development Core Team, 2012) language and environment for statistical computing was used for data analysis. For the above methods we used slightly modified versions of the R-scripts provided by Baur & Leuenberger (2011, under 'File S1'). Scatterplots were generated with the package 'ggplot2' (Wickham, 2010). Data deposited in the Dryad Repository: 10.5061/dryad.hg6st.

## Results

### Measurement error

The majority of the tested morphological characters had low ME values (Table S2 in File S1). Those with higher ME values were the smallest features (e.g. *stv.l*, *ool.l*, *pol.l*, *pdl.l*, *gt7.b*). The highest ME (22.51) was for *pdl.l*, which is among the smallest structures. This ME value can still be considered as acceptable, because an ME threshold below 30 can be considered as low and one below 10 as very low (Harper, 1994; Martin & Bateson, 1986). All other characters measured show

ME values below 10. The smallest ME (0.26) of all characters was shown by *gst.l* which is also the largest character. The other gastral characters as *gst.b* and *gt7.b* had ME values below 10 (Table S2, Files S2).

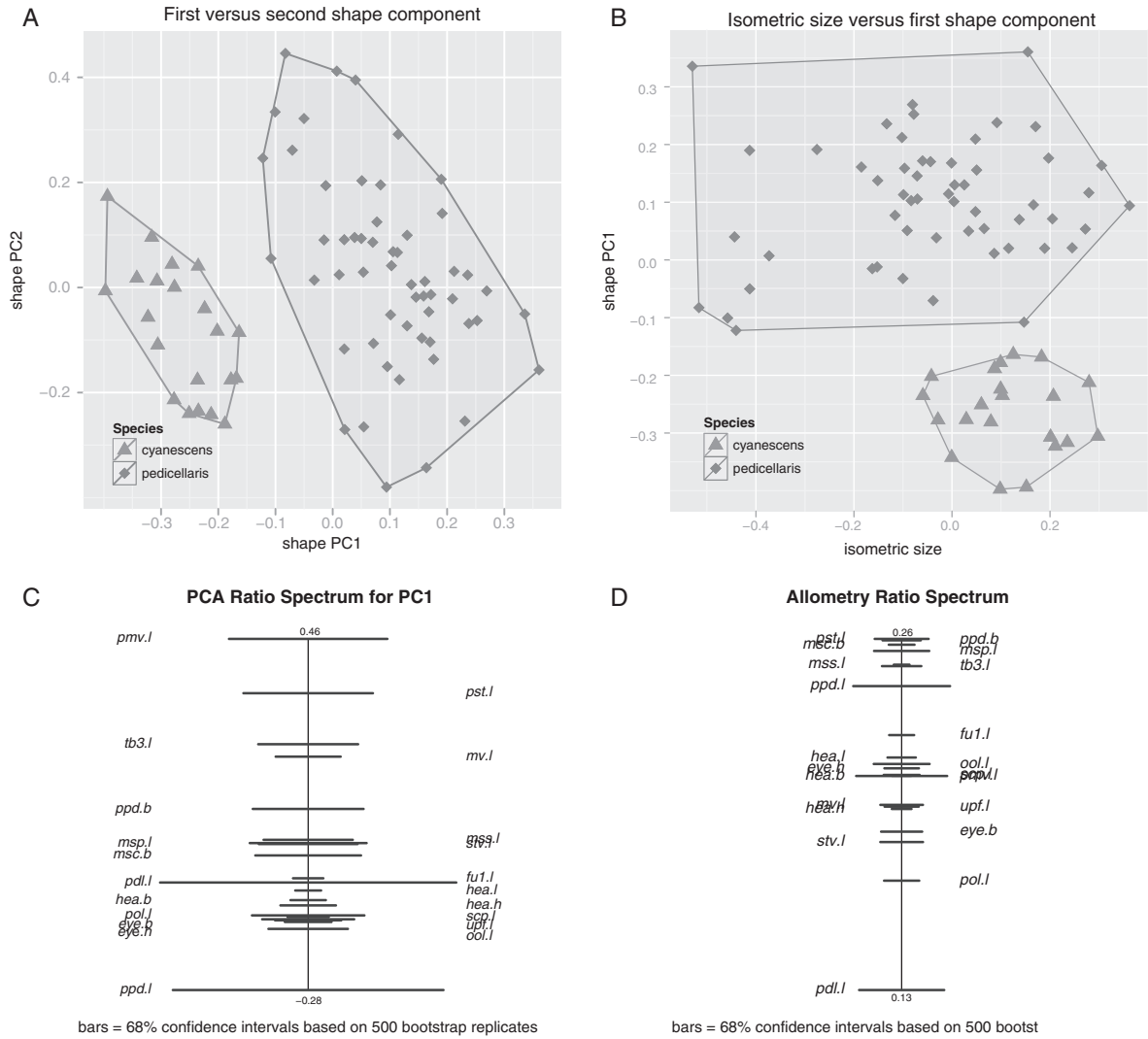
### Morphological Results

*Analysis excluding gastral characters.* Females of the two colour morph groups, *cyanescens* and *pedicellaris*, were clearly separated along the first principal component in shape space, but there was no separation along the second component (Fig. 1A). The scatterplot of isometric size against the first shape PC revealed that the median size of females belonging to the *cyanescens* group was larger than those of those belonging to the *pedicellaris* group, even if size overlaps within the two groups (Fig. 1B). Size variation in *pedicellaris* females was much greater. There was very little correlation of shape with size and therefore hardly any indication of allometry.

On the PCA ratio spectrum of the first shape PC (Fig. 1C), most of the variation was explained by ratios such as *pmv.l:ppd.l* or *pst.l:ppd.l* that correspond to points (indicated by horizontal bars representing 68% confidence intervals of the variable coefficients) lying close to the opposite ends of the spectrum. On the other hand, ratios formed from characters lying adjacent to each other in the spectrum, like *ful.l:msp.l*, contributed very little to the respective component. The PCA ratio spectrum ranged from  $-0.28$  to  $0.46$  for the variable coefficients.

