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Oligochaetes from underground waters of Oman with descriptions of two new species of Phreodrilidae (Oligochaeta): *Antarctodrilus arabicus* n. sp. and *Phreodrilus stocki* n. sp.

Stygofauna of Oman, 7*

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Abstract

The study of twenty-nine oligochaete samples collected in 1996 by J. H. Stock and J. J. Vermeulen (University of Amsterdam), in the Sultanate of Oman, allowed us to draw up an initial inventory of the freshwater oligochaete fauna of the Arabian peninsula, a fauna totally unknown until now. The 147 specimens examined belong to nine species of four families: Phreodrilidae, Naididae, Tubificidae and Enchytraeidae. The Phreodrilidae (2 species) represent more than half of the total specimens; whilst the rest belong mainly to the Naididae.

Two new species of Phreodrilidae (*Antarctodrilus arabicus* n. sp. and *Phreodrilus stocki* n. sp.) are described. Both belong to the subfamily Phreodrilinae, until now not reported from north of the tropic of Capricorn. Other identified species include *Dero (Dero) zeylanica, Allonais paraguayensis* and *Doliodrilus puertoricensis*, which are for the first time recorded in subterranean habitats.

These studies confirm the hypothesis of the presence of Phreodrilidae in the Arabian peninsula as relict taxa inhabiting refuges in hyporheic/groundwater habitats.

The presence of an oligochaete fauna with marine phyletic affinities in underground waters already highlighted in Europe now equally applies to the Arabian peninsula with the discovery of the tubificid genera *Aktedrilus* and *Doliodrilus* in the underground habitats of Oman. As these genera already are well known from the littoral marine or brackish water with a wide range of salinity, we have additional evidence that the migration of interstitial marine meiobenthic tubificid species through water of decreasing salinity may be a way of colonising the subterranean freshwaters.

The present record of *Doliodrilus puertoricensis* (Limnodriloidinae), previously known from Puerto Rico and Belize in the western Atlantic Ocean, represents a large extension of its known distribution area.

Contents

Introduction

Marine oligochaetes of the Arabian Gulf have been studied by Erséus (1985, 1986a, 1986b, 1988, 1989) but the freshwater oligochaete fauna of the Arabian peninsula was totally unknown until now. We had the opportunity of studying twenty-nine oligochaete samples from this part of the world forwarded to one of us (BS) by R. Vonk of the University of Amsterdam. The material was collected by J. H. Stock and J. J. Vermeulen of the University of Amsterdam in 1996, during an expedition in the Sultanate of Oman, an arid country situated along

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the south-eastern margin of the Arabian peninsula. They sampled several different subterranean habitats in which oligochaetes were found. The habitats include the interstitial coarse sediments of dry stream beds (wadis), wells, springs, and one cave.

This paper presents the results of the identification of this material including the description of two new species of Phreodrilidae, a family largely distributed in the southern hemisphere and reported only twice from the northern one: from Sri Lanka (Stephenson, 1913) and Morocco (Giani et al., 1995).

Material and methods

The specimens were collected in wells using a Cvetkov closing vertical net, and in the hyporheon of wadis, springs and the cave by means of the Bou-Rouch pump. Samples from the cave and some springs were collected in superficial waters with a handnet.

The formalin preserved samples were sorted in the laboratory under a dissecting microscope and transferred to 70 % ethanol. In the field, some physical-chemical parameters were directly measured, e.g., the electrical conductivity (eC in µS/cm or mS/cm) and the water temperature.

The geographical position of the sampling stations is given by UTM coordinates. Every site has its code in relation to a station list provided by the University of Amsterdam.

All specimens were mounted in Canada balsam, most of them as whole mounted worms. Mature specimens were previously stained with Harris haematoxylin and some were dissected under a stereo-microscope. Drawings were made by means of a camera lucida.

The type material of the new species is stored in the collections of the Zoological Museum of Amsterdam (ZMA). Other reference specimens are in the authors' own collections.

Systematic account

Family: NAIDIDAE
Subfamily: Naidinae
Dero (Aulophorus) furcata (Müller, 1773)

Examined material. – Thirty-five immature specimens, all collected by J.H. Stock: 10 from a well at Majaz Al Sugra (96/65), on plantation, UTM 0483567/2679077, eC 1004 µS/cm, 30 March 1996; 2 from interstitial waters of a spring formed in 1995 in Rustaq, Bait Qura (96/69), UTM 0443405/2587376, eC 818 µS/cm, 1 April 1996; 5 from a well at Marbat (96/84), UTM 0254392/1879929, eC 2.35 µS/cm, 4 April 1996; 1 from a well at Dahariz South (96/99), UTM 0196965/1883319, eC 4210 µS/cm, 5 April 1996; 17 from a well at Auwqad South (96/101), UTM 0184857/1881731, eC 4010 µS/cm, 5 April 1996.

Remarks. – The branchial fossa displays one pair of parallel palps and three pairs of gills. The measurements for the anterior ventral setae are 50-70 µm, for the posterior ventral setae 44-60 µm, for the needle setae 34-48 µm and for the hair setae 120-180 µm. These setal lengths are within the range recorded for African (Grimm, 1987) and Caribbean specimens (Dumnicka, 1986a; Chagné & Giani, 1998), but they lie at the lower end of range. The *Dero (A.) africana* Michaelsen, 1914 has much larger setae (Grimm, 1985). The presence of intermediate teeth in the needle setae was noted in the new material, a feature already reported for *Dero (Aulophorus) furcata* (Sambugar, 1986; Grimm, 1987).

Distribution and habitat. – Cosmopolitan. Known to inhabit lentic and lotic habitats of surface waters, mainly in the intertropical region. As regards subterranean waters it was previously found in wells of West Indian Islands (Dumnicka, 1986a) and in Morocco (Giani, unpublished data).

Dero (Dero) zeylanica Stephenson, 1913

Examined material. – Eight immature specimens from a well at Dibab (96/23), UTM 0700988/2553839, eC 400 µS/cm, 25 March 1996, Legit: J. H. Stock.

Remarks. – The material collected in Oman is morphologically in accordance with the literature data (Sperber, 1948; Brinkhurst & Jamieson, 1971).

Distribution and habitat. – Previously known only from Southern India and Sri Lanka. Not previously found in subterranean waters.

