

Dactylogyrids (Platyhelminthes: Monogenea) from Sudanese *Labeo* spp., with a description of *Dogielius sennarensis* n. sp. and a redescription of *Dogielius flosculus* Guégan, Lambert & Euzet, 1989

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Summary

Dactylogyrid monogeneans of *Labeo horie* Heckel, 1847 and *L. niloticus* (Linnaeus, 1758) (Cyprinidae) were surveyed at two sites on the River Nile in Sudan. The present study reports the presence of ten species of *Dactylogyrus* Diesing, 1850 and three species of *Dogielius* Bychowsky, 1936 based on a morphometric evaluation of the sclerotised structures. The species found include: *Dactylogyrus nathaliae* Guégan, Lambert & Euzet, 1988; *D. rastellus* Guégan, Lambert & Euzet, 1988; *D. retro-versus* Guégan, Lambert & Euzet, 1988; *D. senegalensis* Paperna, 1969, *D. yassensis* Musilová, Řehulková & Gelnar, 2009 and five other undescribed species of *Dactylogyrus*. The genus *Dogielius* was represented by *Dogielius flosculus* Guégan, Lambert & Euzet, 1989; the newly identified *D. sennarensis* n. sp., and one undescribed *Dogielius* species. While *D. sennarensis* n. sp. resembles *D. intorquens*, it differs from this species and other congeners by having a longer ventral bar and anchor points and nosclerotised vagina. In addition, this study redescribes *D. flosculus* based on the morphology of specimens collected from *L. horie*. All specimens studied had a single large vagina, in contrast to the original description which reported a vagina composed of two unconnected parts. All dactylogyrid species in this study represent new host and geographical records.

Keywords: Dactylogyridae; *Dactylogyrus*; *Dogielius*; Sudan; River Nile

Introduction

Monogenean parasites represent an important part of the parasite community in most fish species. Whittington (1998) estimated that the world fish fauna may ultimately prove to harbour 25 000 monogenean species, of which just 3000–4000 have been described so far. Monogenean parasite diversity generally increases with decreasing latitude or increasing water temperature (Poulin, 2007). In essence, generation time is shorter, and evolution occurs more rapidly in warmer conditions (Cribb *et al.*, 2002). Therefore, recently there is a trend of increasing number of new monogenean spe-

cies being described predominantly from the tropical regions (e.g. Musilová *et al.*, 2009; Přikrylová *et al.*, 2009; Knoff *et al.*, 2015; Pulido-Flores *et al.*, 2015; Soo *et al.*, 2015; Nitta & Nagasawa, 2016). Dactylogyrid monogeneans mainly infect freshwater cyprinids (Teleostei: Cypriniformes), with the suborder Dactylogyrynea Bychowsky, 1937 being the most numerous and diverse group (Cribb *et al.*, 2002). Whilst Gibson *et al.* (1996) published a list of over 900 nominal species of *Dactylogyrus* Diesing, 1850, it is clear from the historical summary that the number of valid dactylogyrid species will continue to increase significantly (Cribb *et al.*, 2002). Representatives of the genus *Dactylogyrus* were reported mainly

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from the Palearctic region, South Asia, Africa and North America and form about one quarter of the 3000-4000 monogenean species known to date (Cribb *et al.*, 2002).

In comparison, the genus *Dogielius* Bychowsky, 1936 includes only 27 species, of which 17 have been described in Africa, four in China, one in India and five from the Palaearctic to date (Pugachev *et al.*, 2009). Species of the genus *Dactylogyrus* do not naturally occur in the Neotropics, where, among others, other dactylogyrid genera such as *Anacanthorus* or *Urocleioides* are present (Kohn & Cohen, 1998).

Fish of the large genus *Labeo* Cuvier, 1817 are widely distributed in Africa and Southeast Asia. More than 100 species are known from both continents (Skelton, 2001; Froese & Pauly 2018), of which at least 80 occur in Africa (Skelton, 2001). Along the Sudanese stretch of the White and Blue Nile, *Labeo* are represented by five species: *L. niloticus* (Linnaeus, 1758); *L. horie* Heckel, 1847; *L. coubie* Rüppel, 1832; *L. forskalii* Rüppel, 1835 (El Moghraby & Abd el Rahman, 1984) and *L. meroensis* Moritz, 2007. The area of occurrence of *L. horie* and *L. niloticus* overlaps within the Blue and White Nile basin, in lakes Albert, Kyoga, Turkana and Rudolf, and in the River Omo (Froese & Pauly, 2018). Both species are predominantly herbivorous and constitute a considerable part of the catch of inland fisheries in the Sudan, making them a commercially important species (el Moghraby & Abd el Rahman, 1984; Azeroual *et al.*, 2010).

Up until now, there have been no intensive fish parasite studies undertaken along the Sudanese stretch of the Nile. As such, there are no records of dactylogyrid monogeneans parasitizing *L. horie* and *L. niloticus*, and just four monogenean species have been reported from the five host species, *i. e.* *Macrogryrodactylus polypteri* Malmberg, 1957 from *Polypterus bichir* Lacepède, 1803 and *Polypterus senegalus* Cuvier, 1829; *Gyrodactylus malalai* Prikry-

lová, Blažek & Gelnar, 2012 from *Coptodon zillii* (Gervais, 1848); *Gyrodactylus* sp. from *Clarias gariepinus* Burchell, 1822) and *Afrogyrodactylus girgiffae* Prikrylová & Luus-Powell, 2014 from *Brycinus nurse* (Rüppel, 1832) (Malmberg, 1957; Khalil, 1964, 1969, 1970; Prikrylová *et al.*, 2012; Prikrylová & Luus-Powell, 2014). On the other hand, 39 dactylogyrid species have been recorded on fish from the Lower Nile in Egypt. To date, 48 monogenean species from five genera (including three subspecies) have been described for African *Labeo* spp.: *Dactylogyrus* (30 species), *Dogielius* (14 species, including two subspecies), *Paradiplozoon* (three species), *Diplozoon* (one species) and *Afrodiplozoon* (one species) (Khalil & Polling, 1997; Musilová *et al.*, 2009; Crafford *et al.*, 2012).

The aim of the present study was to examine and classify monogenean parasites from *L. horie* and *L. niloticus* from the Sudanese stretch of the Blue and White Nile. To the best of the authors' knowledge, this is the first parasitological survey of these two fish species; hence, the data will contribute significantly to our understanding of parasite diversity in tropical regions.

Material and Methods

Live individuals of *L. horie* and *L. niloticus* were obtained from fishermen at two sites in Sudan. Two specimens of *L. horie* and one specimen of *L. niloticus* were obtained in Kosti, a major city located on the western bank of the White Nile (13°10' 18,58" N, 32°40' 19,24" E), while one specimen of *L. horie* and one specimen of *L. niloticus* were obtained at the Sennar Dam on the Blue Nile near the town of Sennar (13°32' 50,61" N, 33°38' 4,23" E). The fish were identified according to Bailey (1994); the species' names following FishBase (Froese & Pauly, 2018).

The gills were examined under a binocular microscope for presence

Table 1. Records of dactylogyrids collected in this study, reported from different *Labeo* spp. hosts.

	<i>Labeo coubie</i>	<i>Labeo horie</i> ⁵	<i>Labeo niloticus</i> ⁵	<i>Labeo roseopunctatus</i>	<i>Labeo senegalensis</i>
<i>Dactylogyrus nathaliae</i>	-	-	+K,S	+ ²	-
<i>Dactylogyrus rastellus</i>	-	+ ^S	-	-	+ ²
<i>Dactylogyrus retroversus</i>	+ ^{2,4}	+ ^K	-	-	-
<i>Dactylogyrus senegalensis</i>	+ ⁴	+ ^{K,S}	+ ^S	-	+ ^{1,2}
<i>Dactylogyrus yassensis</i>	+ ⁴	+ ^{K,S}	+ ^K	-	+ ²
<i>Dactylogyrus</i> sp. 1	-	+ ^K	-	-	-
<i>Dactylogyrus</i> sp. 2	-	-	+ ^K	-	-
<i>Dactylogyrus</i> sp. 3	-	-	+ ^{K,S}	-	-
<i>Dactylogyrus</i> sp. 4	-	-	+ ^K	-	-
<i>Dactylogyrus</i> sp. 5	-	-	+ ^K	-	-
<i>Dogielius flosculus</i>	-	+ ^S	-	-	+ ³
<i>Dogielius sennarensis</i>	-	-	+ ^S	-	-
<i>Dogielius</i> sp. 1	-	+ ^S	+ ^K	-	-

¹Paperna, 1969; ²Guégan *et al.*, 1988; ³Guégan *et al.*, 1989; ⁴Musilová *et al.*, 2009; ⁵Present study

of metazoan parasites according to standard methods (Ergens & Lom, 1970). All monogeneans collected were preserved in glycerine ammonium-picrate mixture (GAP; Malmberg, 1957) and later mounted in Canada balsam for further analysis (Lim & Gibson, 2008). Individual specimens were deposited in the helminthological collection of the Institute of Parasitology, Academy of Sciences of the Czech Republic, České Budějovice, Czech Republic (IP-CAS).

A motorised Olympus BX61 light microscope equipped with phase contrast and digital image analysis (Stream Motion 1.9.2) was used for species identification and measurements (Olympus Corporation, Japan). Drawings were made with the aid of a drawing tube attached to the microscope. All measurements are given in micrometres (μm) with the means followed by the range and number (n) of specimens measured in parentheses. The measurement scheme for the hard structures (i.e. haptor attachment components, vaginal armament and male copulatory organ) follows that of Musilová *et al.* (2009). The numbering of hook pairs (in Roman numerals) follows the recommendations of Mizelle (1936). When all hooks were of the same size and morphology, only one was depicted. Where the hooks differed in size and morphology, all were depicted, with the smallest and largest hooks depicted in specific cases.