The allometry ratio spectrum can be used in a very similar manner, but the most distant variables were those showing the greatest amount of allometry. This was the case for variable ratios *ppd.b:pdl.l* or *pol.l:pst.l*, which are placed close to the ends of the allometry ratio spectrum (Fig. 1D). The lowest amount of allometry was displayed by variables positioned at the centre of the allometry ratio spectrum as was *upf.l:pmv.l* (Fig. 1D). The variable pairs which showed the greatest allometry did not coincide with the variables contributing to the separation of the *cyanescens* and *pedicellaris* groups (Fig. 1C and D). Coefficients of the allometry ratio spectrum ranged from  $0.13$  to  $0.26$ .

The two colour forms received strong morphometric support from the shape PCA and we therefore applied the LDA ratio extractor to find the best separating variable ratios that are at the same time least correlated (see Baur & Leuenberger, 2011: 816–817 for how this algorithm works). The most discriminating ratio was *hea.b:tb3.l* (see ranges of ratio values for the two colour forms in Table 2). Baur & Leuenberger (2011: 818, formula 14) also introduced the measure  $\delta$ , which indicates how well shape discriminates in relation to size. A value of  $\delta$  close to unity means that separation is mainly due to size, whereas shape is important for a value close to zero. In our analysis,  $\delta$  was  $0.09$  for the first ratio vector and thus the separation mainly stemmed from variation in shape. The next best discriminating body ratio as little correlated as possible with *hea.b:tb3.l* is *ool.l:pst.l* (see ranges of ratio values for the two colour forms in Table 2). The second best discriminating



**Fig. 1.** Results of multivariate ratio analysis for females of *Trigonoderus cyanescens* (triangles) and *T. pedicellaris* (diamonds) not incorporating gaster characters. (A) Scatterplot of a principal component analysis (PCA) in shape space. (B) Isometric size versus first principal component in shape space. (C) PCA ratio spectrum of the first principal component. (D) The allometry ratio spectrum. Confidence intervals [horizontal bars in (C, D)], were estimated with a bootstrap of the original values of *z* directly from the empirical distribution.