Allonais paraguayensis (Michaelsen,1905)

Examined material. – Twelve immature specimens: 1 from interstitial waters of a spring formed in 1995 in Rustaq, Bait Qura (96/69), UTM 0443405/2587376, eC 818 µS/cm, 1 April 1996, Legit: J. H. Stock; 3 from a well in South Dahariz (96/99), UTM 0196965/1883319, eC 4210 µS/cm, 5 April 1996, Legit: J. H. Stock; 1 from a well in the A'Muotazah area (Salalah Centre) (96/100), UTM 189032/1882511, eC 3490 µS/cm, 5 April 1996, Legit: J. H. Stock; 3 from surface waters of the spring head of the Wadi Darbat catchment (96/103), UTM 0230717/1897256, eC 754 µS/cm, 5 April 1996, Legit: J. H. Stock; 2 from surface

waters of the Ain Hamran spring (Salah region) (96/106), UTM 0210592/1892363, eC 576 µS/cm, 6 April 1996, Legit: J. H. Stock; 2 from the interstitial waters of Wadi Nakhal (96/126), UTM 0584918/2592170, eC 1210 µS/cm, 9 April 1996, Legit: J. J. Vermeulen.

Remarks. – The material from Oman is morphologically in accordance with the literature data (e.g. Sperber, 1948; Brinkhurst & Jamieson, 1971). The needle setae begin in segment VI, bifid, with very reduced distal teeth.

Distribution and habitat. – Known from Asia, Africa, N. and S. America. Not previously known to inhabit subterranean habitats.

Family: PHREODRILIDAE
Subfamily: Phreodrilinae
Antarctodrilus arabicus n. sp. (Fig. 1)

Examined material. – Holotype. Mature specimen, dissected, stained in Harris haematoxylin and mounted on a slide. Slide n. V.OI.9338, ZMA.

Type locality. – Wadi Taww, S of Halban (96/50), UTM 0604748/2606459, eC 568 µS/cm, 28 March 1996, Legit: J. H. Stock.

Paratypes. – Four mature specimens: 1 dissected, stained in Harris haematoxylin, slide n. V.OI.9341, ZMA, and 3 whole–mounted specimens: 1 stained, slide n. V.OI.9340, ZMA; 2 unstained, slide n. V.OI.9339, ZMA. Locality and collection data as for holotype.

Additional material examined. – 70 specimens from the type locality (28 March 96, 27 mature and 38 immature; 1 April 96, 3 mature and 2 immature); 1 immature specimen from Wadi Taww near Halban (96/01), UTM 0712319/2606459, 23 March 96; 1 mature specimen from Tiwi cave (or "Deep hole"), north of Ferns (96/19), UTM 0712319/2549008, 25 March 96.

Etymology. – The name of the species is derived from "Arabia", the Latin name of the region to which Oman belongs.

Description. – Small-sized species: more than 6.4 mm long and 32 segments (no complete specimens observed); width at II 0.14-0.19 mm, width at XII (clitellum) 0.22-0.26 mm (slide-mounted specimens). Proboscis absent. Conical prostomium, 71-102 µm long, 111- 132 µm wide, with round tip. Mouth large, circular, and surrounded by a lobed lip associated with circular muscle. Cutaneous glands arranged in more or less parallel rows, particularly numerous at setal level of each segment. Clitellum extending over XII-XIII with glandular cells arranged in more or less parallel rows.

Ventral setae from II (Fig. 1 A). Each bundle consisting of a pair of dissimilar setae; one single pointed and thin (1.5-1.8 µm wide), without nodulus, the other bifid, thicker (2-2.8 µm wide) and with distinct nodulus at about 1/3 from distal end. Distal ends of setae of anterior bundles strongly curved. Upper teeth of bifid setae of II and III minute and difficult to see, but reaching about half the length of lower teeth in middle region of body. Setal length ranging from 64-80 µm in segment II to 80-100 µm in middle region of body. Except for anterior bundles, the thinner, single pointed setae seem to be longer than bifid setae, but latter extending more deeply into coelomic cavity. Ventral setae absent from XII and present but not modified on XIII (the spermathecal segment).

Dorsal setae from III (Fig. 1 A), each bundle with 1 (sometimes 2: one longer and one shorter and thinner) smooth (non-serrated) hair, flanked by 2 «support» setae, about 40 µm long, which do not project from setal sacs; support setae, however, difficult to observe. Length of long hair setae ranging from 115-210 µm in anterior segments to 220-330 µm in middle region of body.

Small pharyngeal glands in IV-VI. Large pharynx with eversible roof. Numerous thin dorsal and ventral retractor muscles attaching pharynx to body wall.

Male pores paired, in line with ventral setae, opening somewhat anterior to middle of segment XII. Spermathecal vestibulae paired, opening laterally at the intersegmental furrow 12/13.

Genital organs paired in usual position (Fig. 1 B, C). Testes antero-ventral in XI. Sperm sac extending anteriorly to VII or VIII. Prostate glands absent. Atria confined to XII, tubular to club-shaped, bent, horizontal and directed towards anterior septum of segment. Atrial ampullae 286-364 µm long, maximally 70-120 µm wide. Atria with a layer of tall glandular cells around a distinct lumen, enveloped by a thin layer of circular muscular tissue. Basal part of atria narrowing gradually into short ejaculatory ducts, ending in true pendant penes located in deep folds of body wall (penes sacs 175-210 µm

