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Systematic Parasitology
An International Journal

ISSN 0165-5752

Syst Parasitol
DOI 10.1007/s11230-015-9583-y



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The first record of *Gyrodactylus corleonis* Paladini, Cable, Fioravanti, Faria & Shinn, 2010 (Monogenea: Gyrodactylidae) from the wild

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Received: 25 March 2015 / Accepted: 15 May 2015
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Abstract Specimens of *Gyrodactylus corleonis* Paladini, Cable, Fioravanti, Faria & Shinn, 2010 (Monogenea: Gyrodactylidae) were collected from the body and fins of *Gobius cobitis* Pallas in the western Mediterranean Sea off northwestern Sardinia. This is the first finding of this species in the wild and also represents a new host record. A morphological comparison of the new material with the type description of *G. corleonis* is presented. Since *G. corleonis* was found in the wild on representatives of the Gobiidae, a comparison with species of *Gyrodactylus* von Nordmann, 1832 parasitising gobies is included. The occurrence of *G. corleonis* on different host species and its phylogenetic relationships with gyrodactylids from sand gobies are discussed.

Introduction

Gyrodactylus corleonis Paladini, Cable, Fioravanti, Faria & Shinn, 2010 was described from *Syngnathus typhle* L. held in an aquarium in the Emilia-Romagna region of Italy but was thought to have originally been caught in the Mediterranean Sea off Marseille (Paladini et al., 2010). Given the conditions under which the species was found, its host (or hosts) in the wild is unknown.

Materials and methods

Nine specimens of *Gobius cobitis* Pallas, 10–15 cm in total length, were caught off northwestern Sardinia (western Mediterranean Sea, 41°08'05"N, 9°06'05"E) in October, 2008. These fish were killed in the laboratory by cervical section. Skin, fins and gills were examined under a dissecting microscope for the presence of monogeneans. All monogeneans were collected live and immediately mounted in glycerine-jelly (prepared with 0.5 g carbolic acid) after Gusev (1983).

Measurements and light photomicrographs were made using a Carl Zeiss Jena Amplitval microscope fitted with phase-contrast optics, an ocular micrometer and an Olympus C180 digital camera, at magnifications of ×2,000. The measurement scheme generally followed Malmberg (1970), but for comparison some measurements taken were those used by Gläser (1974) and Shinn et al. (2004). Abbreviations of the linear measurements are as follows: DBL, dorsal bar length; DBW, dorsal bar

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width; HA, hamulus aperture distance; HPL, hamulus point length; HRL, hamulus root length; HShL, hamulus shaft length and HSL, hamulus shaft length *sensu* Shinn et al. (2004); HW, hamulus proximal shaft width; MA, marginal hook aperture; MDW, marginal hook sickle distal width; MDL, marginal hook sickle distal length *sensu* Gläser (1974); MPW, marginal hook sickle proximal width; MSL, marginal hook sickle length; MShL, marginal hook shaft length; ML, marginal hook total length; MTW, marginal hook sickle toe width; MCO, male copulatory organ; VBAW, ventral bar anterior width; VBBL, ventral bar basal length; VBL, ventral bar total length; VBML, ventral bar membrane length; VBPL, ventral bar lateral process length; VBW, ventral bar total width. The filament loop length of marginal hooks was measured from the distal to the proximal loop points on hook. Body size is given for mounted and flattened but unbroken worms; width was measured at the level of the uterus. All measurements are given in micrometres, as the range followed by the mean with standard deviation and number of measurements in parentheses. Descriptive statistics were produced using the software package Statistica 6 for Windows.

Gyrodactylidae van Beneden & Hesse, 1863
***Gyrodactylus* von Nordmann, 1832**

***Gyrodactylus corleonis* Paladini, Cable, Fioravanti, Faria & Shinn, 2010**

Type-host: *Syngnathus typhle* L.

Other host: *Gobius cobitis* Pallas.

Type-locality: Thought to be off Marseille, Mediterranean Sea.

Other locality: Off northwestern Sardinia (41° 08'05"N, 9°06'05"E), Mediterranean Sea.

Site on host: Gills, skin and fins.

Specimens studied: 7 specimens deposited in the collection of the Natural History Museum, London (NHMUK 2015.1.22.1–2) and 18 in the collection of the Institute of Biology of the Southern Seas (IBSS), Sevastopol (No. 526/1–8).

Infection details: 100% of 9 hosts examined; intensity 4–15 (10).