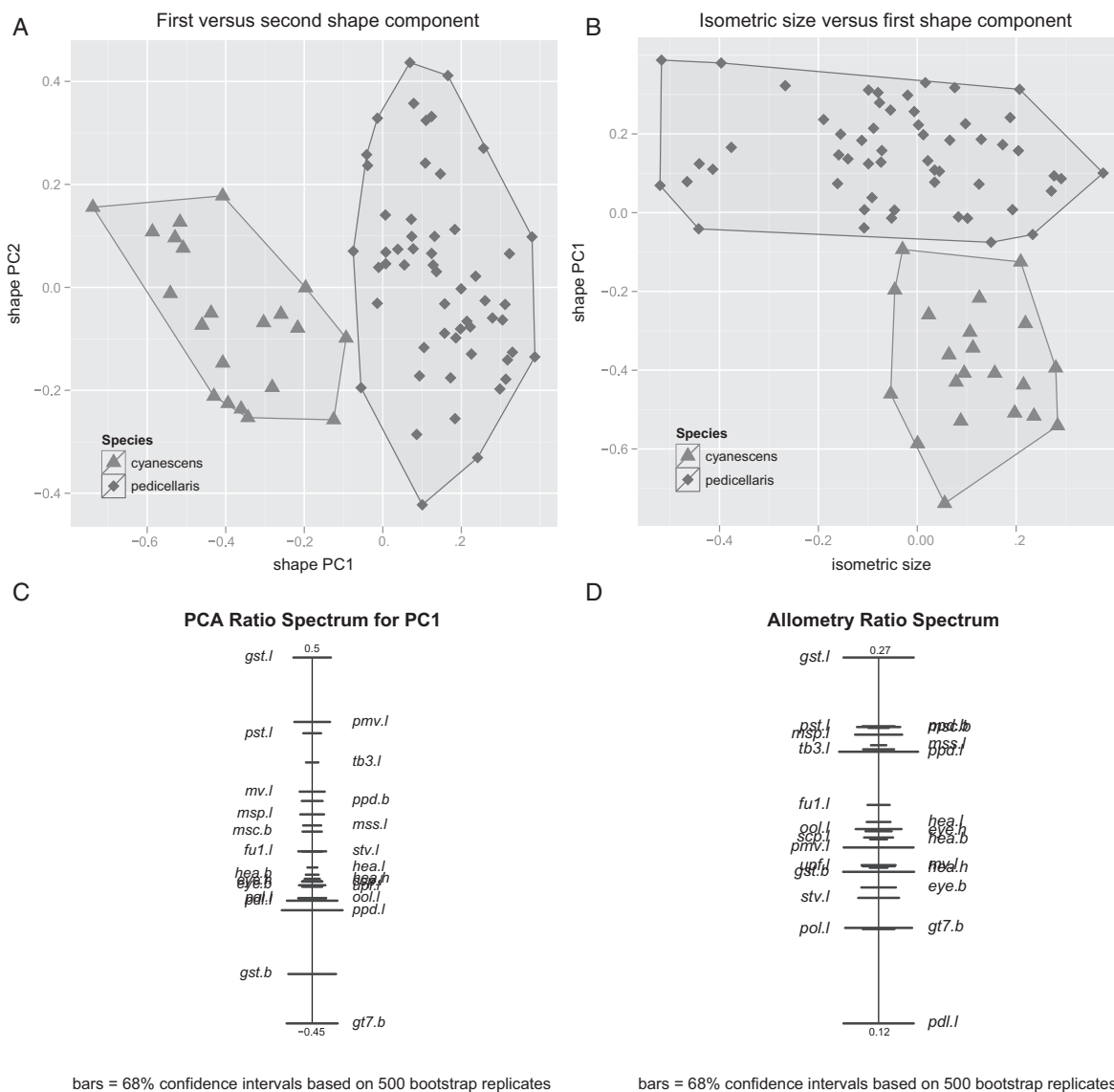
ratio shows 7.03 as standard distance (see Baur & Leuenberger, 2011: 817, formula 12), which was less compared with the standard distance of the best ratio (9.12). It is evident from the scatterplot that both ratios showed a high separation between *cyanescens* and *pedicellaris*-group females. There was only a slight overlap in females of the two groups with respect to the second best ratio, *ool.l:pst.l* (Fig. 3A).