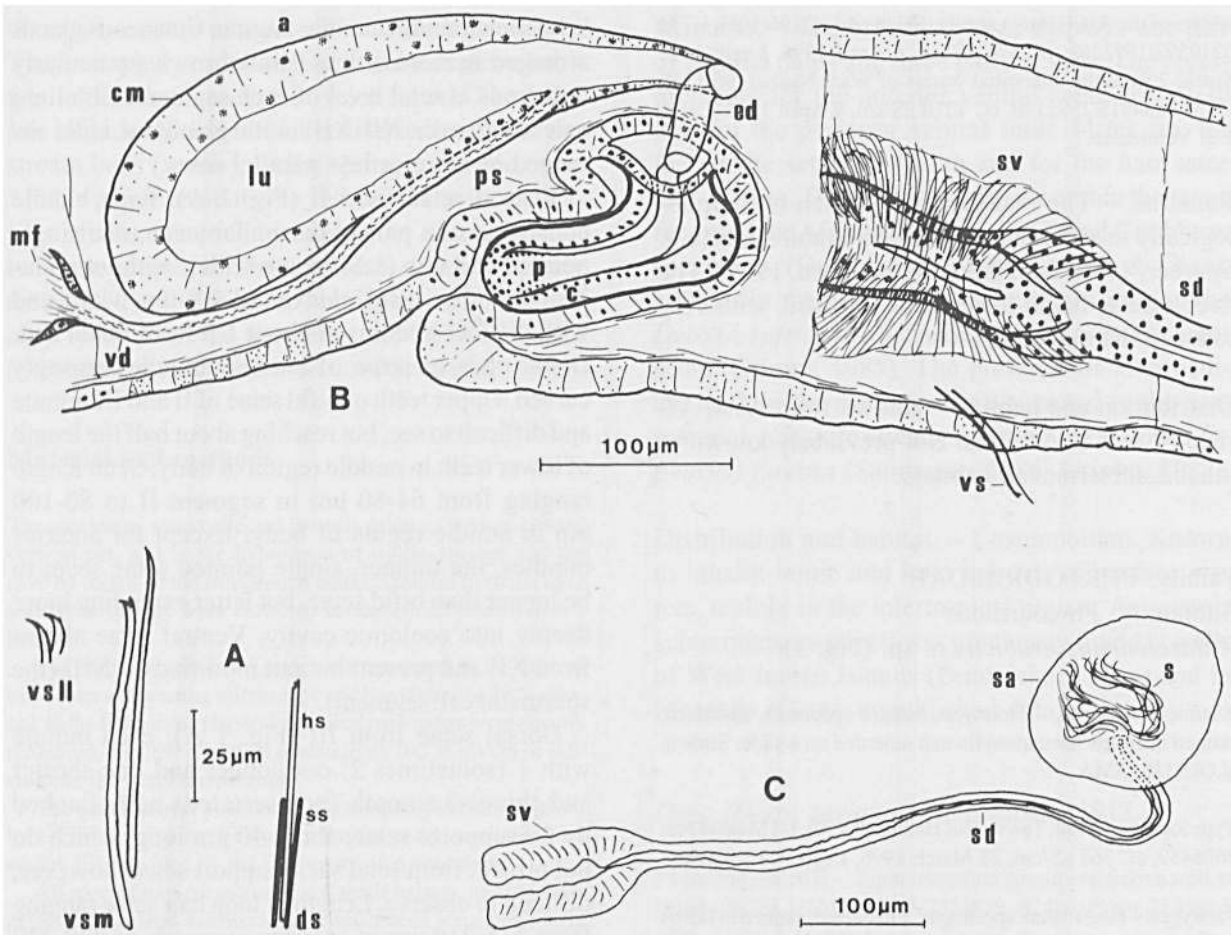

Fig. 1. Antarctodrilus arabicus n. sp. A, Setae; B, Longitudinal view of genital segments; C, Spermatheca (paratype). a, atrium; c, cuticular penis sheath; cm, circular muscles; ds, dorsal setae (hair broken); ed, ejaculatory duct; hs, hair seta (broken); lu, lumen; mf, male funnel; p, penis; ps, penis sac; s, sperm; sa, spermathecal ampulla; sd, spermathecal duct; ss, support setae; sv, spermathecal vestibule; vd, vas deferens; vs, ventral setae; vsm, ventral setae of the middle region; vsII, ventral setae of segment II.

deep). Penes large, 111-148 µm long, 40-58 µm wide, with spaces between inner and outer walls. Distinct cuticular penis sheaths present. Sperm funnels small, located in ventral part of septum 11/12. Vasa deferentia thin, about 6 µm wide, joining atrial ampullae medially but opening into atrial lumen basally.

Spermathecal ducts ending in large, globular, strongly muscular vestibulae (148-177 µm long, 78-100 µm wide) in segment XIII. Ducts 350-590 µm long, 16-32 µm wide, with narrow lumen, extending through segments XIII and XIV. Spermathecal ampullae spherical to ovoid, with thin outer lining, 100-180 µm long, 64-140 µm wide and occupying segment XV. Sperm in loose masses, not filling spermathecal ampullae. Entire spermathecae 627-740 µm long.

Ovaries attached ventrally to anterior septum of XII. Egg sac protruding posteriorly to 14/15. Female funnels at intersegment 12/13.

Remarks. – The lateral location of the spermathecal pores indicates that *Antarctodrilus arabicus* n. sp. belongs to the subfamily Phreodrilinae Brinkhurst, 1991, following Pinder & Brinkhurst (1997). Also according to Brinkhurst (1991), the presence among the phreodrilines of pendant penes characterizes the genus *Antarctodrilus* Brinkhurst, 1991.

Among the eight species previously included in this genus (Pinder & Brinkhurst, 1997), *A. proboscidea* (Brinkhurst & Fulton, 1979) and *A. acanthaseta* Pinder & Brinkhurst, 1997 can be easily distinguished from *Antarctodrilus arabicus* by the presence of a well developed proboscis, serrated hair setae and accessory glands associated with the penis sacs (glands to be confirmed for *A. acanthaseta*).

All the remaining species, except *A. niger* (Beddard, 1894) and *A. africanus* (Goddard & Malan, 1913), have setal characteristics not found in the new species: all ventral setae are bifid in *A. palustris* (Brinkhurst & Fulton, 1979), *A. micros* Pinder & Brinkhurst, 1997 and *A. spinosus* Pinder & Brinkhurst, 1997; *A. uniseta* (Brinkhurst, 1982) has only one seta in each dorsal bundle, resembling the ventral ones; *A. horwitzi* Pinder & Brinkhurst, 1997 and *A. spinosus* are characterized by numerous hair setae.

Antarctodrilus arabicus n. sp. is similar to *A. niger*, but it can be distinguished from the latter by the larger spermathecal vestibulae, the larger atrial lumina, the presence of distinct ejaculatory ducts, the larger size of the penes, and the shorter vasa deferentia. Moreover, *A. arabicus* n. sp. is unique in the genus in having cuticular penis sheaths. Among the Phreodrilidae, such sheaths were previously known only in *Insulodrilus tanganyikae* Brinkhurst, 1970.

Antarctodrilus africanus, for which information is poor, could be, according to Brinkhurst (1965), a synonym of *A. niger*. Consequently, this dubious species has not been taken into account in the discussion above.

Distribution and habitat. – Known only to inhabit groundwaters of Oman.

Phreodrilus stocki n. sp. (Fig. 2)

Examined material. – Holotype. Mature specimen, dissected, stained in Harris haematoxylin and mounted on a slide. Slide n. V.OI.9342, ZMA.

Type locality. – Wadi Ahin at Sohar (96/60), UTM 0454903/2660684, eC 678 µS/cm, 30 March 1996, Legit: J. H. Stock.

Paratype. – Mature specimen, dissected, stained in Harris haematoxylin and mounted on a slide. Locality and collection data as for holotype. Slide n. V.OI.9343, ZMA.

Additional material examined. – Six mature specimens. Locality and collection data as for holotype.

Etymology. – The species is named in honour of the late Professor J. H. Stock, for his great contribution to the study of subterranean invertebrates.