For morphological comparisons, specimens from the National Museum of Natural History, Paris (MNHN), and the Royal Museum for Central Africa, Belgium (RMCA), were examined, specifically *D. nathaliae* Guégan, Lambert & Euzet, 1988, holotype (MNHN 267 HC Ti 208); *D. longiphallus* Paperna, 1973, syntype (RMCA M.T.35.702); and *D. flosculus*, voucher (MNHN 268 HC Tj 209).

Ethical Approval and/or Informed Consent

The conducted research is not related to either human or animal use.

Results

Ten *Dactylogyrus* species and three *Dogelius* species were collected from the gills *L. horie* and *L. niloticus* (Table 1). Morphometric descriptions of all species found are provided below.

Dactylogyridae Bychowsky, 1933

Dactylogyrus Diesing, 1850

Dactylogyrus nathaliae Guégan, Lambert & Euzet, 1988 (Fig. 1)

Type host and locality: *Labeo roseopunctatus* Paugy, Guégan & Agnèse, 1990; River Niger in Bamako, Mali; River Baoule at Missira, Mali (Guégan *et al.*, 1988)

Present record: *Labeo niloticus* White Nile, Kosti (13°10' 18,58" N, 32°40' 19,24" E), Blue Nile Sudan, Sennar (13°32' 50,61" N, 33°38'4,23" E), Sudan

Site: Gill lamellae

Type specimen: Holotype MNHN 267 HC

Voucher specimen: IPCAS M-647

Material examined:

15 flattened specimens (four specimens from *L. niloticus* (Kosti) and 11 specimens from *L. niloticus* (Sennar))

Redescription: Body length 326 (315–334; n = 3); greatest width

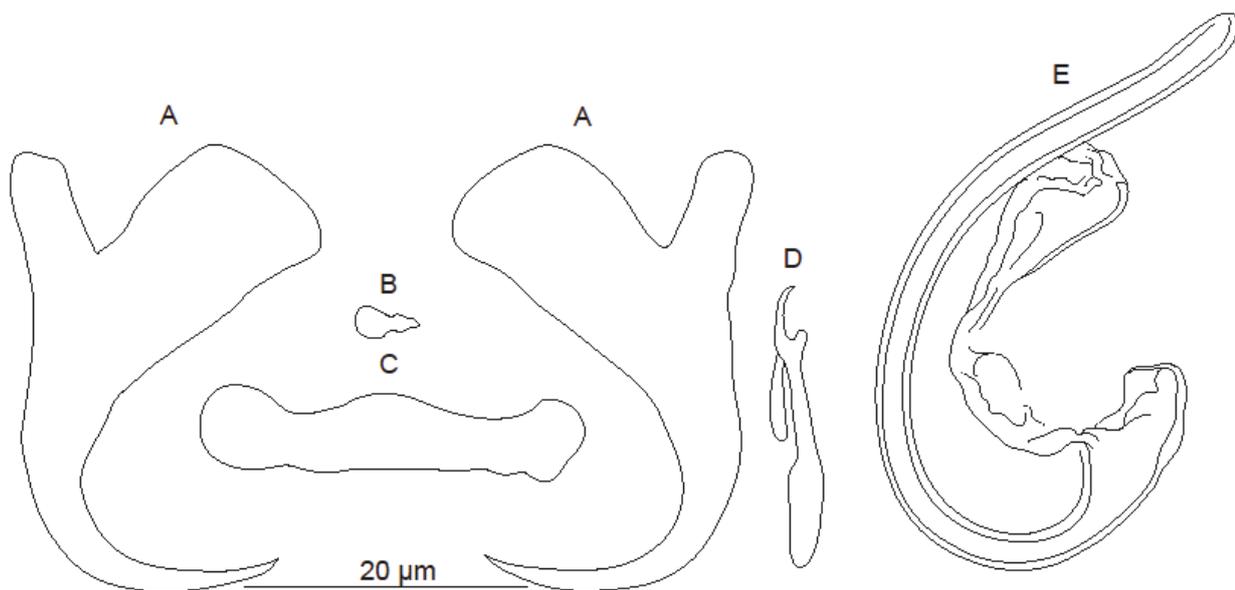


Fig. 1. *Dactylogyrus nathaliae* Guégan, Lambert & Euzet, 1988. A = anchor; B = ventral bar; C = dorsal bar; D = hook; E = copulatory organ

60 (48–70; n = 3). Haptor 43 (33–59; n = 3) long; 58 (36–72; n = 3) wide. Single pair of anchors (dorsal): inner length 31 (29–34; n=15); outer length 31 (29–34; n=15); inner root 15 (13–17; n=15) long; outer root 10 (9–13; n=15) long; point 12 (10–15; n=13) long. Two bars, dorsal: 29 (27–31; n=14) long, 5 (4–7; n=14) wide; ventral: 4 (3–6; n=6). Hooks seven pairs, dissimilar in size; hook lengths (n=6): pair I =19; pair II=14; pairs III, IV, V, VI and VII=14. One pair of needles located near hooks of pair V. No sclerotised vagina observed. Male copulatory organ (MCO) total length 42 (39–47; n=15); tube trace-length 67 (63–71; n=15).

Remarks: Comparison of our specimens from *L. niloticus* with morphometric characters observed from the holotype *D. nathaliae* (MNHN 267 HCTi 208) and measurements given in the original description (Guégan *et al.*, 1988) supports the identity of the newly collected specimens. The haptor is composed of anchors, dorsal and vestigial ventral bars and, typically for this species, marginal hooks of embryonal type with button-extended base. *L. niloticus* represents a new host species for *D. nathaliae*.

***Dactylogyrus rastellus* Guégan, Lambert & Euzet, 1988 (Fig. 2)**

Type host and locality: *Labeo senegalensis* Valenciennes, 1842; River Niger in Bamako, Mali; River Baoule at Missira, Mali (Guégan *et al.*, 1988)

Present record: *Labeo horie* Blue Nile, Sennar (13°32' 50,61" N, 33°38'4,23" E), Sudan

Site: Gill lamellae

Voucher specimen: IPCAS M-648

Material examined: Two flattened specimens

Redescription: Body length 329; greatest width 55. Haptor 65 long; 72 wide. Single pair of anchors (dorsal): inner length 50 (n=2); outer length 37.5 (37–38; n=2); inner root 17.5 (17–18; n=2); outer length 3.5 (3–4; n=2); point 18.5 (18–19; n=2) long, sharply angled relative to the shaft. Shaft double, swollen and long. One bar, dorsal: 20.5 (20–21; n=2) long, 3.5 (3–4; n=2) wide. Hooks seven pairs, dissimilar in size; hook lengths (n=2): pair I = 23; pairs II, III and IV 18 (16–21); pairs V, VI and VII 29 (26–31). No sclerotised vagina observed. MCO total length 28.5 (27–30); tube trace-length 32 (n=2), formed by short copulatory tube, curved into an arch and accessory piece from its middle extending laterally. Ventral bar absent.

Remarks:

This specimen was determined as *D. rastellus* based on morphological characters of sclerotised structures. The size of sclerotised structures corresponds well to the original description of *D. rastellus*; however, inner length and outer length of anchors are shorter with respect to the original species description. *L. horie* represents a new host species for *D. rastellus*.

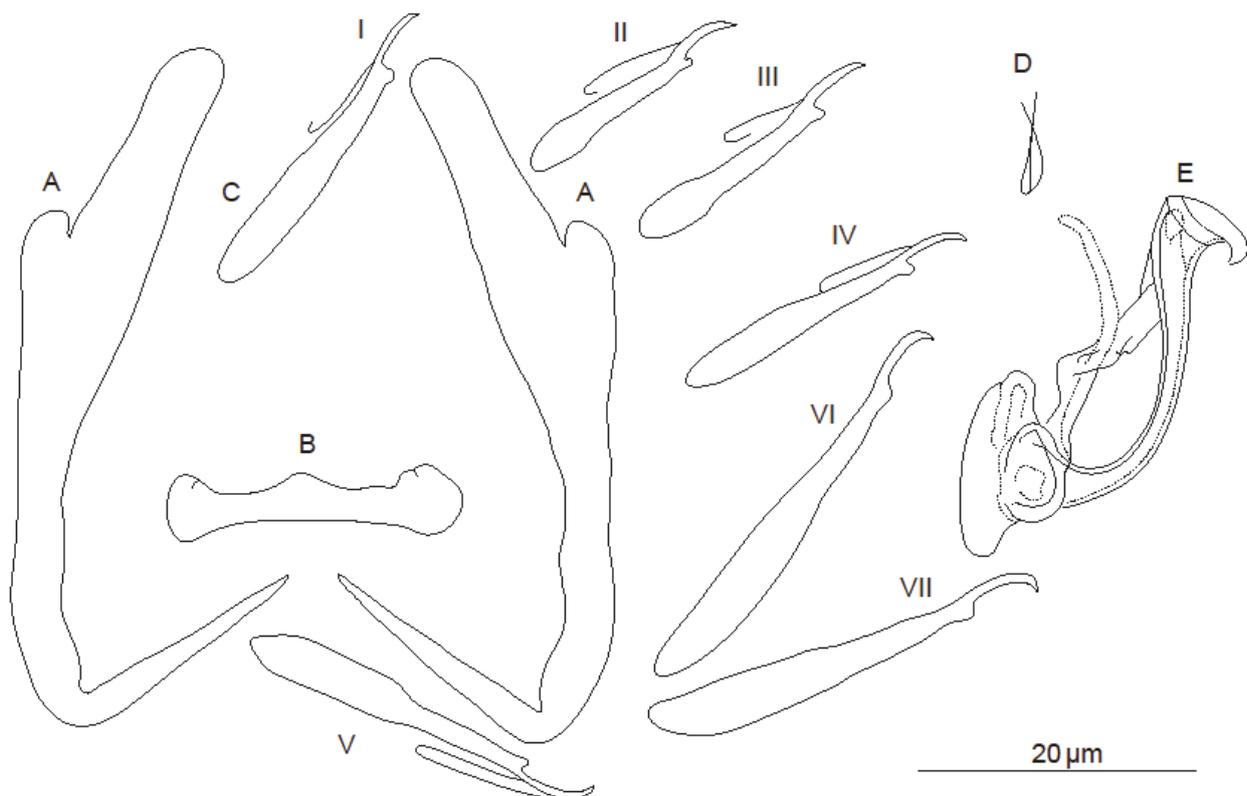


Fig. 2. *Dactylogyrus rastellus* Guégan, Lambert & Euzet, 1988. A = anchor; B = dorsal bar; C = hooks; D = needle; E = copulatory organ