Specimens of *Gyrodactylus corleonis* found on *Gobius cobitis* off northwestern Sardinia are practically identical in the shape of their haptoral structures (Figs. 1, 2, 3)

and most of their dimensions (Table 1) to the original description (Paladini et al., 2010). Only one character, the width of the dorsal bar, was smaller (Table 1). Shinn et al. (2003), however, suggested that the dorsal bar is a flexible structure and should be able to relax or stretch, helping the hamuli to attach by preventing their independent rotation. Thus, this character may depend on the distance between the hamuli.

Among the species parasitising syngnathids, *Gyrodactylus neretum* Paladini, Cable, Fioravanti, Faria & Shinn, 2010 from *Syngnathus scovelli* (Evermann & Kendall) and *G. pisculentus* Williams, Kritsky, Dunnigan, Lash & Klein, 2008 from *Syngnathus fuscus* Store appear morphologically similar to both samples of *G. corleonis*. A detailed differentiation of *G. corleonis* ex *S. typhle* from all known *Gyrodactylus* spp. from syngnathids was presented by Paladini et al. (2010), but no comparison with species from gobiids was considered.

Taking into account that in this study *G. corleonis* was found in the wild on a gobiid, its comparison with other *Gyrodactylus* spp. infecting gobies is presented here. Of the 23 *Gyrodactylus* spp. parasitising members of the Gobioidae in the Holarctic region (Vanhove et al., 2013), *G. bubyri* Osmanov, 1965, which was described from *Knipowitschia caucasica* (Kawrajsky) in the Aral Sea (Osmanov, 1965) and was recently

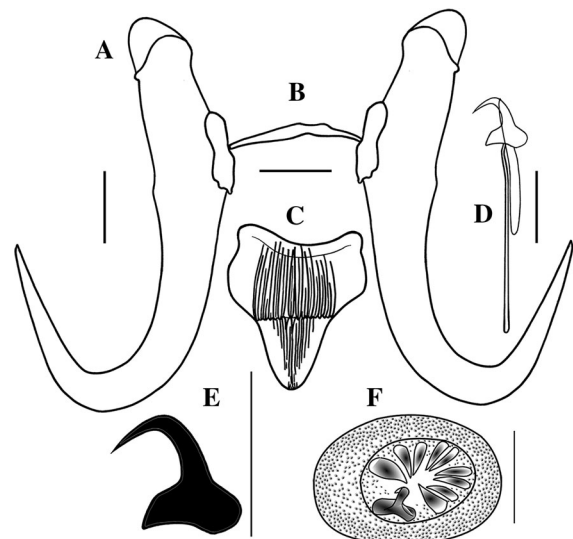


Fig. 1 Haptoral and copulatory structures of *Gyrodactylus corleonis* ex *Gobius cobitis* in the western Mediterranean Sea. A, Hamulus; B, Dorsal bar; C, Ventral bar; D, Marginal hook, total view; E, Marginal hook sickle; F, Male copulatory organ. Scale-bars: 10 µm