Description. – Small-sized species: more than 5 mm long and 24 segments (no complete specimens observed); width at II 0.13-0.20 mm, width at XII (clitellum) 0.20-0.27 mm (slide-mounted specimens). Proboscis absent. Conical prostomium, 78-92 µm long, 96-140 µm wide, with round tip. Mouth large, circular, and surrounded by a lobed lip associated with circular muscle. Cutaneous glands arranged in more or less parallel rows, particularly numerous at setal level of each segment. Clitellum extending over 1/4 XII-XIII with glandular cells arranged in more or less parallel rows.

Ventral setae from II (Fig. 2 A), each bundle with a pair of dissimilar setae; one single-pointed and thin (1.5-2 µm wide), without nodulus, and one bifid, thicker (2.2-3 µm wide), with a distinct nodulus at about 1/3 from distal end. Distal tooth of bifid seta minute in segment II, but increasing up to about half the length of proximal tooth in middle region of body. Length of the two setae similar but 80-90 µm in segment II and 100-115 µm in middle region of body. Except for anteriormost bundles, thinner single pointed setae seem to be longer than bifid setae, but this is only because latter extend more deeply into coelomic cavity. Ventral setae absent from XII and present but not modified on XIII (the spermathecal segment).

Dorsal setae from III (Fig. 2 A), each bundle with 1 or 2 (one longer and one shorter and thinner) smooth hairs, accompanied by paired, thin and straight «support» setae (up to 60 µm long), not projecting from setal sacs and difficult to see. Length of long hair setae ranging from 100-200 µm in anterior segments to 200-335 µm in middle region of body.

Small pharyngeal glands in III-VI. Large pharynx with eversible roof. Numerous thin dorsal and ventral retractor muscles attaching pharynx to body wall.

Male pores paired, in line with ventral setae, slightly posterior to middle of segment XII. Sperma-

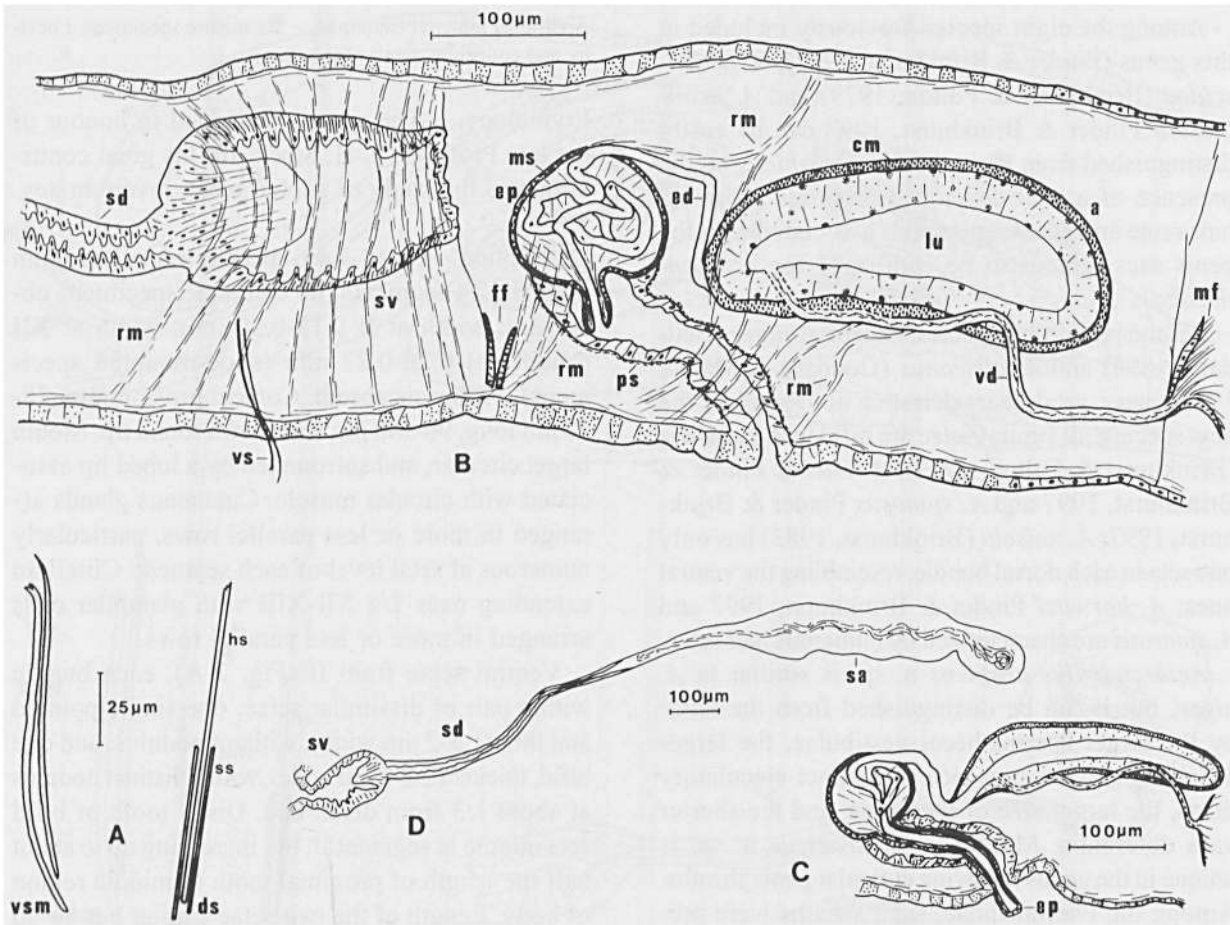

Fig. 2. Phreodrilus stocki n. sp. A, Setae; B, Longitudinal view of genital segments; C, Male apparatus (paratype); D, Spermatheca (paratype). a, atrium; cm, circular muscles; ds, dorsal setae (hair broken); ed, ejaculatory duct; ep, eversible pseudopenis; ff, female funnel; hs, hair seta (broken); lu, lumen; mf, male funnel; ms, muscular sac of pseudopenis; ps, penis sac; rm, retractor muscles; sa, spermathecal ampulla; sd, spermathecal duct; ss, support setae; sv, spermathecal vestibule; vd, vas deferens; vs, ventral setae; vsm, ventral setae of the middle region.

thecal vestibulae paired, opening dorso-laterally in intersegmental furrow 12/13, in line with dorsal setae.

