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Description of last instar larvae of *Ceratogomphus triceraticus* Balinsky, 1963 and *C. pictus* Hagen in Selys, 1854 (Odonata: Gomphidae)

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Abstract: The final instar larvae of the two species of the southern African gomphid genus *Ceratogomphus*, the South African endemic *C. triceraticus* and the more widespread *C. pictus*, are compared based on exuviae. Main differences are the shapes of the prementum and of the last abdominal segments, giving *C. pictus* a more slender and pointed appearance. *Ceratogomphus triceraticus* is slightly larger and on average significantly so. The habitats of both species are described based on own observations in South Africa.

Keywords: exuviae, habitat, southern Africa, dragonfly

Introduction

The southern African genus *Ceratogomphus* comprises two species, *C. pictus* and *C. triceraticus*. Whereas *C. pictus* is common and widespread in southern Africa, *C. triceraticus* is endemic to South Africa where it occurs only locally and is mostly restricted to the Western Cape Province (Samways 2008, Samways & Simaika 2016, Tarboton & Tarboton 2015). The IUCN Global Red List status is Near Threatened NT (Samways 2018).

The larva of *Ceratogomphus* was described by Barnard (1937) as *C. pictus*. The larva of *C. triceraticus* was hitherto considered unknown as Barnard (1937) referred explicitly to *C. pictus* in his description. Thus, the reference for the larval description of *C. pictus* was always Barnard (1937); see the identification keys by Samways & Wilmot (2003) and Suhling et al. (2014) where the morphology of the final stadium of *C. pictus* is illustrated based on their own material by the authors. However, at the time of Barnard's work the second species, *C. triceraticus*, was unknown to science. This species was formally described 26 years later on the basis of one imaginal specimen, without including the larva (Balinsky 1963). When checking Barnard's description of the larva, we noted it was based on younger instar larvae, which could be confirmed: Barnard's collection in Iziko South African Museum, Cape Town, comprises six larvae in approximately the F-2 or F-3 instar. This may have accounted for some slight differences in appearance of Barnard's material comparing with the descriptions based on exuviae.

In 2016 exuviae were collected at several sites in the Western Cape Province by two of the authors (SK, HW), which besides many exuviae of *C. pictus* also included a few exuviae of another gomphid species, similar to *C. pictus*. The latter could not be assigned to any known larva of a gomphid species occurring in the region, *viz. C. pictus*, *Crenigomphus hartmanni*, *Paragomphus cognatus*, and *P. genei* (Samways & Simaika 2016). Thus, it was inferred the new exuviae should belong to the one species with formally undescribed larva, *C. triceraticus*. In this contribution we aim to compare the final instar larvae of *C. triceraticus* and *C. pictus*, based on their exuviae. We also include the material that Barnard (1937) used for his description of the larva of *C. pictus*. In addition, we describe the habitats where exuviae of both species were found.

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Material and Methods

During two three-week field trips to the Northeast and the Southwest of the Republic of South Africa in early 2015 and late 2016 altogether 46 localities were visited and searched for dragonflies. Imagines were photographically documented and in most cases the edges of the waterbodies were searched for exuviae. Exuviae of *Ceratogomphus* spp. were collected at the locations listed in Table 1. Additional exuviae of *C. pictus* from Namibia (leg. F. Suhling) and Natal, South Africa (leg. A. Martens) were used for comparison (cf. Suhling et al. 2014).

Table 1. Locations with records of *C. triceraticus* and *C. pictus* during trips in 2015 and 2016.

