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Advertisement call and tadpole of *Cardioglossa cyaneospila* (Anura: Arthroleptidae) from Nyungwe National Park and Gishwati-Mukura National Park, Rwanda

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The genus *Cardioglossa* Boulenger, 1900 currently comprises 18 species of which most are distributed in the Lower Guinean Forest Zone of Central Africa in Cameroon and adjacent countries (Amiet 1972a, 1972b, Hirschfeld et al. 2015, Blackburn et al. 2021), with only one species occurring in West Africa (*C. occidentalis* Blackburn, Kosuch, Schmitz, Burger, Wagner, Gonwouo, Hillers & Rödel, 2008; Rödel et al. 2001, Blackburn et al. 2008) and two species in the Central African Albertine Rift (*C. cyaneospila* Laurent, 1950, *C. inornata* Laurent, 1952; Laurent 1950, 1952, Hirschfeld et al. 2015, Blackburn et al. 2016). Members of the genus are generally found in closed-canopy rainforests near streams, where males call at ground level or on low vegetation (Amiet 1972b, Rödel et al. 2001, Hirschfeld et al. 2015). The advertisement calls of most species from West and Central Africa have been described in the literature (Amiet 1973, Rödel et al. 2001, Amiet & Goutte 2017) but the calls of *C. alsco* Herrmann, Herrmann, Schmitz & Böhme, 2004, *C. annulata* Hirschfeld, Blackburn, Burger, Zassi-Boulou & Rödel, 2015, *C. congolia* Hirschfeld, Blackburn, Greenbaum & Rödel, 2015, *C. cyaneospila* and *C. inornata* remain unknown. All species for which details of reproduction are known reproduce in streams, and all known tadpoles of the genus have a stream-adapted eel-like shape with long, muscular tails and narrow fins and are found in decomposing leaves or between stones (Blackburn 2008, Hirschfeld et al. 2012, Channing et al. 2012). The tadpoles of only six species have been illustrated or described in detail (Guibé & Lamotte 1958, Lamotte 1961, Perret 1966, Amiet 1972b, Blackburn 2008, Hirschfeld et al. 2012, Channing et al. 2012).

One of the least known species of the genus is *C. cyaneospila* from the Central African Albertine Rift. The species was described from southern Burundi and has been recorded from several localities in the Democratic Republic of the Congo, Uganda, Rwanda, and Burundi at elevations between 1470 and 2300 m a.s.l. (Laurent 1950, 1983, Blackburn et al. 2016). In Rwanda it is known from the Western Province, from Nangumulimbo stream and from Gishwati-Mukura National Park in the northwestern part of the country as well as from two localities in Nyungwe Forest in southwestern Rwanda (Blackburn et al. 2016, Dehling & Sinsch 2023; Fig. 1). We herein specify our previous record from Gishwati Forest, report on records from two additional locations in Nyungwe Forest and describe the advertisement call as well as the tadpole of the species for the first time.

We observed adult males of *C. cyaneospila* at two locations in Nyungwe National Park, near Karamba Trail (-2.47, 29.11; 1930 m a.s.l.) and at Mujabagiro River (-2.44, 29.10; 1820 m a.s.l.) on 27 August 2023 (Fig. 1). At both locations, specimens were located in leaf litter under shrubs close to a stream (Fig. 2). Both streams were lined with tree ferns which fits the description of the preferred habitat of the species (Laurent 1983). At the Karamba site, two males were recorded calling at 1142 h and 1145 h, respectively (Fig. 2). Later in the afternoon (1500–1700 h), a chorus of males emitting the same distinct call was heard at the same locality but not recorded. The new localities extend the known distribution of *C. cyaneospila* in Rwanda. Advertisement calls were recorded as uncompressed files in WAV format with a Sony PCM-D50 Linear PCM Recorder with built-in stereo microphones (Sony Deutschland GmbH, Cologne). For the characterisation of the advertisement call, we analysed a total of six calls from two different males. Stereo recordings were converted to mono at a sampling rate of 44.1 kHz and 16 bits resolution using Adobe Audition 1.5. Spectrograms and waveforms were obtained applying Blackman-Harris Fast Fourier transformation with a FFT window width of 1024 points. Temporal data were obtained from the waveforms and frequency information was obtained from the spectrograms and power spectra. Values are given as arithmetic mean with range