Genital organs paired in usual segmental position (Fig. 2 B, C, D). Testes antero-ventral in XI. Sperm sac long, extending to IV. Prostate glands absent. Atria confined to XII, tubular to reniform depending on its degree of contraction, horizontal and directed towards anterior septum of segment. Atrial ampullae 200-360 µm long, maximally 40-105 µm wide. Atria with 3-8 µm thick layer of circular muscles and thick, glandular inner epithelial lining surrounding distinct lumina; latter up to 70 µm wide, but varying according to contraction degree. Each atrium communicates, through narrow and curved ejaculatory duct, with distal tip of a well set-off sphaerical muscular pseudopenial sac (70-100 µm wide; muscular layer 2-5 µm thick), inside which a long and tightly coiled eversible pseudopenis (8-12 µm wide) is enclosed. Pseudopenis everting through a folded muscular penis sac (inversion of body wall of XII), 82-145 µm long, 45-60 µm wide. In one specimen, one pseudopenis everted, extending about 250 µm from male pore. Numerous muscular fibers attaching ectal parts of atria and pseudopenial sacs to body wall. Sperm funnels broad, located on ventral part of septum 11/12. Vasa deferentia short, thin (6-8 µm), join-

ing atrial ampullae medially but opening into atrial lumen basally.

Spermathecal ducts ending in large muscular vestibulae, attached to dorsal and ventral body wall of segment XIII by fine muscular strands. The vestibular form varying from folded globular (up to 105 µm wide, 150 µm long) to long tubular (up to 60 µm wide, 290 µm long), depending on its contraction degree. Spermathecal ducts well set off from vestibulae, very long (525-800 µm, reaching segment XV) and thin (12-35 µm). Spermathecal ampullae long, thin-walled (375-650 µm long, 85-125 µm wide), reaching segments XVII or XVIII. Sperm in loose but distinct elongated bundles. Entire spermathecae 1.2 to 1.5 mm long.

Ovaries attached ventrally to anterior septum of XII. Egg sac protruding posteriorly to 14/15. Female funnels at intersegment 12/13.

Remarks. – The dorso-lateral location of the spermathecal pores indicates that the new species belongs to the subfamily Phreodrilinae Brinkhurst, 1991, following Pinder & Brinkhurst (1997). The presence of eversible pseudopenes is a diagnostic character of the genus *Phreodrilus* Beddard, 1891 (Pinder & Brinkhurst, 1997). Among the 20 species currently included in this genus, *P. stocki* n. sp. belongs to the group also consisting of *P. subterraneus* (Beddard, 1891), *P. mauienensis* Brinkhurst, 1971, and *P. diemenensis* Pinder & Brinkhurst, 1997; all four species are characterized by highly coiled pseudopenes. *P. stocki* n. sp. is unique in this group because the pseudopenial sacs are clearly separate from the atria. Moreover the vasa deferentia of the new species are short, attached to the basal half of the atria and communicating with the atrial lumina at the ectal ends, instead of long, coiled and entering pseudopenial sacs or at the junctions between the atrium and the later, as in the other species of this group. The very long atria of *P. subterraneus* and *P. mauienensis*, the great body size of the former species (up to 50 mm), and the presence of an accessory gland attached to each muscular pseudopenial sac in the latter, are other reliable differences between these two species and *P. stocki*. *Phreodrilus diemenensis* appears to be the closest relative to *P. stocki*. The setae, the length of the atria and the general shape of the spermathecae are similar, but the vasa deferentia of *P. diemenensis* are clearly longer and the muscular sacs of the pseudopenes are quite different (ovoid apically, narrowing basally and attached to the atria in *P. diemenensis*; sphaeric and clearly separate from the atria in *P. stocki*).

Distribution and habitat. – Only known to inhabit groundwaters of Oman.

Family: TUBIFICIDAE
Subfamily: Tubificinae
Limnodrilus hoffmeisteri Claparède, 1862

Examined material. – One mature and 3 immature specimens from the Ain Hamran spring (Salah region) (96/106), UTM 0210592/1892363, eC 576 µS/cm, 6 April 1996, Legit: J. H. Stock. The sample was taken in the spring itself.

Remarks. –The material from Oman is morphologically in accordance with the literature data (e.g. Brinkhurst & Jamieson, 1971).

Distribution and habitat. – Cosmopolitan. All types of lentic and lotic freshwater habitats.

Subfamily: Limnodriloidinae
Doliodrilus puertoricensis Erséus & Milligan, 1988

Examined material. – One mature and 2 immature specimens from Tiwi cave (or Deep Hole), N of Fens, huge karstic collapse cave, some 700 m from marine littoral (96/19C), handnet in cave lake, day light, UTM 0712319/2549008, eC 36 mS/cm, salinity 15 ‰, 25 March 1996; 1 mature and 6 immature specimens from the same cave, but a large lagoon behind sand and gravel bar, eC 39.3 mS/cm, 25 March 1996; at both sites Legit: J. H. Stock. One mature and 3 immature specimens from wadi Taww, Halban area (96/33), UTM 0604750/2606459, eC 601 µS/cm, 28 March 1996, Legit: J. H. Stock.

Remarks. – The specimens examined clearly belong to the genus *Doliodrilus* as defined by Erséus (1984) and emended by Erséus (1985) and Erséus & Milligan (1988). This little genus – only three species identified until now – is peculiar as *D. diverticulatus* Erséus, 1985 has an unpaired oesophageal diverticulum in segment IX, while in the other two species (including the present specimens), the

oesophagus in IX is modified into a peculiar barrel-shaped part covered with a blood plexus as described by Gustavsson & Erséus (1999). As far as setal characteristics and genital apparatus are concerned, our specimens fit very with the original description of *D. puertoricensis*. So, despite the fact that this species was previously known exclusively from the Caribbean area, there is little doubt that the specimens from Oman belong to this species.

The genus *Doliodrilus* was previously found in the coastal region of the Arabian Gulf of Saudi Arabia (Erséus, 1985), here represented by *Doliodrilus diverticulatus*. This species was later recorded in the Northern Territory of Australia (Erséus 1997). A third species in the genus, *D. tener* Erséus, 1984 has been identified in China (Erséus, 1990a; Erséus et al., 1990).

Distribution and habitat. – Oman (present report), west coast of Puerto Rico (Erséus & Milligan, 1988), and Belize (Erséus, 1990b). The present record, far from the localities previously known, represents a large extension of the distribution area of the species (Fig. 3). This can be explained by the fact that the genus *Doliodrilus* is still poorly known.

The three species of the genus occur in brackish water with widely fluctuating salinity. *D. puertoricensis* has been collected in an enclosed brackish lagoon (Erséus & Milligan 1988) and in subtidal muds from Belize (Erséus 1990b), all subject to fluctuating salinities. The specimens examined by us were collected in an anchyhaline cave with a salinity of 15 ‰ and in the hyporheon of the wadi Taww, with a conductivity of 601 µS/cm. These data confirm the euryhalinity of the species.