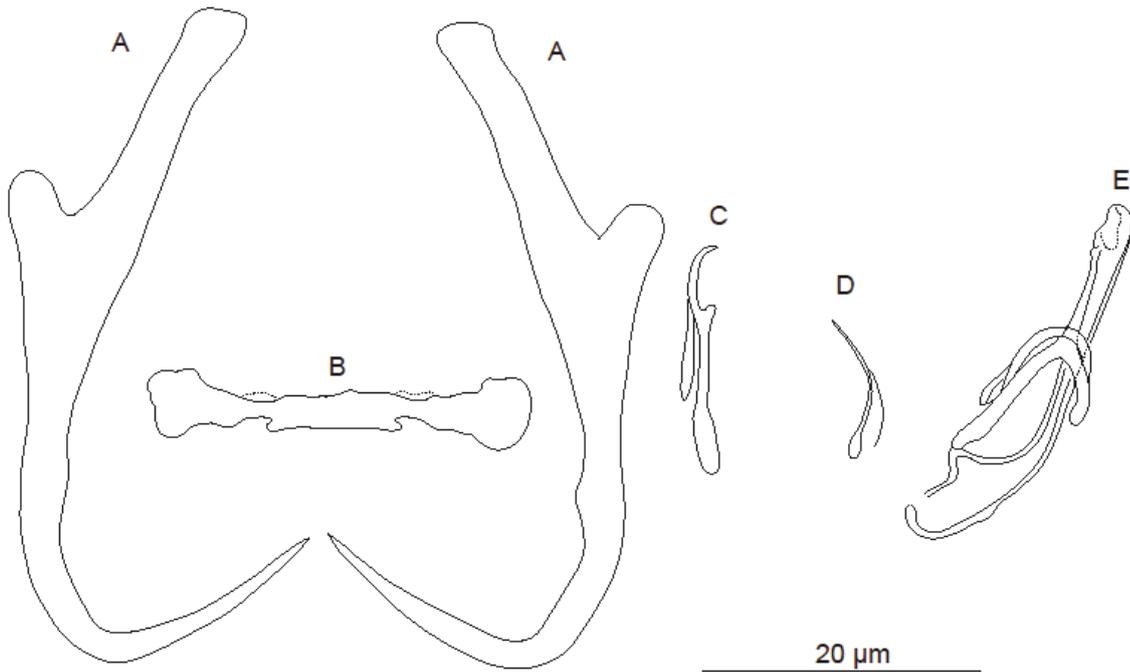


Fig. 3. *Dactylogyus retroversus* Guégan, Lambert & Euzet, 1988. A = anchor; B = dorsal bar; C = hooks; D = needle; E = copulatory organ

***Dactylogyus retroversus* Guégan, Lambert & Euzet, 1988**
(Guégan *et al.*, 1988) (Fig. 3)

Type host and locality: *Labeo coubie* Rüppel, 1832; River Niger in Bamako, Mali (Guégan *et al.*, 1988)

Other records: *Labeo coubie* River Baoule at Missira, Mali (Guégan *et al.*, 1988); *Labeo coubie*, River Gambia, Senegal (Musilová *et al.*, 2009)

Present record: *Labeo horie*, White Nile, Kosti (13°10' 18,58" N, 32°40' 19,24" E), Sudan

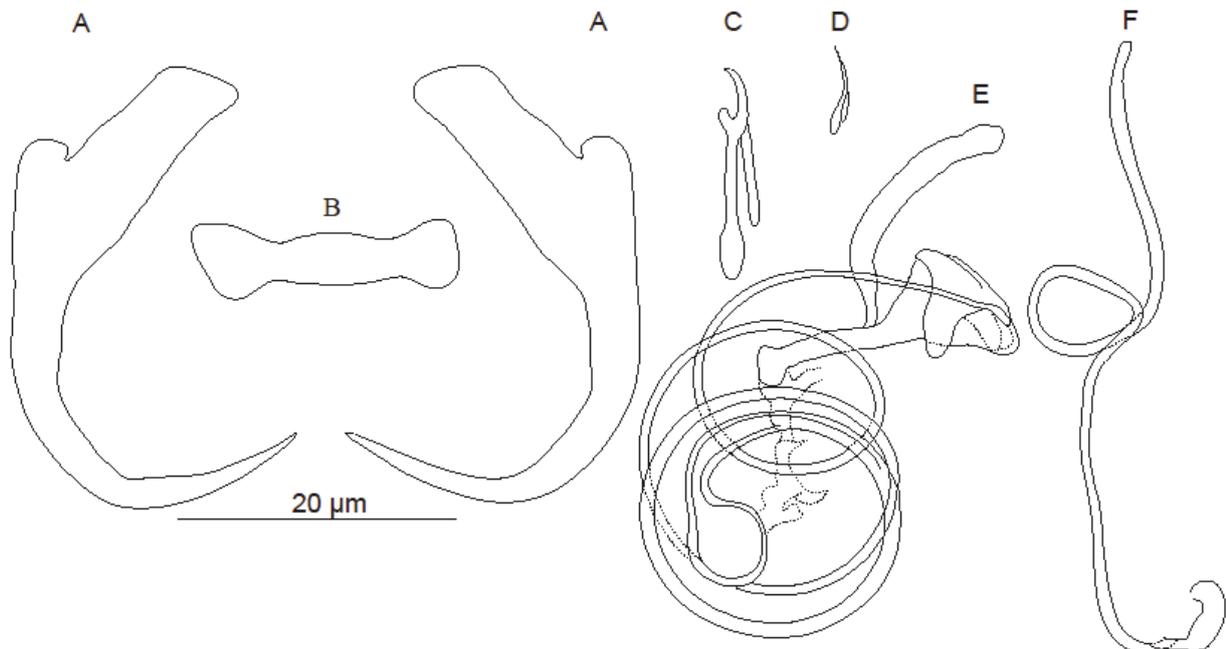


Fig. 4. *Dactylogyus senegalensis* Paperna, 1969. A = anchor; B = dorsal bar; C = hooks; D = needle; E = copulatory organ; F = vagina

Site: Gill lamellae

Voucher specimen: IPCAS M-650

Material examined: 13 flattened specimens

Redescription: Body length 344 (329–358; n=2); greatest width 82 (60–103; n=2). Haptor 65 (55–74; n=2) long; 183 (174–192) wide. Single pair of anchors (dorsal): inner length 45 (41–47; n=13); outer length 32 (29–36; n=13); inner root 17 (15–19; n=13); outer root 4 (2–5; n=13); point 17 (16–18; n=13) long. One bar (dorsal): 27 (24–29; n=13) long, 3 (2–4, n=13) wide. Hooks seven pairs, similar in shape and size; hook lengths 16 (15–16; n=6). Needles (1 pair) located near hooks of pair V. Vagina non-sclerotised. MCO total length 26 (24–28; n=10), tube trace-length 27 (27–28; n=5).

Remarks: The specimens collected during the present study were identified based on morphology of anchors and MCO, which were identical to those presented by Guégan *et al.* (1988) in the original species description. *Dactylogyrus retroversus* can be confused with *D. titus* Guégan, Lambert & Euzet, 1988 as the morphology of both species is almost identical. Both species have a double swollen shaft and the MCO of both species has a short copulatory tube (shorter in *D. titus*) associated with an accessory piece shaped like the letter Y. However, the species can be distinguished by the size of the sclerotised structures, with all features being larger in *D. retroversus* (Dorsal anchors: *D. retroversus* - inner length 42; outer length 29; inner root 18–19 long; outer root 2–3 long; point 17–18 long; *D. titus* - inner length 39; outer length 26; inner root 17 long; outer root 2 long; point 14 long). Note, however, that the

total length and trace-tube length of the copulatory organ is closer to that of *D. titus*. (*D. retroversus* - MCO total length 30–34; tube trace-length 34–35; *D. titus* - MCO total length 20; tube trace-length 27). The finding of *D. retroversus* on *L. horie* represents a new host record.