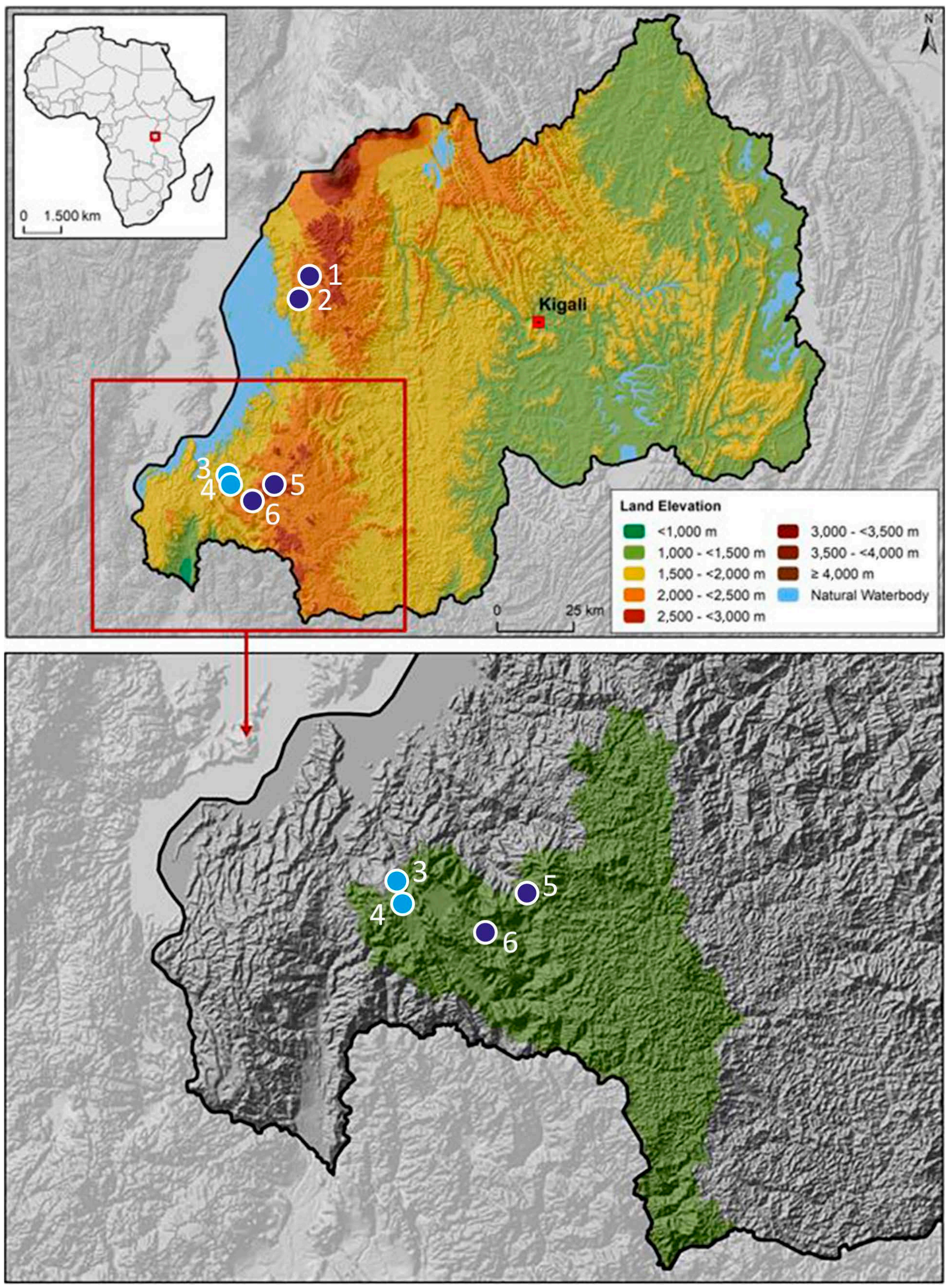

Figure 1. Records of *Cardioglossa cyaneospila* in Rwanda (top) and more specifically in Nyungwe National Park (bottom); taken from the literature (Blackburn et al. 2016, Dehling & Sinsch 2023; dark blue circles) and additional records (this study; light blue circles): (1) Gishwati Forest, Gishwati-Mukura National Park; (2) Nangumulimbo stream, Kayove; (3) Mujabagiro River, Nyungwe National Park; (4) Karamba Trail, Nyungwe National Park; (5) Rukuzi Trail, Nyungwe National Park; (6) unspecified location, Nyungwe National Park.

in parentheses. Definitions of acoustic parameters follow Köhler et al. (2017). Data on the advertisement calls of *Cardioglossa* species used for comparison were taken from the literature (Amiet 1973, 1982, Rödel et al. 2001) and analyses of the recordings provided by Amiet & Goutte (2017).