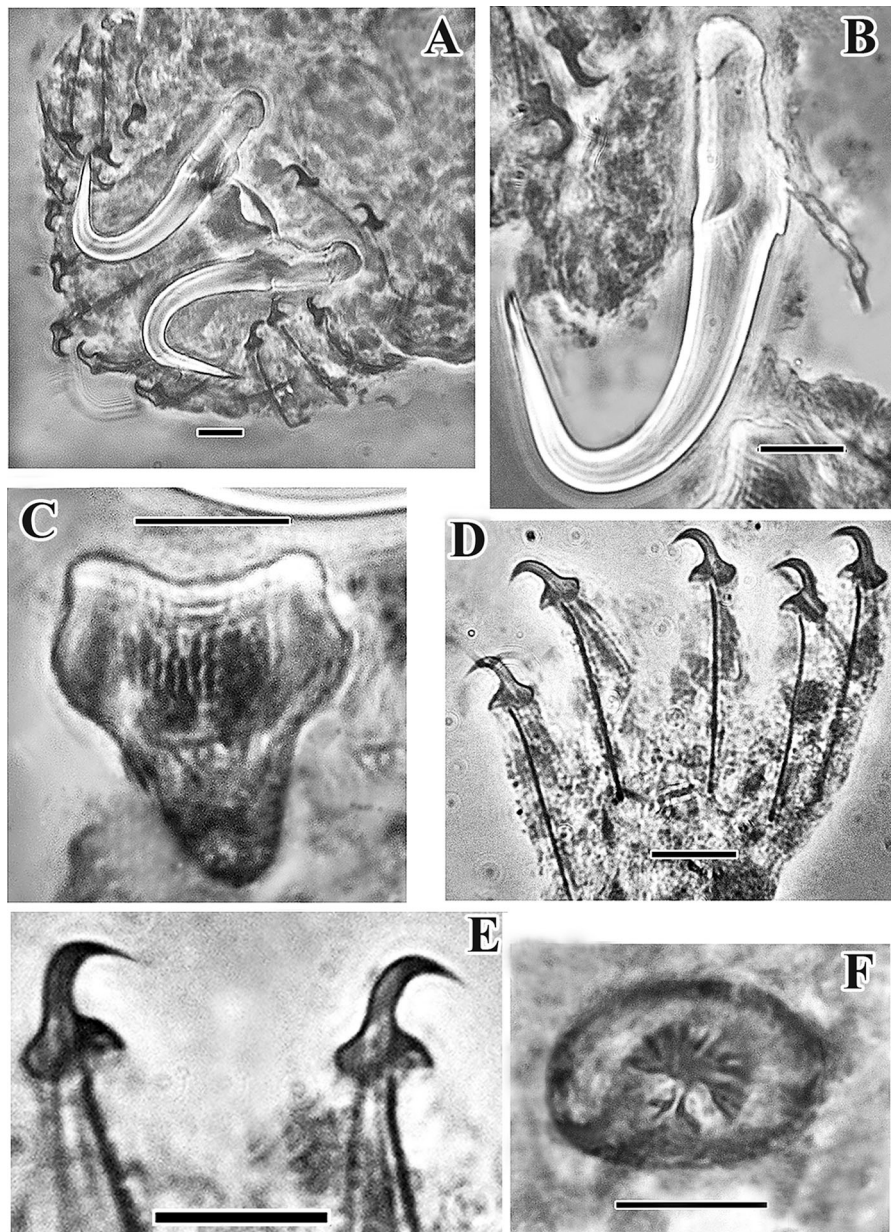


Fig. 2 Photomicrographs of *Gyrodactylus corleonis* ex *Gobioides cobitis* in the western Mediterranean Sea. A, Haptor; B, Hamulus and dorsal bar; C, Ventral bar; D, Marginal hooks; E, Marginal hook sickles; F, Male copulatory organ. Scale-bars: 10 μ m

found in the same host in Strymon River flowing into the Aegean Sea (Vanhove et al., 2013), closely resembles *G. corleonis* in the shape of the ventral bar, with indistinctly lateral processes and a conical and rather short membrane, and massive hamuli with relatively short roots (compare Figs. 2, 3 with figure 569A of Ergens, 1985). However, *G. corleonis* differs in: (i) the larger ventral bar base; (ii) the shorter

length of its membrane (Table 1: VBBL and VBML); (iii) the longer hamuli and marginal hooks (Table 1: HL and ML); and (iv) the shape of the marginal hook sickle (with practically equal proximal and distal parts and a more prominent heel of the latter, compared to a more elongate proximal part and smoother heel of the marginal hook sickle (compare Figs. 1E, 2E with figure 569A of Ergens, 1985).

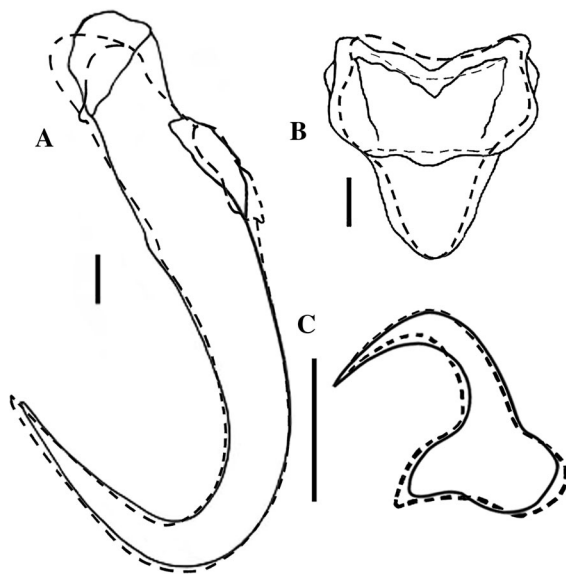


Fig. 3 Size-invariant comparison of the haptoral hardparts of *Gyrodactylus corleonis* from the type-material, redrawn from figure 1 of Paladini et al. (2010) based on specimens from *Syngnathus typhle* (solid line), and new specimens collected from *Gobius cobitis* in the western Mediterranean Sea (broken line). Scale-bars: 10 µm