***Dactylogyrus senegalensis* Paperna, 1969 (Fig. 4)**

Type host and locality: *Labeo coubie*, Lake Volta at the Black and White Volta confluence, Ghana (Paperna, 1969)

Other records: *Labeo senegalensis*, Lake Volta at Yeji, Ghana (Paperna, 1969); *Labeo senegalensis*, River Niger in Bamako, Mali; River Baoule at Missira, Mali; Lake Guiers, Senegal (Guégan *et al.*, 1988)

Present records: *Labeo horie*, White Nile, Kosti (13°10' 18,58" N, 32°40' 19,24" E), Blue Nile, Sennar (13°32' 50,61" N, 33°38'4,23" E), Sudan; *Labeo niloticus*, Blue Nile, Sennar (13°32' 50,61" N, 33°38'4,23" E), Sudan

Site: Gill lamellae

Voucher specimen: IPCAS M-649

Material examined:

Nine flattened specimens (two specimens from *L. horie* (Sennar), four specimens from *L. horie* (Kosti), three specimens from *L. niloticus* (Sennar))

Redescription: Body length 491; greatest width 81. Haptor 74 long; 93 wide. Single pair of anchors (dorsal): inner length 32 (31–33; n=9), outer length 27 (25–28; n=9), inner root 12 (11–14;

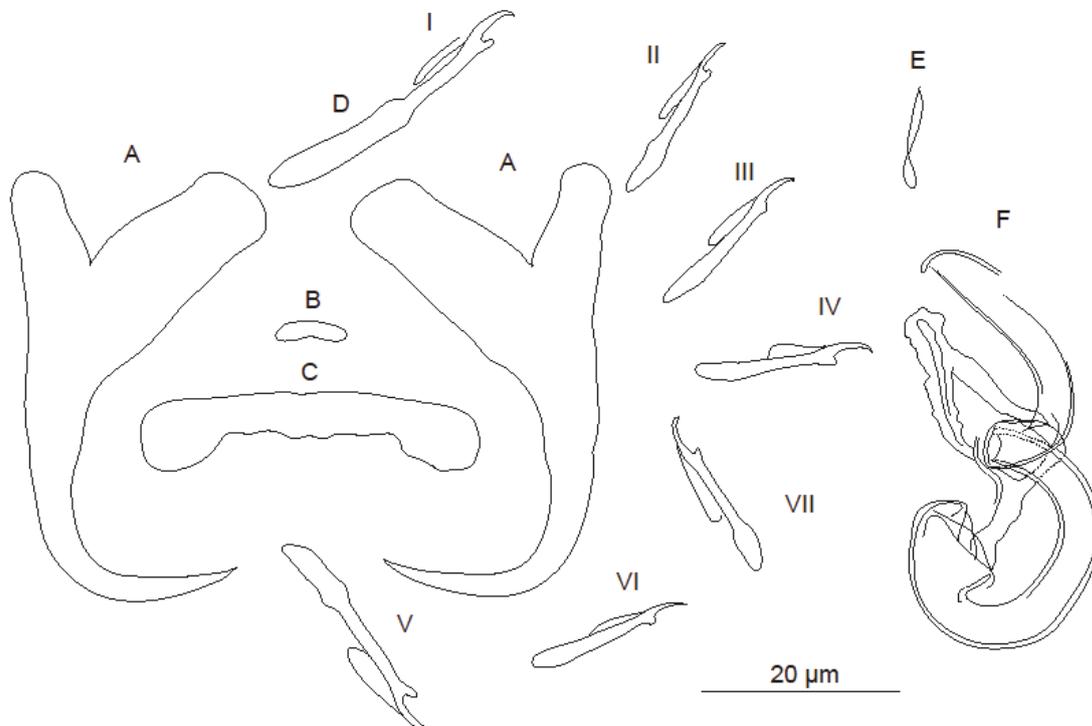


Fig. 5. *Dactylogyrus yassensis* Musilová, Řehulková & Gelnar, 2009. A = anchor; B = ventral bar; C = dorsal bar; D = hook; E = needle; F = copulatory organ

n=9), outer root 3 (2–4; n=9), point 13 (12–15; n=9) long. One bar, dorsal: 19 (17–21; n=9) long, 4 (3–6; n=9) wide. Hooks seven pairs, similar in shape and size; hook length 15 (13–16; n=6). One pair of needles located near hooks of pair V. MCO total length 40 (34–45; n=8); tube trace-length 177 (149–195; n=7); with a coiled tube of three rings passing through the middle. Distal part of the accessory piece characterised by a lateral extension. Vagina sclerotised, long tube forming coiled spiral; total length: 44 (36–48; n=7). Ventral bar absent.

Remarks: The morphology and measurements of the specimens found on *L. horie* and *L. niloticus* in the present study correspond to the descriptions of *D. senegalensis* found on the gills of *L. coubie* and *L. senegalensis* from Ghana (Paperna, 1969) and *L. senegalensis* from Mali and Senegal (Guégan *et al.*, 1988). Both *L. horie* and *L. niloticus* represent new host species for *D. senegalensis*.

***Dactylogyrus yassensis* Musilová, Řehulková & Gelnar, 2009** (Fig. 5)

Synonym: *Dactylogyrus cyclocirrus* Paperna, 1973 of Guégan *et al.* (1988)

Type host and locality: *Labeo coubie*, River Gambie, Campement du Lion, Niokolo Koba National Park, Senegal (Musilová *et al.*, 2009).

Other records: *Labeo senegalensis*, River Niger in Bamako, River Baoule at Missira, Mali; Lake Guiers, Senegal, (Guégan *et al.*, 1988)

Present records: *Labeo horie* White Nile, Kosti (13°10' 18,58"

N, 32°40' 19,24" E), Sudan, Blue Nile, Sennar (13°32' 50,61" N, 33°38'4,23" E), Sudan; *Labeo niloticus* White Nile, Kosti (13°10' 18,58" N, 32°40' 19,24" E), Sudan

Site: Gill lamellae

Voucher specimen: IPCAS M-651

Material examined:

14 flattened specimens (eight specimens from *L. horie* (Sennar), four specimens from *L. horie* (Kosti), two specimens from *L. niloticus* (Kosti))

Redescription: Body length 690 (586–854; n=4); greatest width 166 (91–231; n=4). Haptor robust 105 (79–132; n=4) long; 145 (112–197; n=4) wide. Single pair of anchors, dorsal: inner length 43 (40–46; n=14); outer length 43 (42–46; n=14); inner root, wide 15 (13–17; n=14) long; outer root 9 (7–11; n=14) long; point 13 (10–15; n=14) long. Two bars: dorsal bar 35 (31–38; n=14) long, 6 (5–7; n=14) wide; ventral bar reduced in size, vestigial 8 (7–9; n=10) long; 2 (n=10) wide. Hooks dissimilar in size; hook lengths (n=11): pair I = 28; pair V = 23; pairs II, III, IV, VI and VII = (16–20). One pair of needles located near hooks of pair V. Sclerotised vagina not observed. MCO total length 41 (35–47, n=12), forms a coiled wide tube of about 1.5 ring, which is supported by accessory piece extending from large basal ampulla.

Tube trace-length 74 (62–80; n=12). Accessory piece slightly sclerotised, articulated to base.

Remarks: Specimens were determined as *D. yassensis* based on morphology and size of sclerotised structures. *Dactylogyrus*

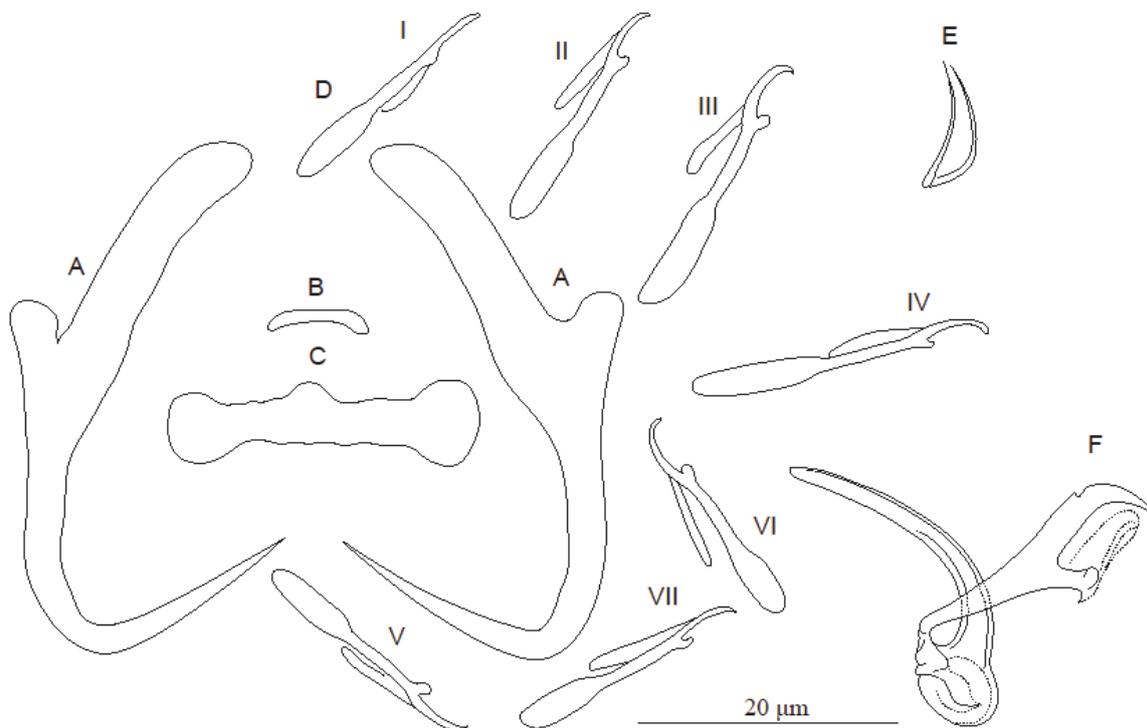


Fig. 6. *Dactylogyrus* sp.1. A = anchor; B = ventral bar; C = dorsal bar; D = hooks; E = needle; F = copulatory organ

yassensis was described based on the revision of type material of *D. cyclocirrus* Guégan *et al.* (1988), now considered the senior subjective synonym (Musilová *et al.*, 2009). The species mentioned above can be easily confused with *D. omega* Guégan & Lambert, 1991, which differs in just some morphological features and measurements. In contrast to *D. omega*, *D. yassensis* possess larger anchors, the shorter point not reaching the level of the inner anchor root tip (extending past the level of inner anchor root tip in *D. omega*), a dorsal bar smaller in relation to anchor size, and a copulatory tube with a noticeably larger diameter (Musilová *et al.*, 2009). The sclerotised structures of *D. yassensis* described here are larger than those of *D. cyclocirrus*, *D. omega* and *D. yassensis* from *L. coubie*; however, they are closest to those of *D. yassensis*. Both *L. horie* and *L. niloticus* represent new hosts species for *D. yassensis*.