In both recorded instances, the advertisement call was emitted in loose series of three calls, repeated at a rate of 4.7 (4.5–5.0; 1st to 2nd call) and 5.7 (5.1–6.3; 2nd to 3rd call) calls/minute. The first call of the series consisted of 3, the subsequent calls of 4 notes (Fig. 3). Duration of three-note calls was 335 (333–337) ms, of four-note calls 405 (394–419) ms. Notes were repeated at a rate of 9.8 (9.3–10.3)/s and individual notes lasted 92.2 (78–126) ms, with the last note of a series always being the longest. Each note was composed of two pulsatile units, separated by a short interval of 11.1 (9–13) ms that was clearly visible and measurable only in the better of the two recordings. The first unit was much shorter and lasted 17.0 (9–25) ms, whereas the second one had a duration of 69.4 (49–107) ms. Amplitude of the first unit was higher than amplitude of the second unit. Dominant frequency slightly increased within a call from 2941 (2906–

Figure 2. Habitat of *Cardioglossa cyaneospila* near Karamba trail, Nyungwe National Park, Rwanda (left), and one of the adult males recorded at that site (right). Photos by MM.

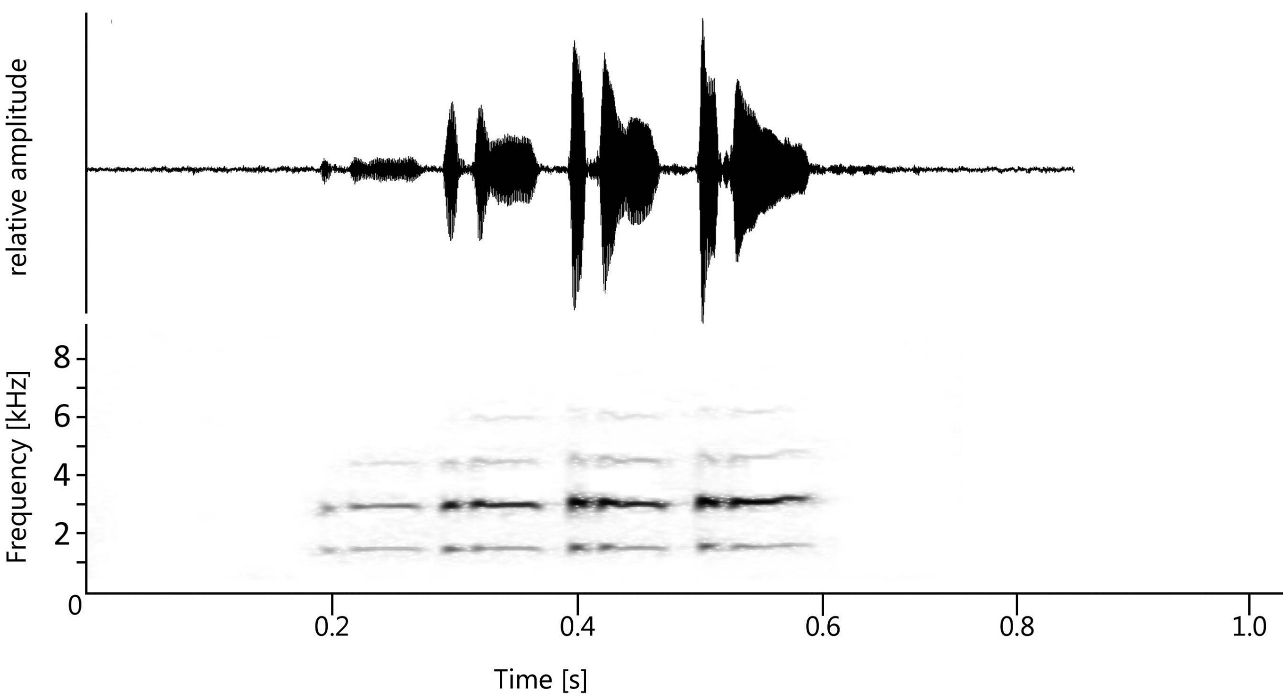

Figure 3. Waveform (top) and corresponding audiospectrogram (bottom) of a four-note advertisement call of a male *Cardioglossa cyaneospila* near Karamba Trail, Nyungwe National Park, Rwanda.