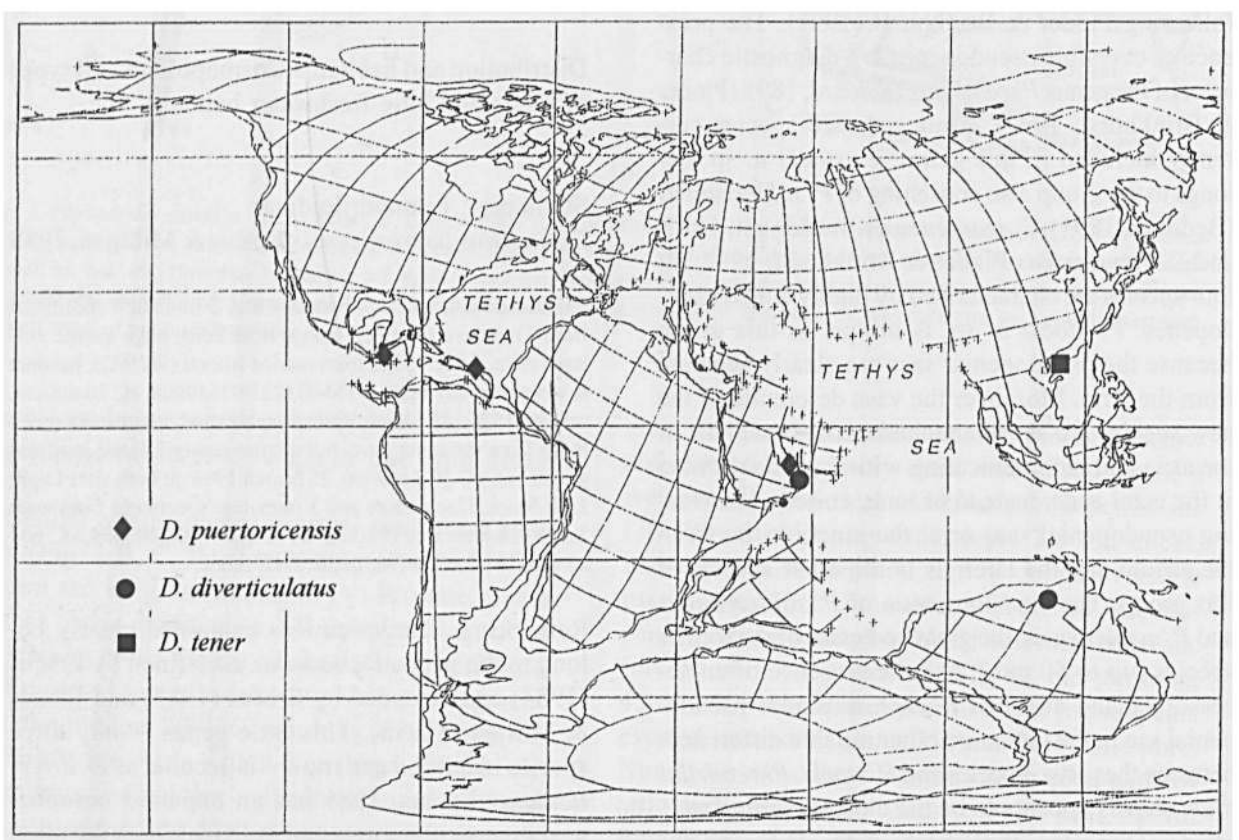

Fig. 3. Map of the known distribution of *Doliodrilus* (Oman, present record).

Subfamily: Phallodrilinae
Aktedrilus sp.

Examined material. – One mature specimen from a well in the A'Muotazah area (Salalah Centre) (96/100), UTM 189032/1882511, eC 3490 µS/cm, 5 April 1996, Legit: J. H. Stock.

Remarks. – The only phallodriline in the Oman material belongs to a group of *Aktedrilus* devoid of penis sheaths and provided with a spermatheca whose ampulla is well set-off from the duct. The spermathecal duct of *Aktedrilus* sp. is cylindrical and thick-walled; the ampulla is spheric, thin-walled and filled with a random mass of sperm. The atria are coiled. The specimen appears to be different from the six species of the genus already identified in the Arabian Gulf coast (see Erséus, 1989). The vasa deferentia and the attachment of the posterior prostate glands were not observed in detail, so we cannot make a final conclusion about the specific identity of our sepecimen. It seems to be close to *A. sinensis* Erséus, 1984, a species only reported from southern China. We note that out of about thirty species of *Aktedrilus* already known, only two, *A. argatxae* Giani & Rodríguez, 1988 and *A. ruffoi* Sambugar, Giani & Martínez-Ansemil, 1999 have been found in freshwaters.

Family: ENCHYTRAEIDAE
Subfamily: Enchytraeinae
Enchytraeus sp.

Examined material. – One mature specimen from interstitial waters of a spring formed in 1995 in Rustaq, Bait Qura (96/69), UTM 0443405/2587376, eC 818 µS/cm, 1 April 1996, Legit: J. H. Stock.

Remarks. – Unfortunately, the state of conservation of the specimen does not allow a specific identification.

Faunistic remarks

This work is the first faunistic inventory of freshwater oligochaetes in Oman, completely unknown until now. The research, headed by J. H. Stock of the University of Amsterdam in 1996, was based on investigations of the fauna of different underground habitats: a total of 127 samples were collected and among them, only 27 include oligochaetes. The frequency of the occurrence of Oligochaeta in all of the collected samples (about 20%) is not high, but it compares with the frequency (39%) found by an Amsterdam expedition in the subterranean waters of the Caribbean West Indian Islands (Dumnicka, 1986b). The 147 examined specimens belong to 9 species of 4 families: Phreodrilidae, Naididae, Tubificidae, Enchytraeidae. The first family, with 83 specimens found in 12 samples, represents more than half of the total fauna; the remaining specimens (64) belong mainly to the family Naididae (54).

The most important biogeographic data are the presence of two new species of Phreodrilidae which represent the first record of the family in the Arabian peninsula: *Antarctodrilus arabicus* n. sp. and *Phreodrilus stocki* n. sp.. The former, with 77 specimens collected, is the most abundant species in the material examined. The second species, with 6 specimens, is less abundant. Remarkably, every species of Phreodrilidae was always alone (no other oligochaete species present) in the collected samples at our disposal.