Dactylogyрус sp. 1 (Fig. 6)

Present record: *Labeo horie* White Nile, Kosti (13°10' 18,58" N, 32°40' 19,24" E), Sudan

Site: Gill lamellae

Material examined: One flattened specimen

Description: Body length 307; greatest width 80. Haptor 88 long; 125 wide. Single pair of anchors (dorsal): inner length 41 (n=1);

outer length 28 (n=1); inner root 21 (n=1) long, terminally rounded internal process; outer root 4 (n=1) long, rounded; point 18 (n=1) long, sharply hooked. Two bars: dorsal bar 20 (n=1) long, wide with the protrusion in the middle, 5 (n=1) wide; ventral bar reduced in size, vestigial 8 (n=1) long; 1 (n=1) wide. Hooks dissimilar in size; hook lengths (n=1): pairs I, V, VI and VII = 18; pairs II, III and IV = 23. Needles (1 pair) located near hooks of pair V. No sclerotised vagina observed. MCO total length 23 (n=1); tube trace-length 32 (n=1), shaped like the letter V.

Remarks: The morphology and measurements of our specimen, especially the anchors and bars, are very similar to those in the original description of *D. longiphallus* Paperna, 1973, syntype (RMCA M.T. 35.702). However, some differences were observed in copulatory organ morphology. The MCO of *D. longiphallus* consists of basal ampulla followed by a narrow, tubular copulatory tube tapering distally. The accessory piece is fixed to the basal ampulla, forming a forked branch that continues on to affinely sclerotised sheath, which serves as a tube guide. *Dactylogyрус sp. 1* unlike *D. longiphallus*, a vagina was not observed. Moreover, the copulatory tube in the specimen studied (23 µm long) was almost half the size of those in *D. longiphallus* specimens measured by Paperna (1973) from Nzoia (39µm), L. Albert (38–40), Mobuku (36–40), Kzinga (40), Ruaha (n=35–38) and Ghana (n=27–36).

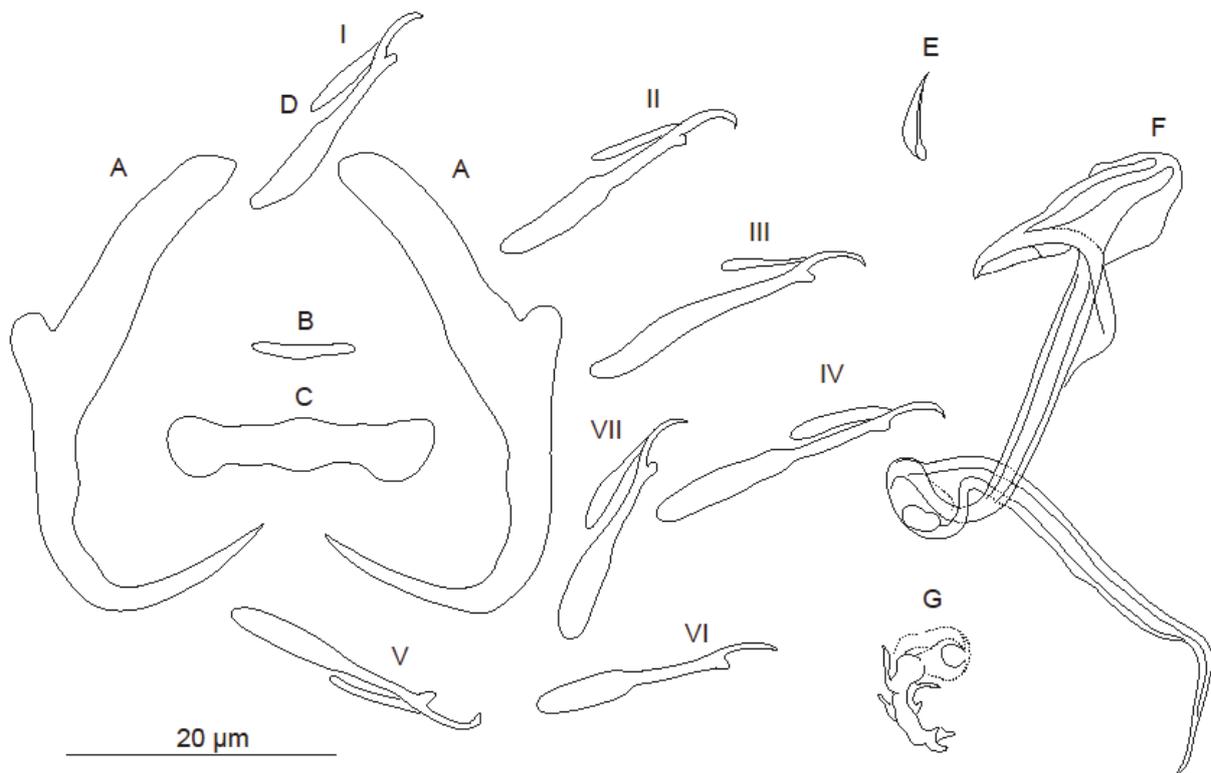


Fig. 7. *Dactylogyрус sp. 2*. A = anchor; B = ventral bar; C = dorsal bar; D = hooks; E = needle; F = copulatory organ; G = vagina

Dactylogyrus sp. 2 (Fig. 7)

Present record: *Labeo niloticus* White Nile, Kosti (13°10' 18,58" N, 32°40' 19,24" E), Sudan

Site: Gill lamellae

Voucher specimen: IPCAS M-642

Material examined: One flattened specimen

Description: Single pair of anchors (dorsal): inner length 34 (n=1); outer length 22 (n=1); inner root 18 (n=1) long; outer root 3 (n=1) long, rounded; point 13 (n=1) long. Two bars (dorsal) 21 long, 4 (n=1) wide; ventral bar reduced in size, vestigial 8 (n=1) long; 1 (n=1) wide. Hooks seven pairs, similar in size 20 (18–22). Needles (one pair) located near hooks of pair V. No sclerotised vagina observed. Copulatory organ total length 34 (n=1); tube trace-length 38 (n=1); MCO forms long tube without accessory piece shaped like the letter L.

Remarks: *Dactylogyrus* sp. 2 was dissimilar to any previously described African *Dactylogyrus* species; however, description of a new species was not possible due to the availability of only one specimen.

Dactylogyrus sp. 3 (Fig. 8)

Present record: *Labeo niloticus* White Nile, Kosti (13°10' 18,58" N, 32°40' 19,24" E), Blue Nile, Sennar (13°32' 50,61" N, 33°38'4,23" E), Sudan

Site: Gill lamellae

Voucher specimen: IPCAS M-643

Material examined: Two flattened specimens (one specimen from *L. niloticus* (Kosti) one specimen from *L. niloticus* (Sennar))

Redescription: Body length 412; greatest width 126. Haptor 74 long; 78 wide. Single pair of wide anchors (dorsal): inner length 39.5 (n=2); outer length 23.5 (n=2); inner root 21.5 (n=2) long; outer root 4 (n=2) long; roundish curved point 15 (n=2) long. Two bars (dorsal) 20 (n=2) long with medially located protrusion; 6.5 (n=2) wide; ventral bar reduced in size, vestigial 6 (n=2) long; 1.5 (n=2) wide. Hooks dissimilar in size (n=2); hook lengths pair I = 20.5; II = 23.5; III = 24.5; IV = 25.5; V = 18.5; VI = 17; VII = 17. Needles (1 pair) located near hooks of pair V. Vagina total length 10. Copulatory organ total length 26, tube trace length 31.5; MCO accessory piece terminates with three finger-like projections. Copulatory tube waved and begins by funnel, passing through the projection.

Remarks: Morphologic features are similar to *Dactylogyrus* sp. 4, mentioned below. Based on morphology and measurements of haptor and male copulatory organ, *Dactylogyrus* sp.3 is similar to *D. dembae* Musilová, Řehulková & Gelnar, 2009, which differs from our study material in sharp angulation of points, leaner anchors, proximal part of shaft being slightly swollen and median width of dorsal bar narrower.

Dactylogyrus sp. 4 (Fig. 9)

Present record: *Labeo niloticus* White Nile, Kosti (13°10' 18,58" N, 32°40' 19,24" E), Sudan

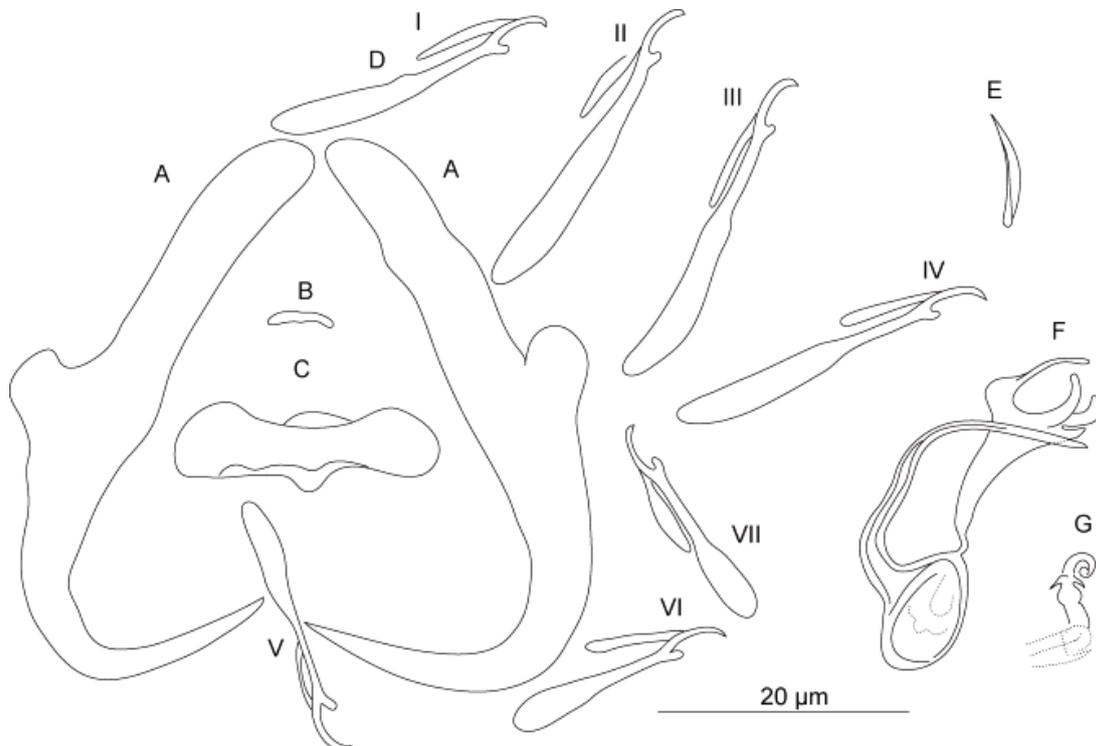


Fig. 8. *Dactylogyrus* sp.3. A = anchor; B = ventral bar; C = dorsal bar; D = hooks; E = needle; F = copulatory organ; G = vagina