3000) Hz in the first note to 3065 (3046–3100) Hz in the last note. The fundamental frequency band was at about 1450–1550 Hz, an additional prominent frequency band at about 4400–4650 Hz, and another one at about 5900–6200 Hz, the latter being visible only in the last two notes (Fig. 3). Prevalent bandwidth was 2800–3200 Hz. Overall amplitude was much lower in the first note, especially in four-note calls, and further increased from the second to the last note (Fig. 3).

The advertisement call of *C. cyaneospila* is most similar to the advertisement calls of the Cameroonian montane species *C. oreas* Amiet, 1972, *C. pulchra* Schiøtz, 1963, and *C. venusta* Amiet, 1972 in being composed of several distinct pulsatile double-unit notes, emitted, however, at a somewhat higher rate of about 12.5 notes/s in *C. oreas* and *C. pulchra* or much higher rate of about 20 notes/s in *C. venusta* (vs. 9.3–10.3/s in *C. cyaneospila*). The dominant frequency (2906–3100 Hz in *C. cyaneospila*) is very similar in the call of *C. oreas* (3000–3500 Hz), whereas the energy is almost evenly distributed between the dominant fundamental at about 2000 Hz and the first harmonic at about 4000 Hz in *C. pulchra*, and higher, at about 4000 Hz in *C. venusta*. The calls differ in being composed of 5–7 (*C. pulchra*) and usually 7 notes (*C. oreas*, *C. venusta*) and a resulting longer total call duration in *C. oreas* (491–513 ms) and *C. pulchra* (390–509 ms), but not in *C. venusta* (380–426 ms) (vs. 3–4 notes, 333–419 ms in *C. cyaneospila*). Despite the similarities in the advertisement calls and altitudinal distribution, *C. cyaneospila* is not closely related to the Cameroonian montane species (Blackburn et al. 2021).

The call of *C. nigromaculata* Nieden, 1908 is composed of two rapidly repeated pulsatile notes, resembling a single double-unit note in the call of *C. cyaneospila*. The total duration is very brief (85–87 ms) and the dominant frequency at about 2200 Hz, with prominent harmonics at about 4600 Hz and 6900 Hz. Somewhat similar are the advertisement calls of *C. escalerae* Boulenger, 1903, *C. trifasciata* Amiet, 1972, and *C. gratiosa* Amiet, 1972, which differ in being composed of brief, more or less regularly spaced notes. The number of notes and their repetition rate is much higher and the call duration longer in *C. escalerae* (8–22 notes; 25 notes/s; 263–720 ms) and *C. trifasciata* (14–22; 25/s; 521–861 ms), but equal, higher and briefer, respectively, in *C. gratiosa* (3–4; 17/s; 184–290 ms). Dominant frequency in the calls of the three species (3900–4300 Hz, 3200–3700 Hz, 3550–3750 Hz, respectively) is higher than in *C. cyaneospila*. The advertisement calls of *C. gracilis* Boulenger, 1900, *C. melanogaster* Amiet, 1972, and *C. schioetzi* Amiet, 1982 consist of a single pulsed note and therefore differ markedly from the call of *C. cyaneospila*. The two sister species *C. leucomystax* (Boulenger, 1903) and *C. occidentalis* as well as *C. elegans* Boulenger, 1906 have calls composed of two different kinds of notes. The first two species both have an advertisement call that contains a long, pulsed note and a second pulsatile note, whereas *C. elegans* emits a long, pulsed note followed by 1–5 tonal notes.

During our field study, we did not have the chance to stay during the night to assess the night-time calling activity of *C. cyaneospila*. We recorded the call of the species at the end of the dry season in Rwanda but it remains unclear if the species also calls at other times of the year.