*Analysis including gastral characters.* The results for differentiating females of the two groups were quite similar for the dataset including gaster characters (Fig. 2A, B), but *gst.l* (gaster length) was revealed as an important character in the shape PCA and allometry ratio spectrum (Fig. 2C, D, respectively). Gaster length was also included in the second best ratio (see ranges of ratio values for the two colour forms in

**Table 2.** The best separating ratios for females of *Trigonoderus cyanescens* and *T. pedicellaris*.

	<i>cyanescens</i>				<i>pedicellaris</i>			
	Min.	Mean	Max.	sd	Min.	Mean	Max.	sd
<i>hea.b/tb3.l</i>	0.81	0.88	0.97	0.04	0.98	1.06	1.14	0.03
<i>ool.l/pst.l</i>	0.38	0.42	0.48	0.03	0.47	0.56	0.65	0.05
<i>ool.l/gst.l</i>	0.05	0.06	0.07	0.01	0.08	0.09	0.12	0.01

Table 2), *ool.l: gst.l* (Fig. 3B), which showed only a moderate allometric behaviour (compare Fig. 2D, where *ool.l* is located in the middle of the allometry ratio spectrum). The other gastral characters were not included in the first two ratios, despite the fact that they appeared at the opposite ends of the PCA



**Fig. 2.** Results of multivariate ratio analysis for females of *Trigonoderus cyanescens* (triangles) and *T. pedicellaris* (diamonds) incorporating gaster characters. (A) Scatterplot of a principal component analysis (PCA) in shape space. (B) Isometric size versus first principal component in shape space. (C) PCA ratio spectrum of the first principal component. (D) The allometry ratio spectrum. Confidence intervals [horizontal bars in (C, D)], were estimated with a bootstrap of the original values of  $z$  directly from the empirical distribution.

ratio spectrum for PC1 with the gaster length (Fig. 2C). The ratio separated the groups by a standard distance of 8.56, which was smaller than the standard distance of the best ratio (10.35), but was higher than the one for the second best ratio (*ool.1*:*pst.1*; 7.03) of the above analysis without gaster characters. Both ratios separated females of *cyanescens* and *pedicellaris* without overlap (Fig. 3B).