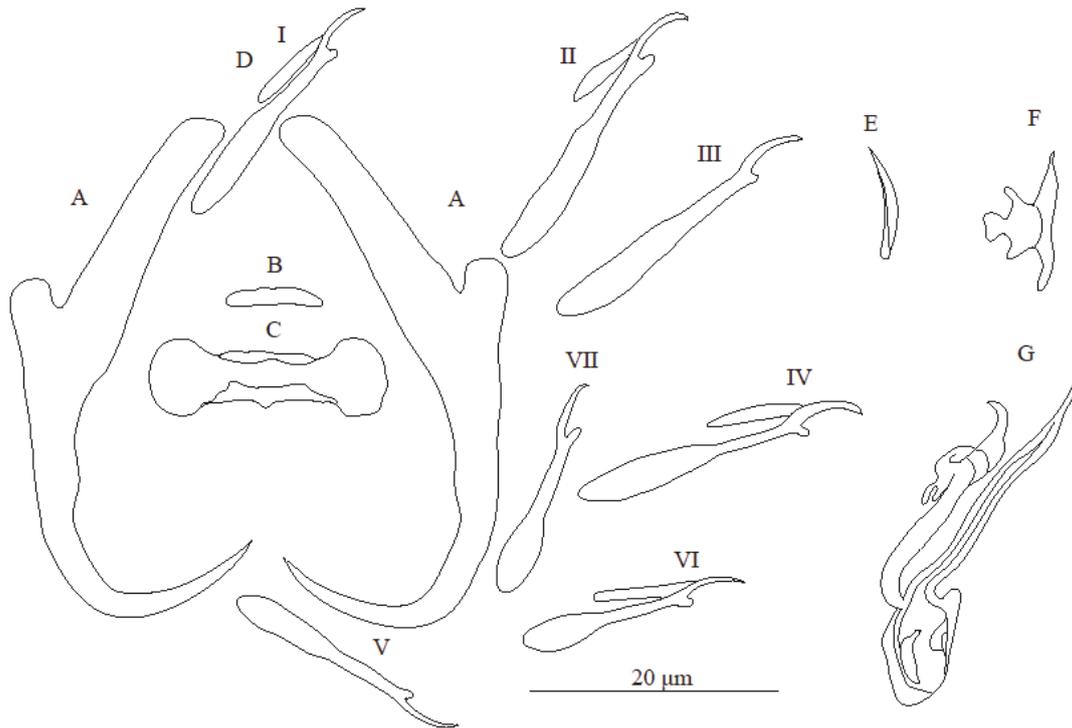


Fig. 9. *Dactylogyrus* sp. 4. A = anchor; B = ventral bar; C = dorsal bar; D = hooks; E = needle; F = copulatory organ; G = vagina

Site: Gill lamellae

Voucher specimen: IPCAS M-644

Material examined: One flattened specimen

Description: Single pair of anchors (dorsal): inner length 47 (n=1); outer length 25 (n=1); inner root 30 (n=1) long; outer root 4 (n=1) long; point 15 (n=1) long. Two bars, dorsal 20 (n=1) long, 6 (n=1) wide; ventral bar reduced in size, vestigial 5 (n=1) long; 1 (n=1) wide. Hooks dissimilar in size; hook lengths pair I = 23; II = 27; III = 28; IV = 28; V = 20; VI = 18; VII = 18. Needles (one pair) located near hooks of pair V. Vagina total length 10. Copulatory organ total length 32, tube trace length 35.

Remarks: Morphology of *Dactylogyrus* sp. 4 is similar to *Dactylogyrus* sp. 3 mentioned above. Unlike the latter species, *Dactylogyrus* sp. 4 has sharply hooked points, and a longer inner length of anchor and inner root length. These features also distinguish the material from another similar species *D. dembae*. Further, the anchor inner root length of *Dactylogyrus* sp. 4 is almost twice as long as that of *D. dembae* (*D. dembae* - inner root of dorsal anchor 16 μm).

Dactylogyrus sp. 5 (Fig. 10)

Present record: *Labeo niloticus* White Nile, Kosti (13°10' 18,58" N, 32°40' 19,24" E), Sudan

Site: Gill lamellae

Present specimen: IPCAS M-645

Material examined: One flattened specimen

Description: Body length 364; greatest width 83. Haptor 83 long; 119 wide. Single pair of anchors (dorsal): inner length 45 (n=1); outer length 32 (n=1); inner root 20 (n=1) long, swollen; outer root 4 (n=1) long; point 13 (n=1) long, roundish, curved to the shaft. Two bars (dorsal) 20 (n=1) long, at the edges balloon-shaped 4 (n=1) wide; (ventral) 8 (n=1) long, reduced in size. Hooks seven pairs, dissimilar in size; hook lengths (n=1): pair I = 18 (n=1), pairs II, III, IV = 23 (n=1); pairs V, VI, VII = 18 (n=1). Needles located near hooks of pair V. Vagina total length 11 (n=1). Copulatory organ total length 32 (n=1), tube of MCO is slightly wave, connected to the accessory piece in its proximal part. Accessory piece forms large ampulla in its base, from which it extends in tube. Distal part forms a hook with finger-like projections.

Remarks: Morphometrics of sclerites are dissimilar to any other African dactylogyrid. *Dactylogyrus* sp. 5 may represent a new species; however, description of a new species was not possible due to the availability of only one specimen.

Dogielius Bychowsky, 1936

Dogielius flosculus Guégan, Lambert & Euzet, 1989 (Fig. 11)

Type host and locality: *Labeo senegalensis*, River Niger in Bamako, Mali; River Baoule at Missira, Mali (Guégan *et al.*, 1989)

Present record: *Labeo horie* Blue Nile, Sennar (13°32' 50,61" N, 33°38' 4,23" E), Sudan

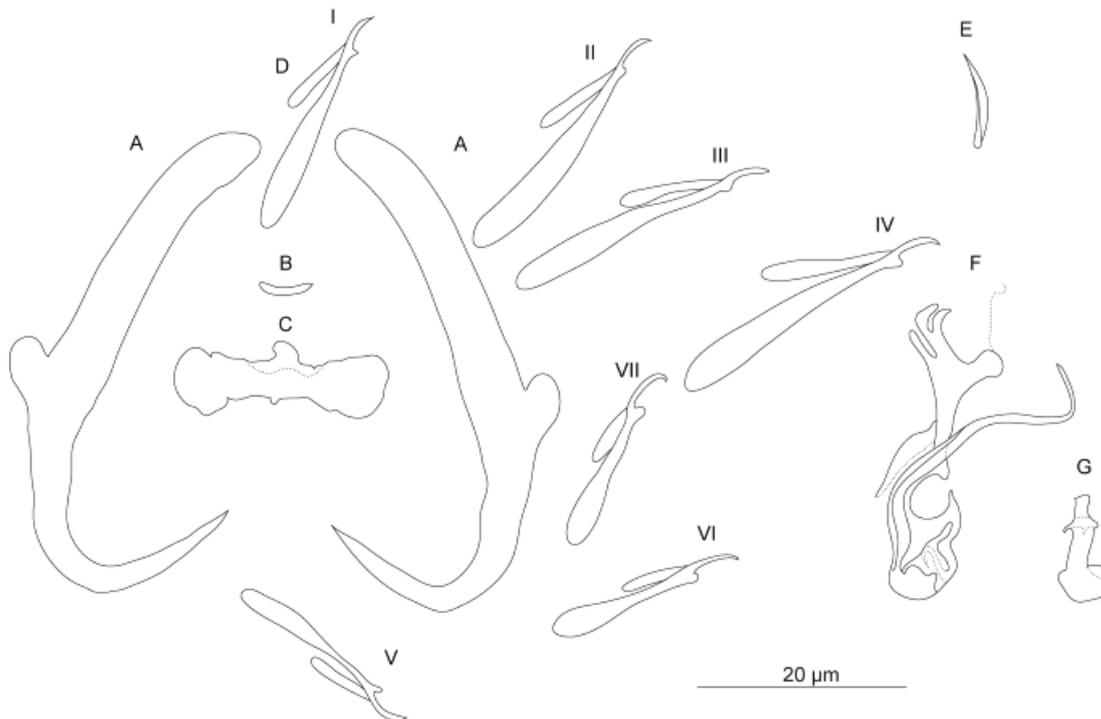


Fig. 10. *Dactylogyrus* sp. 5. A = anchor; B = ventral bar; C = dorsal bar; D = hooks; E = needle; F = vagina; G = copulatory organ

Site: Gill lamellae

Type specimen: holotype MNHN 268 HC (Tj 209)

Voucher specimen: IPCAS M-640

Material examined: 10 flattened specimens from *L. horie* (Sennar)