A tadpole of stage 41 (Gosner 1960) was collected from a stream using a dip net in the Gishwati-Mukura National Park (1.82, 29.36; 2080 m a.s.l.) at 14:35 h on 27 September 2015 (Fig. 4). The tadpole was preserved and stored in 10% buffered formaldehyde. It is deposited in the herpetological collection of the Zoologisches Forschungsmuseum Alexander Koenig, Bonn, Germany (ZFMK 104184). Identification is based on overall body shape and dorsal pattern. Description follows Hirschfeld et al. (2012). Measurements are given in mm. Data on other tadpoles used for comparison were taken from the literature (Lamotte 1961, Perret 1966, Amiet 1972b, Blackburn 2008, Hirschfeld et al. 2012, Channing et al. 2012).

Description of the tadpole: Body depressed and elliptical in dorsal and lateral views (Fig. 4); body length (10.8) 25.9% of total length (41.7); maximum body height (5.9) 54.7% of body length; maximum body width (6.9) postocular; snout acuminate in dorsal view (Fig. 4); nostrils small, round, situated dorsally; closer to snout tip than to eye; nostril–snout distance (1.5) 13.9% of body length, shorter than eye–nostril distance (2.2); eyes oval, slightly wider (1.5) than high (1.3), located dorsolaterally; eye diameter (anterior–posterior) 13.9% of body length; eye–snout distance 4.1; eye–end of spiracle distance (9.8) 90.7% of body length; eye–spiracle skin fold distance (3.6) 33.3% of body length; interorbital distance (4.9) exceeding internarial distance (2.3) by factor of 2.1; tail long (31.0), 74.1% of total length, with narrow fins (Fig. 4); dorsal fin originating about one-eighth of tail length posterior to tail base, initially as low seam, becoming higher posterior to about one-third of tail length, reaching maximum height near tail tip (Fig. 4); ventral fin originating at tail base; ventral fin higher than dorsal fin along first half of tail, equally high in second half of tail; maximum tail height including fin (5.4) slightly less than body height; muscular part of tail axis broad and thick, tapering towards tail tip in posterior third of tail length; maximum height of tail muscle axis (3.2) 58.7% of total tail height; fin tip narrowly rounded; vent tube median; spiracle sinistral, conspicuously large, visible in dorsal and lateral view, originating at midbody; spiracle tube long (5.1), 47.5% of body length, directed horizontally with round opening; mouth opening anteroventrally; oral disc width (2.3) 72% of body width; labial tooth row formula 0/0; upper jaw and lower jaw strongly serrated (Fig. 5); strongly keratinised parts forming semi-circles; anterior lip curved, overlapping upper jaw marginally; numerous rows of small papillae densely covering posterior lip near lower jaw and extending laterally onto edges of upper lip; papillae on outer posterior row very long (Fig. 5). Body and tail dark grey/anthracite with light silvery marbling in life (Fig. 4); marbling almost evenly distributed, more pronounced towards tail tip; in dorsal view, two non-marbled, anthracite-coloured areas medially on dorsum, on head and body; triangle-shaped area inter- and postocular, adjacent to both eyes; anterior non-marbled area in line with anterior eye line, ending posteriorly in triangular shape, about twice length of eye; two consecutive blunt triangles with narrowest tip pointing anteriorly; ventral fin transparent and unpigmented.

The tadpole of *C. cyaneospila* matches the general characteristics of tadpoles of *Cardioglossa* described so far. They are rather small to medium-sized and are characterized by a long spiracle and a stream-adapted eel-like shape with long, muscular tail with narrow fins. Like in other arthroleptid tadpoles, these characteristics may be an adaptation to living between stones and gravel in flowing water bodies (Channing et al. 2012, Hirschfeld et al. 2012, Mapouyat et al. 2014; Griesbaum et al. 2019). Furthermore, the posterior lip is dominated by conspicuous papillae, the tadpole lacks labial teeth (0/0) and the upper and lower jaws are distinctly and strongly serrated (Lamotte 1961, Blackburn 2008, Hirschfeld et al., 2012).

Figure 4. Tadpole of *Cardioglossa cyaneospila* (ZFMK 104184; Gosner stage 41) in preserved state in (A) lateral, (B) dorsal, and (C) ventral view (scale bar represents 5 mm); and in life in (D) dorsolateral view and (E) dorsal view (not to scale). Photos by JMD.