ID	Name/ locality	Location	Province	Latitude	Longitude	Habitat	Altitude	Date of visit	Records	
				° S	° E		m a.s.l.		*C. triceraticus*	*C. pictus*
1	Kurisa Moya	Haenertsburg	Limpopo	23.80559	29.93725	Farm dam	1589	06-i-2015	-	2♂♂
2	Field & Stream	Dullstroom	Mpumalanga	25.42666	30.01724	Farm dam	1870	12-i-2015	-	10♂♂, 3♀♀, >100 exuviae
3	Field & Stream	Dullstroom	Mpumalanga	25.44250	30.00622	Brook	1740	13-i-2015	-	3♂
4	Magaliesberg	Wigwam	North West	25.80548	27.32129	Rivulet	1300	15-i-2015	-	2♂♂
5	Matjiesrivier	Cederberg	Western Cape	32.51942	19.35057	Brook	725	11-xi-2016	1♂	-
6	Kromrivier	Cederberg	Western Cape	32.53264	19.26012	Brook	893	08-xi-2016	1♂	-
7	Grootrivier	Cederberg	Western Cape	32.62862	19.43639	River	474	10-xi-2016	12 exuviae	4 exuviae
8	Sneeuwkop	Cederberg	Western Cape	32.91646	19.45237	Farm dam	961	09-xi-2016	-	6 exuviae
9	Watervalrivier	Tulbagh	Western Cape	33.21431	19.13572	Rivulet	249	14-xi-2016	4♂♂	2♂♂
10	Orange Grove Farm	Robertson	Western Cape	33.73424	19.79243	Farm dam	338	30-x-2016	-	1♂, 1♀
11	Bergrivier	Paarl	Western Cape	33.74903	18.96777	River	105	03-xi-2016	-	1♂
12	Angala Hotel	Simondium	Western Cape	33.84992	18.93443	Farm dam	237	03-xi-2016	-	>30 exuviae
13	Fynbos	Villiersdorp	Western Cape	33.99970	19.31979	Scrubland above river	453	02-xi-2016	-	1♂

Throughout the paper the term ‘exuviae’ is used to refer to the final instar exuviae and not to any earlier instar.

For the description and the comparison of the two species, different measurements were carried out. As all measurements were carried out on exuviae of the last stadium, we used measurements of sections of body parts that were at most only slightly deformed. These included the width and length of

the labium and the abdomen. The absolute length of the body and the width of the head, however, cannot be determined accurately from exuviae, and therefore these measurements allow only rough comparisons. Measurements of the total length as well as the length and width of the abdomen were done with a sliding gauge (1/100 mm accuracy). Microscopic photographs were taken for measurements of the labium by using a CMEX 5000 (Euromex) camera. The measurement distances in the photos were measured with ImageFotov3 (1/100 mm accuracy).

All in all, 12 exuviae of *C. triceraticus* (2 males, 10 females) from one locality (Table 1, locality 7) and of *C. pictus* 25 exuviae (11 males, 14 females) from three localities (Table 1) were used for the measurements. Due to missing parts in some exuviae not all morphological features of all larval cases could be measured. For statistical comparisons of measurements of the two species we applied t-tests in the software Past 3.24.

Description of the larvae

Generic characters

Both species of *Ceratogomphus* have the typical appearance of gomphid larvae: the antennae have four segments of which the third is usually massively built and the labium is flat and nearly rectangular. The general shape is that of a gomphid (Figure 1) without any of the very prominent characters of some other genera, i.e. no abdominal tube, no flattened dilated 3rd antennal segment, and S10 not enveloped by S9. The most distinct character is the shape of the dorsal abdominal spines which have a slim base in cross-section giving them a keel-like appearance at least on segments (S6) S7 to S9 and quite prominent on S9 where the ridge covers the whole length of the segment. The wing sheaths are divergent in both species extending the posterior margin of S3. In Suhling et al. (2014) the wing sheaths are wrongly depicted running parallel which is probably due to the use of a deformed exuvia as reference for the drawing. The closely related genus *Phyllogomphus* according to Carle (1986) has S10 in form of an elongated breathing tube, which is not present in *Ceratogomphus*.

Differential diagnosis

Size: Although *Ceratogomphus triceraticus* is on average significantly longer and has a broader maximum head width than *C. pictus* (Table 2) the difference is not large enough to allow clear distinction. Except for a few areas on the abdomen, the entire body is covered with microscopically small short setae. Longer setae are located on the front parts of the head, the tarsi, tibiae and femora. Long bristles are also arranged on the lateral edges of the abdomen (Figure 1).