Redescription: Body length 356 (295–390; n=3); greatest width 107 (95–116; n=3). Haptor 80 (52–109; n=3) long; 129 (98–170;

n=3) wide. Shaft is long and thin. Single pair of anchors (ventral): inner length 45 (43–47; n=10); outer length 50 (48–53; n=10); point 22 (17–25; n=10) long, thin at the end, bent. Robust bar (ventral) 47 (45–50; n=9) long, 9 (8–10; n=9) wide. Hooks seven pairs, similar in size 19 (14–21; n=5) long. Needles located near hooks of pair V. Vagina total length 30 (25–35; n=9), bulb-shaped

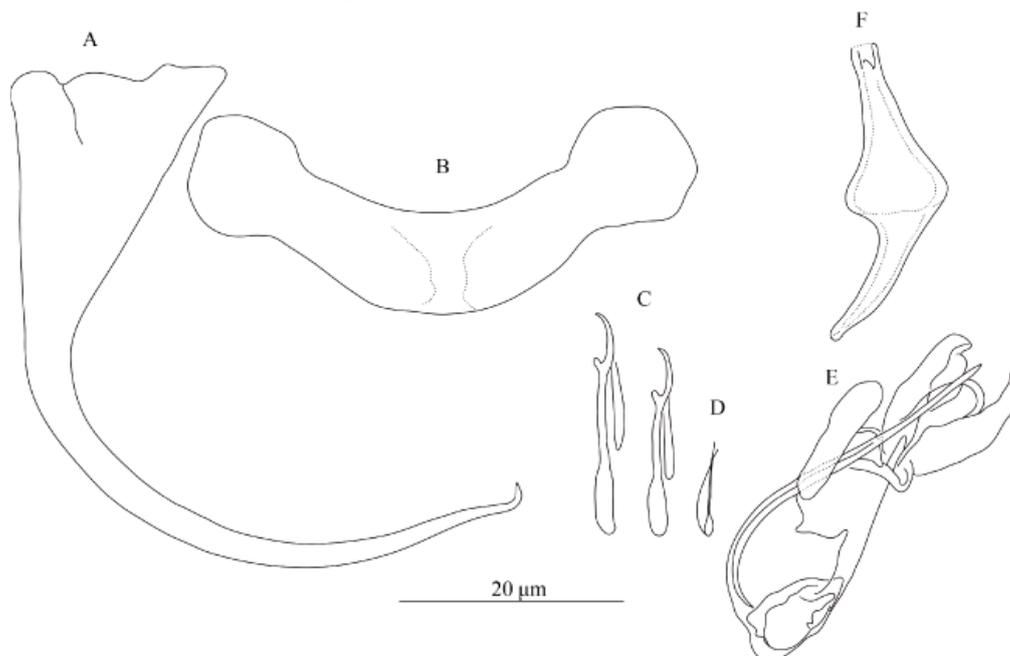


Fig. 11. *Dogielius flosculus* Guégan, Lambert & Euzet, 1989. A = anchor; B = ventral bar; C = hooks; D = needle; E = hook; F = vagina; G = copulatory organ

in the middle, from which tapering projections extend on both sides. Copulatory organ total length 33 (22–45; n=10), a thin tube with a clearly defined funnel; tube with accessory piece forms a number 8, which opens on one side.

Remarks: This specimen was determined as *D. flosculus* based on morphology and size of sclerotised structures. The anchors are narrow and long, and the measurements correspond well to the original description. The MCO comprises a thin tube connected with the funnel. The holotype MNHN 268 HC (Tj 209) from *L. senegalensis* was partially damaged and thus the copulatory organ and vagina could not be observed. Here, we provide a redescription of *D. flosculus* with illustrations. Morphology and measurements of the haptor and copulatory organ shows these specimens to be conspecific. The vagina of our *D. flosculus* specimen had a unique shape among the species congeners, being very large vagina and composed of two parts connected in the middle. The original description of *D. flosculus* shows the vagina composed of two unconnected parts, however, when the two parts are connected, it closely resembles the vagina of our specimens, both morphologically and by size. In the case of the genus *Dogielius*, a disconnected vagina has not yet been observed and, in terms of functionality, it is unlikely that it ever will be. A comparison of the sclerotised structure dimensions for *Dogielius* from this study and those of *D. flosculus* described by Guégan *et al.* (1989) are provided in Table 2. The finding of *D. flosculus* on *L. horie* in Sudan represents a new host and geographic record for this species.

***Dogielius sennarensis* n. sp.** (Fig. 12)

Type host and locality: *Labeo niloticus* Blue Nile, Sennar (13°32' 50,61" N, 33°38'4,23" E), Sudan

Site: Gill lamellae

Type specimens: Holotype and four paratypes IPCAS M-639

Material examined: Seven flattened specimens

Etymology: The species name refers to the type locality

Description: Anchors, hooks and bars stretched across the haptor, dominant ventral bar. Four eyes located on the front of the body. Whole body relatively short and wide. Body length 316 (216–387; n=6); greatest width 87 (62–120; n=6). Haptor 80 (45–134; n=6) long; 109 (58–158; n=6) wide. Single pair of anchors (ventral): inner length 32 (31–33; n=7); outer length 46 (43–50; n=7); point 32 (28–35; n=7) long. Shaft relatively distinct from the point. Point quite short and rounded, ending with a small bend. One bar (ventral) 72 (70–76; n=7) long, 7 (7–8; n=7) wide. Hooks seven pairs, similar in size 18 (16–20; n=1) long. Needles located near hooks of pair. Copulatory organ total length 32 (30–34; n=6). MCO comprises a very thin tube passing through the fork-shaped accessory piece.

Remarks:

The haptor in the material studied was comprised of anchors with long shafts, long thin points and a huge bar. *D. sennarensis* n. sp. mainly differs from other members of the genus *Dogielius* in the length of the points, its 32 µm (mean) point being longer than most

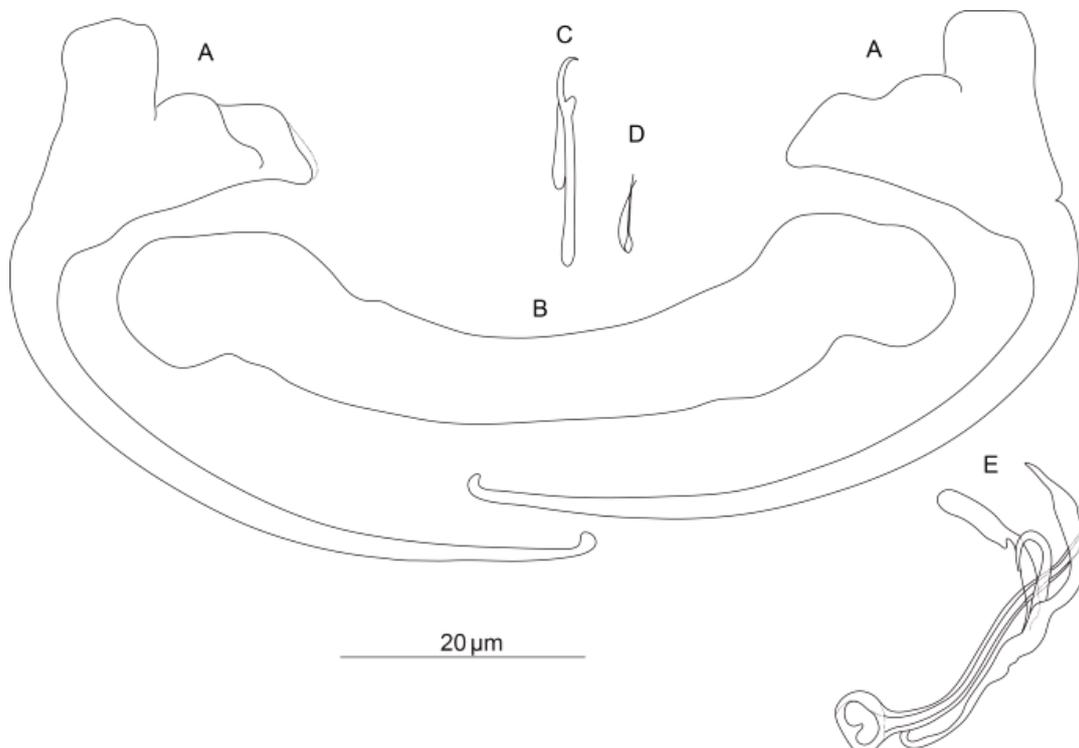


Fig. 12. *Dogielius sennarensis* n.sp. A = anchor; B = ventral bar; C = hooks; D = needle; E = copulatory organ