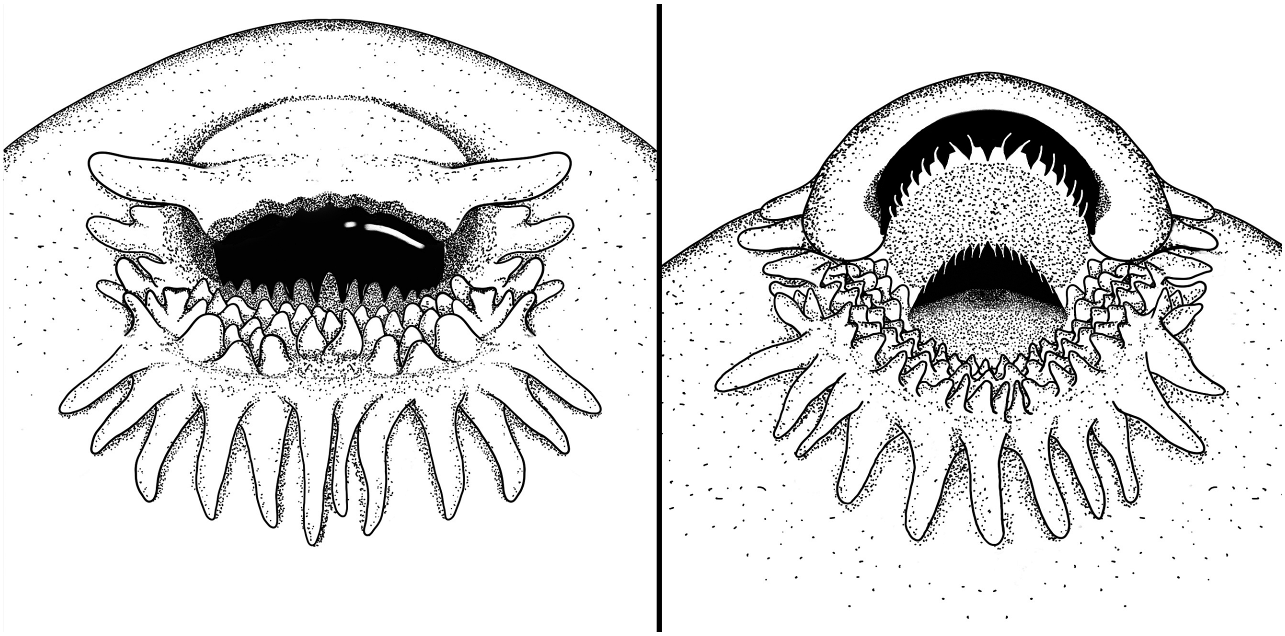

Figure 5. Mouth parts of the tadpole of *Cardioglossa cyaneospila* (Gosner stage 41) in ventral view, with closed jaws (left) and open jaws (right); not to scale. Drawings by SG.

Similar to the tadpole of *C. pulchra*, the tadpole of *C. cyaneospila* has a depressed and elliptical body in dorsal and lateral views, which distinguishes the two species from the remaining described tadpoles with more elongate body shape. The tail makes up about ¾ of the total length in *C. cyaneospila*, which is similar to *C. melanogaster*, whereas in the other species the tail makes up only about ⅔ of the total length. The tail fins of all species are narrow, but differ from each other in the origin of the dorsal fin: in *C. oreas manengouba* and *C. schioetzi* the dorsal fin originates at the base of the tail, in *C. pulchra* a short distance posterior to tail base, in *C. cyaneospila* at about one-eighth of tail length posterior to tail base, in *C. gracilis*, *C. leucomystax*, and *C. occidentalis* one quarter of tail length posterior to the tail base, and in *C. melanogaster* just posterior to half of the tail length. Unlike in any other *Cardioglossa* tadpole, the anterior lip of the tadpole of *C. cyaneospila* has papillae on its outer edges.

C. leucomystax and *C. occidentalis* have a much shorter spiracle than the large spiracle of *C. melanogaster*, *C. pulchra*, *C. oreas manengouba*, *C. schioetzi* and *C. cyaneospila*. The spiracle originates at the second third of the body in *C. cyaneospila*, *C. oreas manengouba*, *C. pulchra*, and *C. schioetzi*, but in the posterior third of the body in *C. leucomystax*, *C. melanogaster*, and *C. occidentalis*. The orientation of the opening at the posterior end of the spiracle is horizontal in *C. leucomystax*, *C. schioetzi*, and *C. cyaneospila*; posteriodorsal in *C. pulchra* and *C. occidentalis*; and posterioventral in *C. melanogaster* and *C. oreas manengouba*.

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