Head: The head is very similar in both species: slightly wider than long, with three ocelli. The posterior margin of the head is clearly concave in dorsal view (Figure 2a, g). In the lateral view, the head forms a wedge-shaped profile (Figure 2b, h). The articulation of postmentum and prementum reaches the anterior margin of the front coxa (Figure 3a, 4a; fcox). The shape of the prementum differs: the anterior border of the prementum of *C. triceraticus* is more strongly convex than that of *C. pictus* (Figure 2e, k). The labial palpus of *C. pictus* is slightly more slender and the movable hook distinctly longer (Figure 2c, i). Particularly, the general shape of the prementum differs (Figure 2e, f, k, l), with that of *C. pictus* being stockier, i.e. shorter compared to its width (ratio max width to length and ratio min width to length, Table 2), but less wide at its base (ratio maximum to minimum width higher, Table 2).

Table 2. Comparison of various size measurements of *Ceratogomphus triceraticus* (N=12 for abdomen values, N=11 for total length, head and prementum values as well as ratios) with *C. pictus* (N=25, for abdomen values: N=11). For statistical comparison student t-test was used; significant p-values are in bold

Character: size in mm	*Ceratogomphus triceraticus*		*Ceratogomphus pictus*		*t*	*p*
	Mean	sd	Mean	sd		
Total length	31.90	0.65	30.70	1.27	2.99	**0.005**
Head width	6.31	0.23	5.55	0.24	8.69	**< 0.001**
Prementum						
Width max (at palps)	3.15	0.08	3.08	0.21	1.28	0.209
Width min (at base)	1.66	0.07	1.42	0.10	7.98	**< 0.001**
Length	3.56	0.07	3.40	0.15	4.33	**< 0.001**
Ratio max/min width	1.90	0.08	2.17	0.08	9.46	**< 0.001**
Ratio max width /length	0.88	0.01	0.91	0.05	2.26	**0.032**
Ratio min width/length	2.16	0.07	2.40	0.14	7.14	**< 0.001**
Abdomen						
Width S9 (max)	5.31	0.10	4.40	0.23	12.57	**< 0.001**
Length S9	2.27	0.19	2.41	0.15	2.66	**0.014**
Length S10	1.70	0.06	1.90	0.14	4.41	**< 0.001**
Ratio width/length S9	2.35	0.11	1.83	0.07	14.55	**< 0.001**
Ratio width S9/length S9+10	1.30	0.03	0.99	0.03	23.46	**< 0.001**

Explanation: In *C. triceraticus* there were 12 exuvia, but for any of the measurements we could only compare N=11, since one specimen had no head and accordingly no measurements for head, labium and ratios were available from it. So here N=12 for abdomen measurements and N = 11 for head and all prementum measurements.

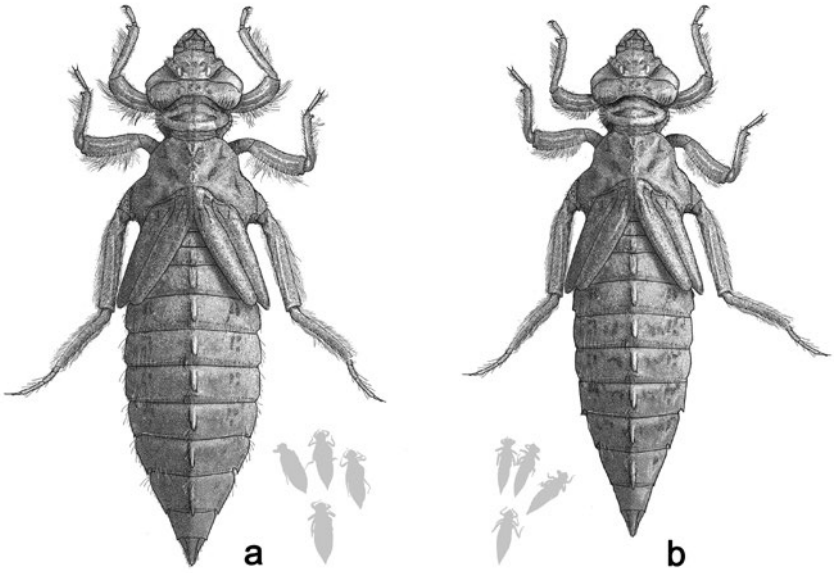

Figure 1. Dorsal view of the general habitus and silhouettes of exuviae of (a) *Ceratogomphus triceraticus* and (b) *C. pictus*, depicting the different size, more slender and pointed shape of the abdomen of *C. pictus* and the keel-like dorsal abdominal spines in both species. Drawing OM.