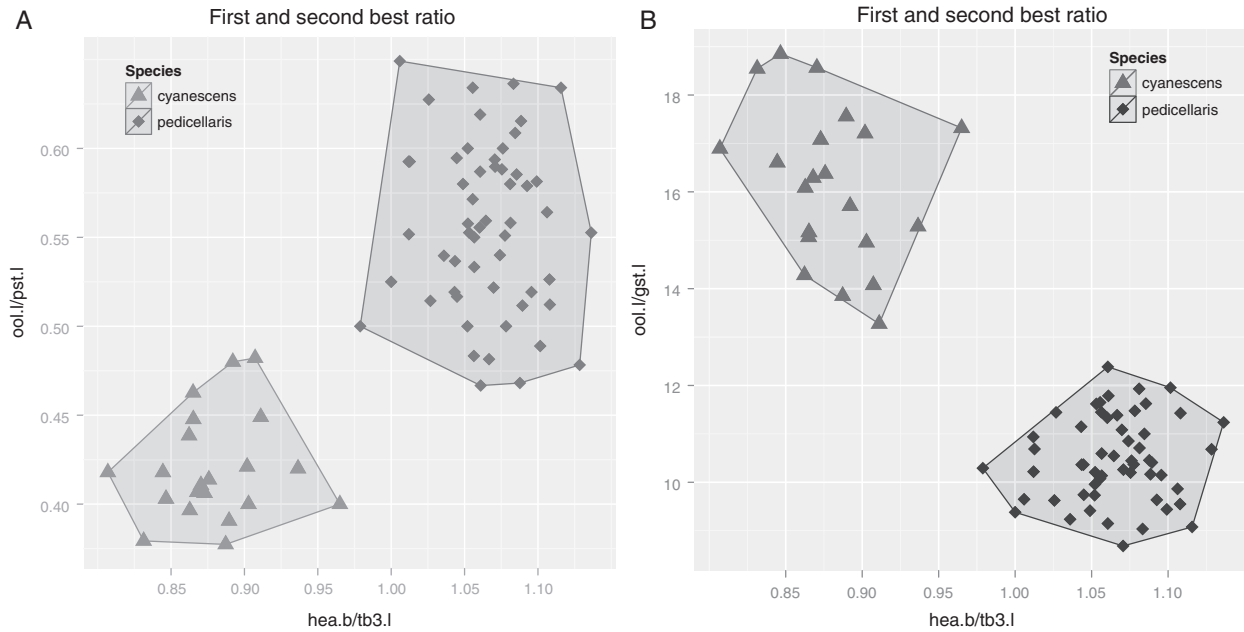
#### Taxonomy

Based on the results of MRA the differences found between females (Table 2) suggest the existence of two separate species

rather than just two colour forms of a single species. The males of the two groups show a high morphological homogeneity. Based on our preliminary observations there is no large difference between males.

#### Key to females of *Trigonoderus cyanescens* and *T. pedicellaris*

- Head breadth usually less than length of metatibia (*hea.b*:*tb3.l* = 0.81–1.01). Pedicel dark brown to black, at least dorsally. First funicle segment dark brown to black, and subcylindrical (Fig. 4A). Notaulus distinct posteriorly, usually reaching posterior margin of mesoscutum (Fig. 4C).



**Fig. 3.** Scatterplots of the two most discriminating ratios for females of *Trigonoderus cyanescens* (triangles) and *T. pedicellaris* (diamonds). Plot (A) shows first versus second ratio from the analysis not incorporating gaster characters; plot (B) shows first versus second ratio from the analysis incorporating gaster characters.

Gaster elongate and acuminate (Fig. 4C), 13.3–18.9 times as long as OOL

*T. cyanescens* (Förster)

– Head breadth usually greater than length of metatibia ( $hea.b:tb3.l = 0.98–1.14$ ). Pedicel pale, yellow (Fig. 4B). First funicle segment pale-yellow to reddish brown, at least proximally, and obviously wider distally than proximally (Fig. 4B). Notaulus superficial posteriorly, not reaching posterior margin of mesoscutum (Fig. 4D). Gaster less elongate and less acuminate (Fig. 4F), only 8.7–12.4× as long as OOL