Among the seven *Gyrodactylus* spp. recently described from sand gobies in the Balkan region (Vanhove et al., 2013), three species, namely *G. bios* Vanhove, Economou, Zogaris, Giakoumi, Zanella, Volckaert & Huyse, 2013, *G. charon* Vanhove, Economou, Zogaris, Giakoumi, Zanella, Volckaert & Huyse, 2013 and *G. hellemansi* Vanhove, Economou, Zogaris, Giakoumi, Zanella, Volckaert & Huyse, 2013 share the following characters with *G. corleonis*: ventral bar short, with blunt lateral processes and moderate, triangular, rounded membrane; marginal hook sickle with pronounced heel and rather long point; and length, point/shaft and root/shaft proportions of hamuli. However, *G. corleonis* can be easily distinguished from these taxa as follows: (i) the sturdier marginal hook sickle with a more sharply curved point, the end of which is markedly turned downwards (compare Figs. 1E, 2E with figures 3b, f, k and 4b, c, g of Vanhove et al., 2013); (ii) the wider proximal part of the marginal hook sickle; and (iii) the wider hamuli (Table 1: MPW and HW).

Of the six *Gyrodactylus* spp. parasitising gobiids in the Mediterranean Sea (Huyse et al., 2006; Vanhove et al., 2013), *G. branchialis* Huyse, Malmberg & Volckaert, 2004, *G. gondae* Huyse, Malmberg &

Volckaert, 2004 and *G. arcuatus* Bychowsky, 1933 are clearly distinguishable from *G. corleonis* by the shape of the ventral bar with long lateral processes. The other three, namely *G. ostendicus* Huyse & Malmberg, 2004, *G. ruginensis* Gläser, 1974 and *G. ruginoides* Huyse & Volckaert, 2002 (Table 1), have haptoral structures similar to those of *G. corleonis*; however, they all differ in the greater dimensions of the bars, hamuli and marginal hooks (Table 1). Furthermore, in the case of *G. ostendicus*, the ratio of root length to hamulus shaft length (Table 1: HRL/HShL) is 1/4 vs 1/2 in *G. corleonis*, whereas in the other two species: (i) the ratio of ventral bar base length to membrane length (Table 1: VBBL/VBML) differ (*c.* 2 vs *c.* 1 in *G. corleonis*); (ii) the anterior width of the ventral bar is smaller (Table 1: VBAW), (iii) the shape of the marginal hook sickle differs, namely the distal and proximal parts are situated almost perpendicularly to each vs the distal part distinctly tilting towards the proximal part (compare figures 4a-d of Huyse & Volckaert, 2002 and figure 1 of Gläser, 1974 with Figs. 1E, 2E); and (iv) the distal and proximal parts of the sickle are slightly narrower (Table 1: MDW and MPW).

In addition to the six above-mentioned species, *G. orecchiaie* Paladini, Cable, Fioravanti, Faria, Di Cave & Shinn, 2009 and *G. longipes* Paladini, Hansen, Fioravanti & Shinn, 2011 have been recorded in the Tyrrhenian and Adriatic Seas from farmed populations of *Sparus aurata* L. (see Paladini et al., 2009, 2011). *Gyrodactylus corleonis* significantly differs from both of these species in all its haptoral hardparts.

Discussion

Nine species of *Gyrodactylus* are presently known from the Mediterranean Sea, namely *G. corleonis*, *G. branchialis*, *G. ostendicus*, *G. gondae*, *G. ruginensis*, *G. ruginoides* and *G. arcuatus* from wild populations of gobies plus *G. orecchiaie* and *G. longipes* from farmed populations of *Sparus aurata* (Huyse et al., 2006; Paladini et al., 2009, 2011). *Gyrodactylus corleonis* was originally described from the pipefish *Syngnathus typhle* and shown to be morphologically very similar to other *Gyrodactylus* spp. infecting *Syngnathus* spp. (Paladini et al., 2010). Moreover, a close phylogenetic relationship of *G. corleonis* with *G. neretum* and *G. eyipayipi* Vaughan, Christison, Hansen & Shinn, 2010

Table 1 Dimensions of the opisthaptoral hard-parts and MCO of *Gyrodactylus corleonis* Paladini, Cable, Fioravanti, Faria & Shinn, 2010 from *Gobius cobitis* in the Mediterranean Sea and from aquarium hold *Syngnathus typhle* and of closely related congeners parasitising fishes of the family Gobiidae