The antenna is slightly curved in lateral view, ventrally slightly flattened; it consists of four segments, the third segment is much longer than wide, and the fourth segment minuscule in both species. However, in *C. pictus* the fourth segment is more elongate than in *C. triceraticus* (Figures 2d, j). Antennomers 1 to 3 possess longer setae laterally.

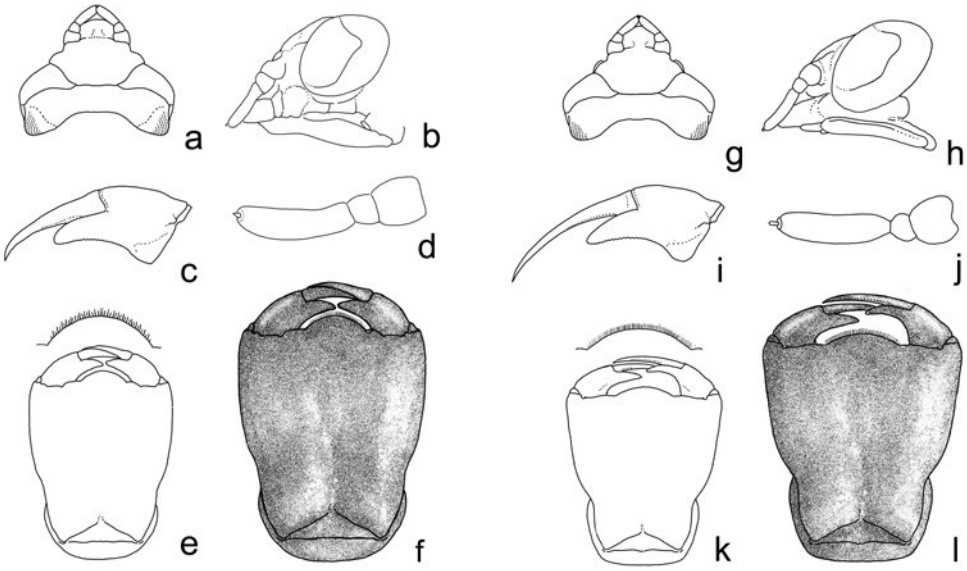

Figure 2. Details of head morphology of *Ceratogomphus triceraticus* (a-f) and *C. pictus* (g-l). (a, g) head, dorsal view, (b, h) head, lateral view, (c, i) palpus, ventral view, (d, j) antenna, lateral view, (e, f, k, l) prementum, ventral view. Drawing OM

Thorax: In the final larval stadium, wing cases in both species slope sideways, extending posterior margin of S3 (Figure 1a, b). Legs short and stocky, with stretched hind-legs extending to 8th abdominal segment. All legs with rows of setae interrupted by bare areas. Pro- and mesofemora with prominent short hook at distal end (Figures 3b, 4b, see arrows). Tarsal formula: 2–2–3.

Abdomen: The abdomen of both species is enlarged in the middle, maximum width on S5; all tergites with very short setae, lateral margins of abdominal segments with rows of some longer setae. In dorsal view the abdomen of *C. triceraticus* is distinctly wider than that of *C. pictus* (Figure 1a, b, 3d, 4d). This becomes clearly evident in the width to length ratio of S9 and also the ratio of the width of S9 to the length of S9+S10 (Table 2). By this *C. pictus* has in dorsal and lateral view a slender and pointed abdomen compared to *C. triceraticus*. Lateral spines present on segments S7 to S9 (Figures 3a, 4a); in *C. triceraticus* those at S7 were often difficult to recognize because they were covered with hairs and mud.