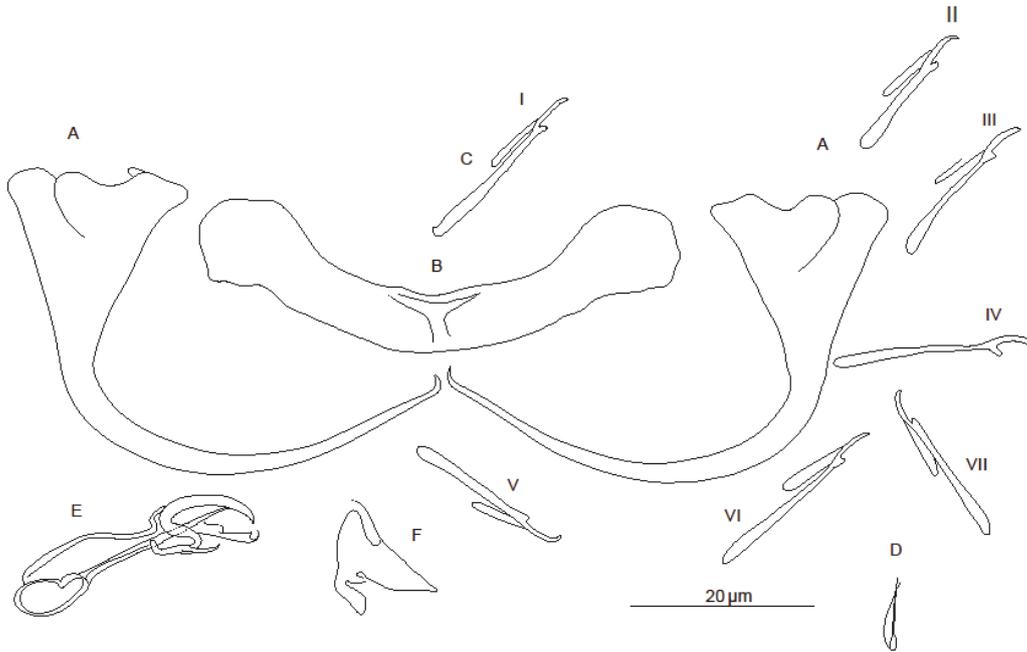


Fig. 13. *Dogielius* sp.1. A = anchor; B = ventral bar; C = hooks; D = needle; E = vagina; G = copulatory organ

other congeners. The ventral bar (70–76 µm long) is longer than the vast majority of African *Dogielius* species (except *D. grandijugus* Guégan, Lambert & Euzet (1989) (80–100 µm) and *D. phryganeus* Guégan & Lambert, 1990 (74 µm), from which it differs in the size of the other structures (Guégan *et al.*, 1989; Guégan & Lambert, 1990; Musilová *et al.*, 2009). The most obvious feature distinguishing *D. sennarensis* n. sp. from other congeners is the absence of a non-sclerotised vagina. Nevertheless, the majority of *Dogielius* spp. exhibit similar copulatory organ morphology, except for those that are coiled. The copulatory organ of *D. sennarensis* n. sp. is relatively small in comparison with other *Dogielius* spp., though the shape of the *D. sennarensis* n. sp. MCO and morphology of its sclerotised parts resembles those of *D. intorquens* Crafford, Luus-Powell & Avenant-Oldewage, 2012, found on *L. umbratus* (Smith, 1841) and *L. capensis* (Smith, 1841) at the Vaal Dam in South Africa (Crafford *et al.*, 2012). In this case, however, it differs in the size of its copulatory organ (larger in *D. sennarensis* n. sp.; *D. intorquens*, accessory piece 25 µm long; *D. sennarensis* 32 µm). Morphometric differences were also observed in the haptor sclerites, having a longer outer root and anchor point length and a significantly larger ventral bar than *D. intorquens*. A comparison of all measurements for the species mentioned above is provided in Table 2.

***Dogielius* sp. 1** (Fig. 13)

Present records: *Labeo horie* Blue Nile, Sennar (13°32' 50,61" N, 33°38'4,23" E), Sudan; *Labeo niloticus* White Nile, Kosti (13°10' 18,58" N, 32°40' 19,24" E)

Site: Gill lamellae

Voucher specimen: IPCAS M-646

Material examined: Two flattened specimens

Description: Body length 324 (323–325; n=2); greatest width 88 (83–93; n=2). Haptor 61 (56–66; n=2) long; 142 (138–145; n=2) wide. Single pair of anchors (ventral): inner length 32 (n=2); outer length 43 (n=2); point length 22 (20–24; n=2) long. Shaft of anchor clearly distinguished from point, which is thin and long. Anchors elongated in width and flattened. One bar (ventral) 54.5 (53–56; n=2) long, huge; 6.5 (6–7; n=2) wide. Hooks seven pairs, similar in size 19 (16–22; n=1) long. Needles located near hooks of pair V. observed. Vagina total length 12 (n=1). Copulatory organ total length 30 (28–33; n=3), comprising a tube extending from the funnel supported by the accessory piece and ending in a fork-like hook.

Remarks: The haptor and copulatory organ are most similar to those of *D. flosculus*, though the vagina observed in our specimen differs significantly. Moreover, the inner length of the anchors is shorter, the ventral bar longer and the copulatory organ shorter than in *D. flosculus*. *Dogielius* sp.1 probably represents a new species; however, description of a new species was not possible due to the availability of only two specimens.

Discussion

While the River Nile is the longest river in Africa and supports more than 800 fish species (including Lake Victoria; Witte *et al.*, 2009), current knowledge on monogeneans parasitising those fish is relatively poor, despite many of them being of commercial importance (El Moghraby & Abd el Rahman, 1984). This study presents first records on the occurrence of 13 dactylogyrid species from two sites

Table 2. Comparison of measurements (μm ; mean with range in parentheses) of the haptor hard parts of *Dogielius flosculus* collected from *Labeo horie* (this study) and *L. senegalensis* (Guégan *et al.*, 1989), *Dogielius intorquens* collected from *L. umbratus* and *L. capensis* (Crafford *et al.*, 2012) and *Dogielius sennarensis* n. sp. collected from *L. niloticus* (this study). n = number of individuals measured.

	<i>Dogielius intorquens</i> Crafford, Powell & Oldewage, 2012 (n=11)	<i>Dogielius sennarensis</i> n.sp. (present study)	<i>Dogielius flosculus</i> (present study)	<i>Dogielius flosculus</i> Guégan, Lambert & Euzet, 1989 (n=10)
Host and locality	<i>Labeo umbratus</i> - SouthAfrica; <i>Labeo capensis</i> - SouthAfrica	<i>Labeo niloticus</i> - Sudan - Sennar	<i>L. horie</i> -Sennar, Sudan	<i>L. senegalensis</i> - Mali
Anchor	Mean (Range)	Mean (Range; number of individuals measured)		
Inner length	29 (23–34)	32 (31–33; n=7)	45 (43–47; n=10)	43 (40–46)
Outer length	37 (30–44)	46 (43–50; n=7)	50 (48–53; n=10)	45 (42–49)
Point length	23 (17–28)	32 (28–35; n=7)	22 (17–25; n=10)	25 (23–29)
Ventral bar				
Total length	45 (33–53)	72 (70–76; n=7)	47 (45–50; n=9)	47 (45–50)
Median width	6 (3–7)	7 (7–8; n=7)	9 (8–10; n=9)	8
Hooks	18 (13–20)	18 (16–20; n=1)	19 (14–21; n=5)	19.5 (18–21)
I	16 (11–20)			
II	15 (12–20)			
III	19 (12–21)			
IV	17 (13–21)			
V	18 (13–23)			
VI	19 (15–23)			
VII	19 (16–25)			
Copulatory organ				
Total length	26 (16–31)	32 (30–34) (n=6)	33 (22–45) (n=10)	42 (37–47)
Tube trace length	23 (14–31)			
Vagina			30 (25–35) (n=9)	18

along the Sudanese Nile parasitizing two new hosts, the African cyprinids *L. horie* and *L. niloticus*. The data presented is the first for dactylogyrid parasites from Sudan and for both *Labeo* species. The previous lack of parasite species reported from this region arises from an absence of parasite studies in Sudan, rather than any absence of species. Indeed, to the best of our knowledge, this is the first such study in the region. The lack of previous studies has been due, in large part, to difficulties in gaining access to certain African regions and problems associated with collecting material.

Our data supplements the monogenean diversity parasitizing *Labeo* spp. with five undescribed *Dactylogyryus* spp. and one undescribed *Dogielius* spp. and also provides a new description of the species of *Dogielius*. Both morphology and measurements of the sclerotised parts in the undescribed species did not correspond with any of the known *Dactylogyryus* and *Dogielius* species; hence, we suggest that these species are new to science. Unfortunately, owing to the limited number of specimens available, we were unable to provide full species descriptions.

Despite the low number of host individuals examined (i.e. 3 individuals of *L. horie* and 2 of *L. niloticus*), monogenean diversity ap-

pears relatively high in the two fish species examined, with seven species collected from *L. horie* and 10 species from *L. niloticus*. On the other hand, diversity was comparable with that for *L. victorinus* (nine spp.), *L. senegalensis* and *L. parvus* (both eight spp.) (Khalil & Polling, 1997; Musilová *et al.*, 2009); and lower than that for the widespread *L. coubie* (Khalil & Polling, 1997), which has the highest monogenean diversity (18 spp.) of any African *Labeo* spp. According to Guégan *et al.* (1989), presence of similar parasites on *L. coubie* and *L. senegalensis* suggests a close phylogenetic affinity between the two cyprinids. In fact, both species, along with *L. roseopunctatus*, belong to a monophyletic group, and thus are highly likely to share the same parasites. Similarly, *L. horie* and *L. niloticus* belong to the same group as *L. senegalensis* (close relationship between *L. horie* and *L. senegalensis*; Lévêque *et al.*, 1991), which would also explain the presence of the same monogenean species, despite the geographic distance between populations. Monogeneans are known as host-specific parasites and may even be the most host-specific of all fish parasites (Whittington *et al.*, 2000). This high degree of host specificity is mainly explained through the coevolution of specialist parasites and their

host. In general, specificity is inversely related to host range, with specificity decreasing as host range increases (Desdevises *et al.*, 2002). Further, species that use more resources (generalists) tend to be more widespread and abundant than specialised species limited to a narrow range of resources (Mendlová & Šimková, 2014). Species mentioned in present study partly meet the definition, while undescribed *Dactylogyrus* spp. and *Dogielius* sp. require further studies.

Taking into account that the estimated number of monogenean species parasitising one host ranges from three (Lim, 1998) to five (Whittington, 1998), and that there are approximately 80 *Labeo* species in Africa (Skelton, 2001), it can be assumed that the possible number of parasitic monogeneans on these hosts could approach 400 species. This indicates that current knowledge of monogenean fauna (i.e. 59 spp., including the species reported in this paper) parasitising African *Labeo* fishes presently represents just 12–19% of the actual amount, and descriptions of new species from this area are highly anticipated.

Conflict of Interest

Authors state no conflict of interest

Acknowledgements

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