Information on the subterranean oligochaete fauna is rather scarce, and for the intertropical region, in particular. Juget & Dumnicka (1986) in a review of subterranean waters, reported a total of 65 species of stygobiont Oligochaeta of which 56 have been identified only from the paleartic area. Giani et al. (2001) have added 32 new species described from 1986 to 2000, bringing the total number of stygobiont species all over the world to 97. Among them, only 15 species are not paleartic, possible suggesting that the non-paleartic fauna lacks extensive research. It is noteworthy that in the last 14 years only 3 species (*Astacopsidrilus naceri*, Giani, Martin & Juget, 1995 from Morocco, *Haplotaxis villiersi* Omodeo, 1987 and *Villiersa guanivora* Omodeo, 1987 from Guinea) were described from outside the paleartic region. The two new species of Phreodrilidae, *Antarctodrilus arabicus* n. sp and *Phreodrilus stocki* n. sp., can be added to the non-paleartic subterranean oligochaete fauna. The first one was found in interstitial waters of wadi Taww and of the anchihaline Tiwi cave. The second spe-

cies was found in the interstitial waters of wadi Ahin. Among the other identified species, *D. (Dero) zeylanica, Allonais paraguayensis* and *D. puertoricensis* are for the first time mentioned in subterranean habitats. The absence in the samples of representatives of the genera *Pristina* and *Pristinella* is worthy of note because they are the dominating stygophilous genera, together with *Dero*, in the subterranean fauna of Caribbean West Indian Islands (Dumnicka, 1986b) and in the intertropical freshwaters of Africa (Grimm, 1987). The Phreodrilidae are a family of great biogeographical interest for its probable Gondwanian origin and high endemicity at species level (Pinder & Brinkhurst, 1997). They were found in running and standing cool waters of Tasmania, New Zealand, southeastern and south-western parts of Australia and several oceanic islands of the southern hemisphere below the latitude of 45°. Moreover they were found below latitude 39° S in S. America, in a high altitude lake in Andes and in south African lowland rivers and upland streams. The findings from equatorial areas in ancient African rift valley lakes, and from hyporheic waters in Morocco are few. The Sri Lankan record is from an upland stream (for all data see Pinder & Brinkurst, 1997). Of the eight genera of the family, only two (*Astacopsidrilus* and *Nesodrilus*) come from the northern hemisphere; our data increases this number to 4.

The two species *Antarctodrilus arabicus* n. sp. and *Phreodrilus stocki* n. sp. belong to the subfamily Phreodrilinae until now restricted to the area south of the tropic of Capricorn. In fact most species of the genus *Antarctodrilus* are from Australia, one species – *A. niger* (Beddard, 1894) – is from S. America, S. Africa and a number of subantartic islands, another species – *A. africanus* (Goddard & Malan, 1913) – is from S. Africa. The genus *Phreodrilus* is known only in Australia and New Zealand with the exception of one species, *P. branchiatus* Beddard, 1894, present in Australia and Chile.

So the two new records enlarge the so far known distribution area for every genera and confirm the presence of Phreodrilidae in the northern hemisphere, as already surmised by Giani et al. (1995). In this work the authors, on the basis of new data, shed new light on the hypothesis of the Gondwanian origin of the family and predicted its presence in the Arabian peninsula. Moreover the presence of Phreodrilidae only in underground waters of Morocco lead them to assume that the nothernmost taxa are relict inhabiting environments that can be considered as refuges (groundwaters or ancient lakes of Africa). The presence of the family in subterranean waters of the Arabian peninsula supports all previous conclusions. It's noteworthy to mention that the Phreodrilidae in Oman were found only in interstitial habitats and they are completely absent in the superficial habitats sampled (two springs) and in the lake inside the Tiwi cave. We stress that *Antarctodrilus arabicus* n. sp. was found in the interstitial water of this cave. Findings of preodrilids in north-west (arid) Australia are from groundwater bores and springs (see Pinder, 2001).

We know very little about the ecology and biology of subterranean Phreodrilidae (as well as for those of surface waters). Juget & Yacoubi-Khebiza (1997) have shown that *Astacopsidrilus naceri* is a stygobiont species, with a preference for the hyporheic environment; as it is very rare in the wells found along the watersheds of the various wadis examined. They conclude that the hyporheon of alluvial plains can be considered a refuge for superficial species subjected to hydrogeological perturbations and high temperatures. Very little is known of the three other species known for the subterranean environment: *Phreodrilus subterraneus* Beddard, 1891 and *P. beddardi* Benham, 1904, collected in New Zealand and *Astacopsidrilus novus* Jackson, 1931 in Australia.

As regards temperature, our data demonstrate that the preference of Phreodrilidae for cool waters is not exclusive: the temperature at which our species were found ranges from 24.9° to 29°C. The colonization of groundwaters is probably due to their escape from inhospitable environments such as warmer surface waters. Pinder & Brinkhurst (1997) reported an apparent wider tolerance to temperature for two other species (based on their distributions): *Phreodrilus branchiatus* and *Antarctodrilus proboscidea* (Brinkhurst & Fulton, 1979).

As regards water mineralization, the species seem highly tolerant, especially *A. arabicus* n. sp. which was found in the interstitial water of the anchyaline cave at 22 ‰ of salinity. It is worth noting that only three other phreodrilid species -*Astacopsidrilus*

campbellianus (Benham, 1909), *A. ostiensis* Pinder & Erséus, 2000 and *Insulodrilus litoralis* (Michaelsen, 1924)- have been recorded in highly mineralised waters (intertidal or estuarine habitats) (Pinder & Erséus, 2000).

The Limnodriloidinae *Doliodrilus puertoricensis* was previously identified in the west coast of Puerto Rico and Belize. The present record represents a large extension of its known distribution area, and a tethydian distribution could be suggested for the genus *Doliodrilus*. Nevertheless, Wang & Erséus (submitted) discovered eight new species of *Doliodrilus* from southern China, suggesting that this genus is likely to be Indo-Pacific, and the caribbean occurrence of *D. puertoricensis* could be a recent introduction (Erséus, pers. comm.)

It is worth noting the presence in the underground waters of Oman of two tubificids taxa belonging to the marine subfamilies Limnodriloidinae (*Doliodrilus puertoricensis)* and Phallodrilinae (*Aktedrilus* sp). The presence in underground habitats of Europe of an oligochaete fauna with marine phyletic affinities was already highlighted by us (Sambugar et al., 1999); the Oman records strengthen the hypothesis as far as the Arabian peninsula is concerned. The genera *Aktedrilus* and *Doliodrilus* are currently found in the littoral marine or brackish water within a large range of salinity. The migration of interstitial marine meiobenthic tubificid species through water of decreasing salinity could be how they colonized subterranean freshwaters.

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References

Brinkhurst RO. 1965. A taxonomic revision of the Phreodrilidae (Oligochaeta). *J. Zool., Lond.* **147:** 363–386.