Both species have elongated (in dorsal view keel-shaped) dorsal protuberances along the abdominal segments S2 to S9. In *C. triceraticus* these are blunted dorsal hooks on S2 (sometimes S1) to S8, the protuberance on S9 being prominently pointed (Figure 3c). In *C. pictus* the dorsal protuberances are more variable; they may already be pointed on S6 and further on to S9 (Figure 4c, upper drawing), or few protuberances may be pointed (e.g. Figure 4c, lower drawing). The ventral side of the abdomen of exuviae is sometimes inflated to a various extent (Figure 4c). The caudal appendages are equal, the cerci nearly as long as the paraprocts (Figures 3g, 4g). The marks of male accessory genitalia ventrally at S2 (Figures 3e, 4e) and female gonapophysis (Figures 3f, 4f) at anterior margin of S9 are clearly visible in both species.

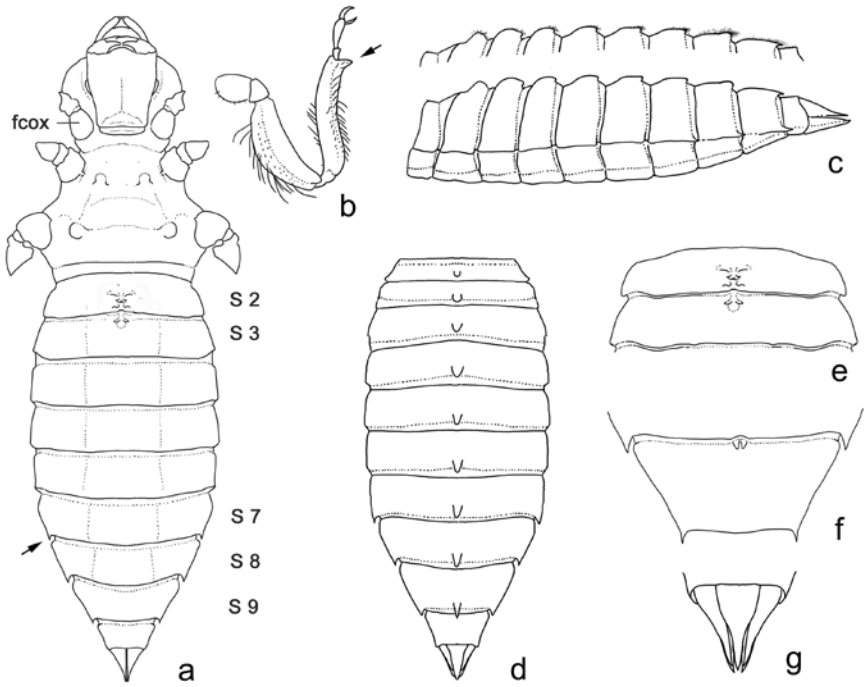

Figure 3. Thorax and abdomen of *Ceratogomphus triceraticus*. (a) head, thorax and abdomen in ventral view (fcox – fore coxa, S 2-S9 abdominal segments), (b) fore-leg in ventral view (arrow indicates lateral spine), (c) abdomen in lateral view, with and without setae, (d) abdomen in dorsal view, (e) abdominal segments S2 and S3 in ventral view (male), (f) S 8 and S9 with female gonapophysis, (g) anal pyramid in dorsal view. Drawing OM & HW.