Species	<i>G. corleonis</i> Paladini, Cable, Fioravanti, Faria & Shinn, 2010	<i>G. bubyri</i> Osmanov, 1965	<i>G. bios</i> Vanhove, Economou, Zogaris, Giakoumi, Zanelia, Volckaert & Huyse, 2013	<i>G. charon</i> Vanhove, Economou, Zogaris, Giakoumi, Zanelia, Volckaert & Huyse, 2013	<i>G. hellemansi</i> Vanhove, Economou, Zogaris, Giakoumi, Zanelia, Volckaert & Huyse, 2013	<i>G. ostendicus</i> Huyse & Malmberg, 2004	<i>G. rugiensi</i> Gläser, 1974	<i>G. rugiensoides</i> Huyse & Volckaert, 2002
Host	<i>Gobius cobitis</i> Pallas	<i>Syngnathus typhle</i> L.	<i>Knipowitschia caucasica</i> (Kawrjisky in Berg, 1916)	<i>K. thessala</i> (Vinciguerra)	<i>K. milleri</i> (Ahneft & Bianco)	<i>K. croatica</i> Mrakovcic, Kerovec, Misetic & Schneider	<i>P. microps</i> ; <i>P. minutus</i> (Pallas)	<i>P. minutus</i> ; <i>P. pictus</i> (Malm); <i>P. lozanoi</i> (de Buen)
Source	Present study	Paladini et al. (2010)	Osmanov (1965); Ergens (1985)	Vanhove et al. (2013)			Gläser (1974)	Huyse & Volckaert (2002)
Hamulus								
HL ^a	53–57 (55 ± 1.2; n = 27)	54–58	42–49 ^b	51–55	42–53	40–43	50–61	55–64
HPL	23–26 (25 ± 0.9; n = 27)	26–28	23–24	28–29	21–27	18–21	27–32	27–32
HSHL	40–43 (41 ± 1.0; n = 27)	–	31–36	–	–	–	39–44	39–48
HSL	34–36 (35 ± 1.0; n = 27)	31–34	–	31–33	24–31	24–27	–	–
HA	19.5–22 (20.5 ± 1.2; n = 27)	20–23	–	14–20	11–20	14–19	–	–
HW	9–10 (9.5 ± 0.7; n = 27)	8–9	–	6.6–7.7	5.2–7.9	5.4–6.2	–	–
HRL	19–21 (20 ± 0.8; n = 27)	18–21	12–19	16–20	14–19	12–15	13–21	18–22
Ventral bar								
VBW	19–22 (20; n = 22)	20–24	17–25	23–31	17–28	20–30	–	–
VBAW	16–18 (16.5; n = 12)	–	–	–	–	–	21–29	24–31
VBL	18–22 (20.5; n = 12)	22–25	–	17–25	16–26	19–24	15–20	15–23
VBBL	9–11 (9.5; n = 25)	8–10	4–6	6–8	4–9	4–5	3.4–6.8	5.2–9.7
VBML	8–10 (9; n = 12)	8–14	12	9–17	9–18	13–18	9–15	11–17
VBPL	1–2 (2; n = 12)	0.2–1.2	–	1.4–2.6	1.2–2.6	1.2–2.7	–	–