*T. pedicellaris* Thomson

## Discussion

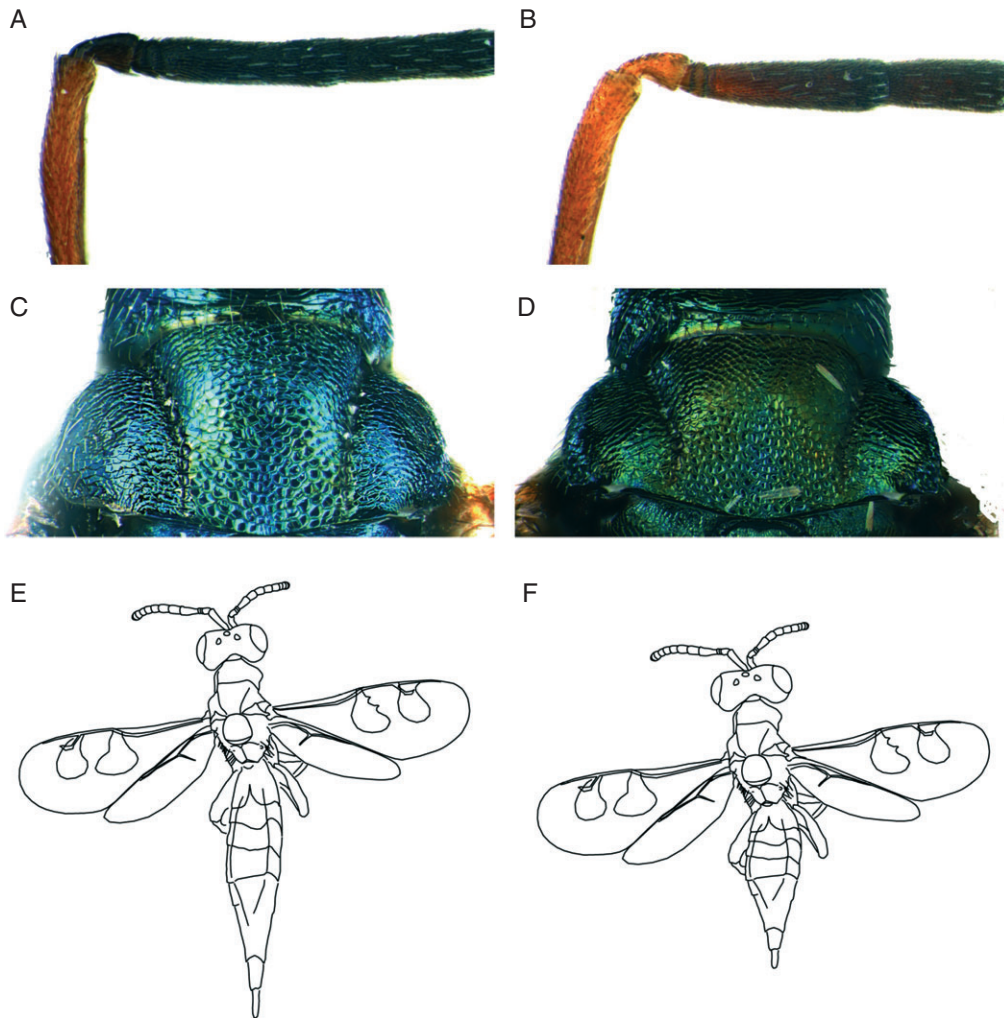
We found that multivariate ratio analysis (MRA) provided additional evidence for clarification of the status of *Trigonoderus pedicellaris*, and also useful information for refining the selection of characters for taxonomic analysis. Interestingly, variables that provide the best separating ratios originated from different body parts, such as the ratio of head breadth (*hea.b*) to length of the metatibia (*tb3.l*). However, commonly used ratios applied for identification are usually composed of different measurements of single or adjacent body parts, such as head breadth:length, malar space:eye height, scutellum length:breadth (e.g. Graham, 1969; Janzon, 1986; Bouček, 1988). Our results suggest that such commonly used ratios may be limited in their usefulness because they were obviously less powerful for separating species. Baur & Leuenberger (2011) came to the same conclusion. Using MRA, the body of

a specimen is taken as a whole, each distance measurement can be compared with any other and it indicates which of the ratios are best for differentiating cryptic species.