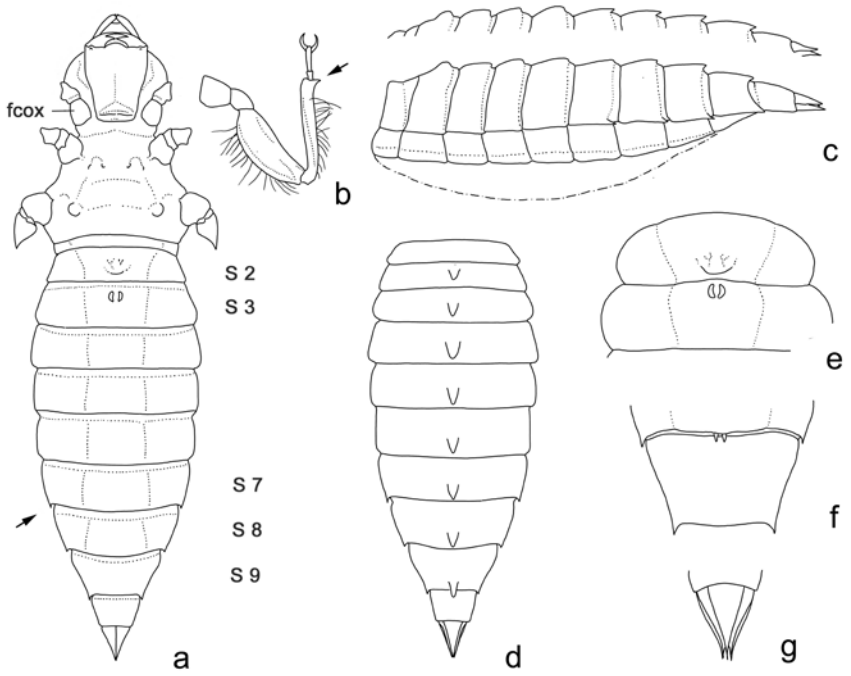

Figure 4. Thorax and abdomen of *Ceratogomphus pictus.* (a) head, thorax and abdomen in ventral view (fcox – fore coxa, S 2-S9 abdominal segments), (b) fore-leg in ventral view (arrow indicates lateral spine), (c) abdomen in lateral view, with variable dorsal line; dashed line indicates maximum ventral inflation, (d) abdomen dorsal view, (e) abdominal segments S2 and S3 in ventral view (male), (f) S 8 and S9 with female gonapophysis, (g) anal pyramid in dorsal view. Drawing OM & HW.

Habitats

All exuviae of *C. triceraticus* were found at the Grootrivier, Cederberg, South Africa (Table 1). At this location the water was a rather large brook, 8–10 m wide, slowly or moderately fast flowing at stretches and interrupted by rapids on hard ferruginous quartzite bedrock with large polished boulders that were obviously regularly flooded at times with high water (Figure 5). The ground consisted of bare rock or gravel and coarse sand in pans. No submerged vegetation was present at this locality. The stream was lined by emergent herbaceous plants and dense, almost impenetrable bush vegetation within the Fynbos biome. The exuviae clung vertically to emergent riparian water plants or overhanging shrub twigs, 5–15 cm above the water surface. At this locality also a few exuviae of *C. pictus* were collected.

Figure 5. Habitat of *Ceratogomphus triceraticus* where the exuviae were collected. Grootrivier, Mount Ceder. Photo HW.

Adult males of *C. triceraticus* were recorded at three further localities (Table 1). All waterbodies were rocky mountain streams, lined by shrubs and herbaceous vegetation. The stream-bed consisted of bare rock, boulders, rapids, waterfalls and basins with gravel or sand ground (Figure 6a). At one of these localities, patches of immersed Fennel-leaved Pondweed (*Stuckenia pectinata*), stands of the semiaquatic Palmiet (*Prionium serratum*) and tufts of Fiber Optic Grass (*Isolepis cernua*) were present (Figure 6b). At this brook adult males of both *Ceratogomphus* species were recorded syntopically.

Exuviae of *C. pictus* were found at four localities out of ten locations where we recorded the species (Table 1). The vast majority of exuviae was collected at dams, i.e. artificial ponds along brooks constructed for agricultural use or trout fishing in hilly open areas (Figure 7). One small reservoir where more than 100 exuviae were collected, had steep rocky banks but also shallow parts with dense stands of Bulrush (*Typha capensis*) harbouring a colony of Southern Red Bishop (*Euplectes orix*). The ground consisted of mud on quartzite bedrock. Exuviae were collected from any substrates such as sand, gravel, stones, rocks, riparian water plants and bush twigs. They were found in horizontal to vertical position between 0 and 30 cm above the water surface, often covered with dried mud. Adult males of *C. pictus* were also encountered at two small natural mountain streams with waterfalls, rapids and pools, the ground of the latter consisting of gravel and sand, locally with immersed vegetation and stands of emergent plants (Figure 8). One adult male was recorded at a lowland river with lush vegetation.