Table 1 continued

Species	<i>G. corleonis</i> Paladini, Cable, Fioravanti, Faria & Shinn, 2010	<i>G. bubyni</i> Osmanov, 1965	<i>G. bios</i> Vanhove, Economou, Zogaris, Giakoumi, Zanelle, Volckaert & Huyse, 2013	<i>G. charon</i> Vanhove, Economou, Zogaris, Giakoumi, Zanelle, Volckaert & Huyse, 2013	<i>G. hellemansi</i> Vanhove, Economou, Zogaris, Giakoumi, Zanelle, Volckaert & Huyse, 2013	<i>G. ostendicus</i> Huyse & Malmberg, 2004	<i>G. rugtensi</i> Gläser, 1974	<i>G. rugiensoides</i> Huyse & Volckaert, 2002
Host	<i>Gobius cobitis</i> Pallas	<i>Syngnathus typhle</i> L.	<i>Knipowitschia caucasica</i> (Kawrajsky in Berg, 1916)	<i>K. thessala</i> (Vinciguerra)	<i>K. croatica</i> Mrakovcic, Kerovec, Misetic & Schneider	<i>K. panizzae</i> (Verga); <i>Ponatoschistus microps</i> (Krøyer); <i>P. marmoratus</i> (Risso)	<i>P. microps</i> ; <i>P. minutus</i> (Pallas)	<i>P. minutus</i> ; <i>P. pictus</i> (Malm); <i>P. lozanoi</i> (de Buen)
Source	Present study	Paladini et al. (2010)	Osmanov (1965); Ergens (1985)	Vanhove et al. (2013)		Huyse & Malmberg (2004)	Gläser (1974)	Huyse & Volckaert (2002)
Dorsal bar								
DBW	16–19 (18; n = 18)	23–27	15–17	16–34	15–30	17–25	10–13	–
DBL	2–3 (2.5; n = 18)	2.5–3.8	1–2	1.6–2.7	1.5–2.7	1.5–2.0	–	–
Marginal hook								
ML	32–33 (32.5; n = 23)	31–35	23–26	28–31	23–33	23–30	17.5–21	31–35
MSHL	26–27 (26.5; n = 23)	25–28	–	21–26	19–28	17–23	14–17	24–28
MSL	7–8 (7; n = 23)	6.7–8.3	6	6.0–7.1	3.6–5.9	6.3–7.3	3.5–4.5	6.2–7.8
MDW	5–6 (5.5; n = 23)	5–6.4	–	4.6–6.6	3.2–5.8	3.2–5.1	–	3–4.5
MDL	3–4 (3.1; n = 23)	–	–	–	–	–	–	–
MA	6 (n = 23)	6.1–7.3	–	5.9–6.9	4.0–6.2	5.7–7.1	–	4.5–6.1
MPW	6 (n = 23)	5.5–6.2	–	3.8–4.8	2.5–4.0	3.3–4.1	–	3.4–4.6
MTW	2–3 (2.5; n = 23)	2.7–3.1	–	1.1–2.5	1.2–2.0	1.1–2.4	–	1.2–1.8
Loop	16–17 (16.5; n=10)	–	–	–	–	–	–	–
MCO width	17–20 (n = 5)	20–29	–	9–14	9–11	–	13–14	–

^a See Materials and methods for abbreviations; ^b Measurements different from present data for *G. corleonis* are highlighted in bold; ^c Ranges for measurements are given for all records from different hosts

has been confirmed by comparison of rDNA sequences (Paladini et al., 2010; Ziętara et al., 2012). Furthermore, each of the six known gyrodactylid species from pipefish has previously been found on only one host species. Consequently, the presented finding of *G. corleonis* on *Gobius cobitis* is the first record on a second host and, moreover, on a phylogenetically unrelated fish. However, *S. typhle* and *G. cobitis* are sympatric and share similar habitats, occurring in coastal regions, in estuaries and in intertidal zones of the northeastern Atlantic and the Mediterranean, Black and Azov Seas in biocoenoses associated with seagrass beds Froese & Pauly (2014). It is, therefore, possible that similarities in host ecology may have promoted the radiation of gyrodactylids onto distantly-related hosts. It is also worth noting that among all known gyrodactylids, *Gyrodactylus bubyri* from *Knipowitschia caucasica* is the most morphologically similar to *G. corleonis*, *G. neretum* and *G. pisculentus*, all from *Syngnathus* spp. Moreover, in accordance with the phylogenetic relationships of marine gyrodactylids indicated by DNA analysis (Ziętara et al., 2012), *Gyrodactylus* spp. from sand gobies of the genera *Knipowitschia* Iljin, 1927 and *Pomatoschistus* Gill, 1863 are very close relatives of *G. corleonis* and two other species from syngnathids. Some of these gyrodactylids, namely *G. rugiensis*, *G. rugiensoides* and *G. micropsi* Gläser, 1974, are also morphologically similar to *G. corleonis*, and their hosts also occur in coastal waters and are often found in the same habitats of pipefishes and gobies.

The finding of *G. corleonis* on *Gobius cobitis* suggests that genetic and morphological data may need to be looked at again in terms of the relationships of gyrodactylids from syngnathids and gobiids. Moreover, for a more detailed analysis of the occurrence of *G. corleonis* on two unrelated host species, it is necessary to obtain molecular data for verification of the identification of the current material collected from *Gobius cobitis* and to confirm that this species also infects *S. typhle* in the wild.

Acknowledgements We are very grateful to Dr David Gibson for his help in preparing this article and to two anonymous reviewers for their suggestions.

Conflict of interest The authors declare that they have no conflict of interest.

Compliance with ethical standards All applicable institutional, national and international guidelines for the care and use of animals were followed.

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