Qualitative characters may provide another important variable set for separating specimens. Peters & Baur (2011) stated that coloration of body parts such as antennae, legs and the gaster should be used with caution because in some cases they can show a high intraspecific variation. Even considering colour pattern there can in some cases be a larger variation, with overlap between closely related species. In the case of the two studied *Trigonoderus* species, we found that the coloration of antennal segments in combination with morphometric characters could separate specimens with high reliability.

Measurement error (ME) was estimated for all features (Table S2 in File S1). Those morphometric features that showed the largest measurement error values were the smallest structures. The lowest ME values were obtained for the largest body parts such as mesosoma and gaster length. Therefore, we recommend taking measurements of small body parts at magnifications greater than 60×. Nevertheless, at a magnification of 60×, the ME values of the smallest features were still below the admissible levels of 30% proposed by Harper (1994), Martin & Bateson (1986), Nakagawa & Schielzeth (2010) and Wolak *et al.* (2012).

The use of gaster length in the second set of analyses showed that this character indeed enhanced the separation of females of the two cryptic species, being part of the second-best ratio to separate females (*ool.l:gst.l*). The %ME (Table S2 in File S1) of the gaster length was the smallest, whereas the %CV (Table S1 in File S1) of this character was not considerably



**Fig. 4.** A,B, antenna (lateral) of female: (A) *Trigonoderus cyanescens*, (B) *T. pedicellaris*; C,D, mesoscutum of female: (C) *T. cyanescens*, (D) *T. pedicellaris*; E,F, habitus of female: (E) *T. cyanescens*, (F) *T. pedicellaris*.

higher than for other characters. Based on these results, it can be inferred that the gaster length should not be discarded due to telescoping as a morphometric character in Pteromalidae, as it can be useful in some cases. Storage of specimens in ethanol does not alter gastral length considerably due to the fixation by the structure of the female ovipositor.

The habitus of the female of *T. cyanescens* appears closer to that of *T. filatus*, because the gaster is much longer than the length of the head and mesosoma and its body therefore is more slender (Fig. 4E). On the other hand, females of *T. pedicellaris* are more similar to those of *T. pulcher* because the gaster is approximately as long as the combined length of the head and mesosoma and the body therefore appears less slender (Fig. 4F). Nevertheless, females of both *T. cyanescens* and *T. pedicellaris* can be separated from those of other Palearctic *Trigonoderus* based on the number of fuscous clouds on the forewings and the lack of pilosity on the prepectus. The similarity in habitus between *T. cyanescens* and *T.*

*filatus* resulted in Erdős (1960) describing *binubilatus* – now recognized as a synonym of *T. cyanescens* (see File S1) – as a variety of *T. filatus*. Actually Erdős (1960) was the second author after von Novitzky (1955) to recognize the difference in habitus between *T. cyanescens* and *T. pedicellaris*, and this is why he placed a *T. cyanescens* specimen into *T. filatus*. Another record of *T. filatus* var. *binubilatus* from Romania (Valea lui Traian, Constanta county) by Tudor (1971) may also be considered as a misidentification of *T. cyanescens*. The host species recorded for the latter, *P. hispidus*, results in a new host record for *T. cyanescens*. Other characteristics such as body coloration and wing pattern show clearly that any female *Trigonoderus* with two forewing fuscous clouds can be only *T. cyanescens* or *T. pedicellaris*. The only known Palearctic species with females having comparatively long gasters are *T. cyanescens* and *T. filatus*, females of all other species, such as *T. pedicellaris*, *T. pulcher*, *T. princeps*, *T. nobilitatus* and *T. sokanowskii*, have shorter gasters.



## Supporting Information

Additional Supporting Information may be found in the online version of this article under the DOI reference: 10.1111/syen.12026

**File S1.** Type discussion and species redescrptions, descriptive statistics of the measured characters (Table S1), measurement error (ME) with 95% CI interval limits of continuous morphological characters (Table S2) and list of measured females used for the morphometric study (Appendix 1).

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