Figure 6. Habitat of *Ceratogomphus triceraticus* where adult males were observed. (a) waterfalls alternating with rapids and pools, (b) rock pool with submerged and emergent vegetation. Watervalrivier, Tulbagh. Photo HW.

Figure 7. Secondary habitat of *Ceratogomphus pictus* where >100 exuviae were collected. Farm dam Dullstroom, Mpumalanga. Photo HW.

Discussion

In this study we compare the final instar larvae of *Ceratogomphus triceraticus* and *C. pictus*. Our assessment of both species is based on final stadium exuviae. While the identification of *C. pictus* was secured by the key by Samways & Wilmot (2003), who reared the larvae up to emergence (Samways pers. comm.), identification of *C. triceraticus* was tentative since we did not observe the emergence of adults. However, as the both types of exuviae share most characters, including the keel-like dorsal protuberances, and because the only unknown gomphid larva from the Cape was *C. triceraticus*, we assume our identification valid.

The history of the larval description of the two *Ceratogomphus* species is in so far somehow confusing as the description of the larva under the name of *C. pictus* by Barnard (1937) is obviously based on younger instar larvae of *C. triceraticus*, and not *C. pictus*. This becomes clearly evident when comparing our material with the description and photos of the original specimens in Barnard's collection. Barnard, not knowing of a second species of *Ceratogomphus* at that time, naturally described the larvae under the name of the species he knew and which occurred at his study site. Nobody noted that the larva of the endemic *C. triceraticus* had already been described in 1937 while the larva of the more common species, *C. pictus* remained undescribed. The original description of *C. pictus* is therefore probably that by Samways & Wilmot (2003). Therefore, older records of the two species based on larvae or exuviae have probably to be re-evaluated. Larvae collected at an impoundment of the Great Berg River were bred and identified as *C. pictus* (Harrison, 1958), which also matches the typical secondary habitat of this species (see below). Harrison's statement that "a number of nymphs were bred out to confirm Barnard (1937)" appears rather ambiguous. However, our comparison, summarized in Figure 9, should help to clearly distinguish the two species of *Ceratogomphus*.

Figure 8. Supposed primary habitat of *Ceratogomphus pictus* where adult males were observed. (a) riffles and pool, (b) deep rock pool with sand ground. Brook near Magaliesberg, Wigwam. Photo HW.