Brinkhurst RO. 1991. A phylogenetic analysis of the Phreodrilidae (Annelida, Oligochaeta), with a description of a new species. *Can. J. Zool.* **69:** 2031–2040.

Brinkhurst RO, Jamieson BGM. 1971. *Aquatic Oligochaeta of the world.* Oliver & Boyd, Edinburgh.

Chagné P, Giani N. 1998. Taxinomie et faunistique des Oligochètes aquatiques de la Martinique. *Bull. Soc. Hist. Nat., Toulouse* **134:** 21-32.

Dumnicka E. 1986a. Naididae (Oligochaeta) from subterranean waters of West Indian Islands – Distribution, taxonomic remarks and description of a new species. *Bijd. Dierk.* **56** (2): 267-281.

Dumnicka E. 1986b. Oligochaeta from subterranean waters of West Indian Islands. Fauna aquatica. *4° Congreso Internacional de Espeleologia. Barcelona*, 95-98.

Erséus C. 1984. The marine Tubificidae (Oligochaeta) of Hong Kong and Southern China. *Asian mar. Biol.* **1:** 135-175.

Erséus C. 1985. Annelida of Saudi Arabia. Marine Tubificidae (Oligochaeta) of the Arabian Gulf coast of Saudi Arabia. *Fauna Saudi Arabia* **6** (1984): 130-154.

Erséus C. 1986a. Marine Tubificidae (Oligochaeta) of the Arabian Gulf coast of Saudi Arabia (Part 2). *Fauna Saudi Arabia* **7** (1985): 59-65.

Erséus C. 1986b. Marine Tubificidae (Oligochaeta) of the Arabian Gulf coast of Saudi Arabia (Part 3). *Fauna Saudi Arabia* **8:** 3-5.

Erséus C. 1988. Marine Tubificidae (Oligochaeta) of the Arabian Gulf coast of Saudi Arabia (Part 4). *Fauna Saudi Arabia* **9:** 19-22.

Erséus C. 1989. Marine Tubificidae (Oligochaeta) of the Arabian Gulf coast of Saudi Arabia (Part 5). *Fauna Saudi Arabia* **10:** 11-19.

Erséus C. 1990a. Marine Oligochaeta of Hong Kong. In: Morton B ed. *Proceedings of the Second International Marine Biological Workshop: The Marine Flora and Fauna of Hong Kong and Southern China, Hong Kong* **1**(1986): 259-335.

Erséus C. 1990b. The marine Tubificidae (Oligochaeta) of the barrier reef ecosystems at Carrie Bow Cay, Belize, and other parts of the Caribbean Sea, with descriptions of twenty-seven new species and revision of *Heterodrilus*, *Thalassodrilides* and *Smithsonidrilus*. *Zool. Scr.* **19** (3): 243-303.

Erséus C. 1997. The marine Tubificidae (Oligochaeta) of Darwin Harbour, Northern Territory, Australia, with descriptions of fifteen new species. In: Hanley RH, Caswell G, Megirian D and Larson HK eds. *Proceedings of the Sixth International Marine Biological Workshop. The marine flora and fauna of Darwin Harbour, Northern Territory, Australia. Darwin, Australia*, 99-132.

Erséus C, Milligan MR. 1988. *Limnodriloides faxatus* and *Doliodrilus puertoricensis*, new Limnodriloidinae (Oligochaeta: Tubificidae) from Puerto Rico. *Proc. Biol. Soc. Wash.* **101**(1): 11-14.

Erséus C, Daoyuan S, Yanling L, Bin S. 1990. Marine Oligochaeta of Jiaozhou Bay, Yellow Sea coast of China. *Hydrobiologia* **202:** 107-124.

Giani N, Martin P, Juget J. 1995. A new species of Phreodrilidae (Oligochaeta), *Astacopsidrilus naceri* sp. nov., from Morocco (North Africa), with notes on the biogeography of the family. *Can. J. Zool.* **73:** 2375-2381.

Giani N, Sambugar B, Rodríguez P, Martínez-Ansemil E.

2001. Oligochaetes in southern European groundwater: new records and an overview. *Hydrobiologia* **463:** 65-74.

Grimm R. 1985. Beitrage zur Systematik der Afrikanischen Naididae (Oligochaeta) II. *Dero raviensis* (Stephenson, 1914) und *Aulophorus africanus* Michaelsen, 1914 – zwei verbreitete afrikanischer Arten. *Mitt. Hamb. Zool. Mus. Inst.* **82:** 109-117.

Grimm R. 1987. Contribution towards the taxonomy of the African Naididae (Oligochaeta). IV. Zoogeographical and taxonomical considerations on African Naididae. *Hydrobiologia* **155:** 27-37.

Gustavsson LM, Erséus C. 1999. Morphology and phylogenetic implications of oesophageal modification in the Limnodriloidinae (Oligochaeta, Tubificidae). *J. Zool. Lond.* **248:** 467-482.

Juget J, Dumnicka E. 1986. Oligochaeta (incl. Aphanoneura) des eaux souterraines continentales. In: Botosaneanu L ed. *Stygofauna Mundi, E. J. Brill., Leiden*, 234-244.

Juget J, Yacoubi-Khebiza M. 1997. Contribution à l'écologie de l'espèce *Astacopsidrilus naceri* Giani & Martin, 1995 (Phreodrilidae, Oligochaeta) en provenance des eaux souterraines du Maroc. *Annls Limnol.* **33** (3)**:** 149-161.

Pinder AM. 2001. Notes on the diversity and distribution of Australian Naididae and Phreodrilidae (Oligochaeta: Annelida). *Hydrobiologia* **463:** 49-64.

Pinder AM, Brinkhurst RO. 1997. Review of the Phreodrilidae (Annelida; Oligochaeta; Tubificida) of Australia. *Invertebr. taxon.* **11:** 443–523.

Pinder AM, Erséus C. 2000. New Phreodrilidae (Annelida: Clitellata) from Tasmanian estuaries. *Pap. Proc. R. Soc. Tasm.* **134:** 29-33.

Sambugar B. 1986. *I Naididi italiani (Oligochaeta).* PhD thesis, University of Padova (Italia).

Sambugar B, Giani N, Martínez-Ansemil E. 1999. Groundwater oligochaetes from southern-Europe. Tubificidae with marine phyletic affinities: new data with description of a new species, review and consideration on their origin. *Mém. Biospéol.* **XXVI:** 107-116.

Sperber C. 1948. A taxonomical study of the Naididae. *Zool. Bidr. Upps.* **28:** 1-296.

Stephenson J. 1913. On a collection of Oligochaeta mainly from Ceylon. *Spolia Zeylan.* **8:** 251-276.

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