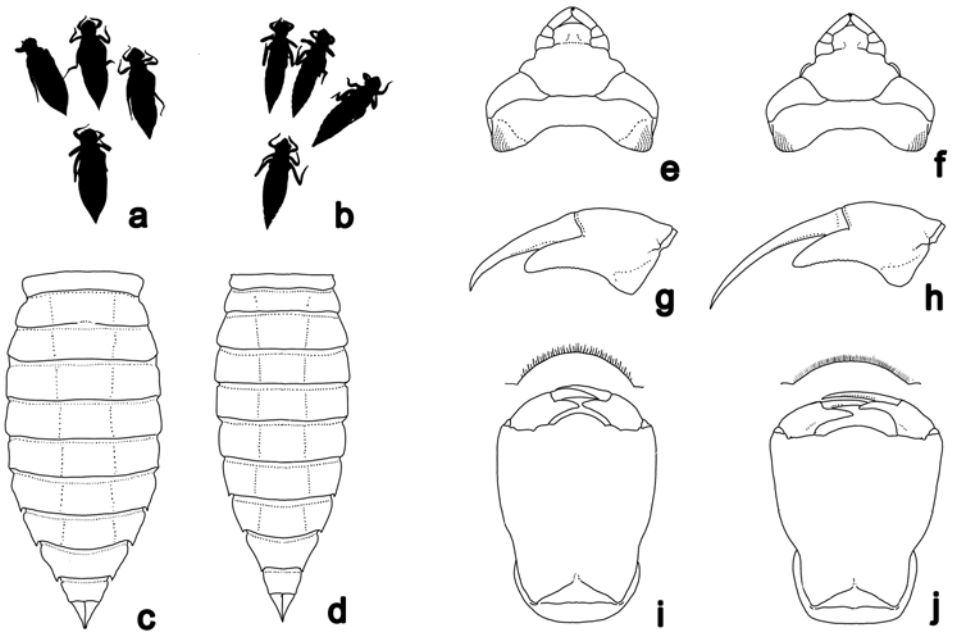

Figure 9. Comparison of *Ceratogomphus triceraticus* (a, c, e, g, i) and *C. pictus* (b, d, f, h, j): (a, b) silhouettes of the habitus; (c, d) abdomen in ventral view (unisex), (e, f) head in dorsal view; (g, h) left palpus in ventral view; (i, j) prementum in ventral view. Drawing OM.

Identification key to final-instar larvae/exuviae of *Ceratogomphus*

For convenience we give here approximate measurements, for precise measurements with standard deviations cf. Table 2)

1 Posterior part of the abdomen broad (ratio width S9 to length of S9+S10 ≈ 1.3) and S10 more elongate (Figure 9c); anterior border of prementum prominently convex (Figure 9i); prementum max width: min width ratio ≈ 1.9. . . . . *Ceratogomphus triceraticus*

1' Posterior part of the abdomen slender (ratio width S9 to length of S9+S10 ≈ 1.0) (Figure 9d); anterior border of prementum slightly convex (Figure 9j); prementum stockier, with basis more slender (ratio max width: min width ≈ 2.2) . . . . . *Ceratogomphus pictus*

According to Carle (1986) *Ceratogomphus* belongs to the subfamily Phyllogomphini, together with *Phyllogomphus* Selys, 1854, consisting of about a dozen species in sub-Saharan Africa, and *Isomma* Selys, 1892 from Madagascar. Final instar larvae of both genera are described (*Phyllogomphus*: P.S. Corbet 1956, S.A. Corbet 1977, Di Domenico et al. 1994, Butler 2003; *Isomma*: Butler 2003) and also available to us (FS), thus comparisons of the larval morphology are possible. Larvae of *Phyllogomphus* differ from *Ceratogomphus* distinctly in some aspects (S10 transformed into a distinct breathing tube, anterior border of prementum concave). The larva of *Isomma hieroglyphicum* comes closer to *Ceratogomphus*, in general appearance particularly to *C. pictus*. However, the shape of the concave anterior border of the prementum is somewhat different to both *Ceratogomphus* species, the abdominal segment 10 is slightly elongated, and the keeled dorsal protuberances are all distinctly pointed (Butler 2003; own material FS). However, as a Malgassian genus *Isomma* will not co-occur with *Ceratogomphus*. The key to the gomphid genera in Suhling et al. (2014) therefore still applies, also with adding *C. triceraticus*.

Ecology of the species

During our fieldtrips in South Africa we encountered *C. triceraticus* at four localities (at one of them exuviae only) and *C. pictus* at eleven sites (at four of them exuviae). Both species were found at mountain streams in open landscapes, at two localities syntopically. Conspicuously, most records of *C. pictus* (imagines and exuviae) were made at farm dams. Also, in Natal farm dams were the main habitat of *C. pictus*, up to an elevation of 1500 m a.s.l. (Samways 1989). In Namibia all exuviae were found at large impoundment lakes (seven lake records), only adults were recorded at few other sites (Suhling et al. 2017). Thus, pond- and lake-like secondary habitats with riparian emergent vegetation and sandy or muddy ground obviously offer suitable conditions for the development of the species. Indeed, Harrison (1958) collected larvae from deep mud at the bottom of an impoundment. By contrast, *C. triceraticus* seems to be entirely restricted to running waters containing calm sections with coarse detritus, gravel or sand on the bottom (Dijkstra 2021). However, so far, no information on the microhabitat and the larval biology is available of *C. triceraticus*. Field and experimental studies could reveal further differences between the two sister species.

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