

NEW RECORDS OF *LEPTACANTHICHTHYS GRACILISPINIS* AND *MICROLOPHICHTHYS MICROLOPHUS* (ACTINOPTERYGII: LOPHIIFORMES: ONEIRODIDAE) FROM THE SUBARCTIC ATLANTIC OCEAN, INCLUDING NEW LOPHIIFORM BARCODING DATA AND A RARE OBSERVATION OF A COPEPOD PARASITE IN CERATIOID ANGLERFISHES

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Poulsen J.Y. 2019. New records of *Leptacanthichthys gracilispinis* and *Microlophichthys microlophus* (Actinopterygii: Lophiiformes: Oneirodidae) from the subarctic Atlantic Ocean, including new lophiiform barcoding data and a rare observation of a copepod parasite in ceratioid anglerfishes. Acta Ichthyol. Piscat. 49 (4): 403–414.

Abstract. In an ongoing effort to document and/or validate taxonomic identifications and monitor fishes in the subarctic Atlantic Oceans, including the production of pragmatic identification material, two new distributional records of ceratioid anglerfishes are presented: *Leptacanthichthys gracilispinis* (Regan, 1925) and *Microlophichthys microlophus* (Regan, 1925) of the dreamer family Oneirodidae. The former belongs to the relatively rarely observed “long-pectoraled” subgroup whereas the latter is a relatively common species distributed circumglobally in temperate and tropical waters. Both species were recorded for the first time off Greenland and the specimens could be expatriated although the diversity of deep-sea pelagic fishes in the subarctic Atlantic Ocean is not well known. In addition, molecular barcoding *Cox1* DNA sequences of subarctic Atlantic lophiiform taxa are included, where the material was available, many being produced as part of the Greenland fishes barcoding program, a continuous effort to register and barcode all Greenland fish species. The program has currently barcoded 220 taxa of approximately 300 known fish species observed in Greenland waters, with the ceratioid anglerfishes constituting one of the most problematic fish groups in the region in terms of sampling, identification, and taxonomic assignments using integrative taxonomy. Taxonomic issues based on molecular OTUs** are reported for the genera *Caulophryne*, *Cryptopsaras*, and *Dolopichthys* based on *Cox1* data. Finally, a relatively large copepod parasite in the family Pennellidae was found on *L. gracilispinis* and constitutes one of only two copepod parasites recorded on ceratioid anglerfishes.

Keywords: Ceratioidei, Greenland fishes, Monitoring of subarctic fishes, diversity, *Cox1*

INTRODUCTION

Anglerfishes of the suborder Ceratioidei are the deep-sea component of the order Lophiiformes, otherwise associated with mostly shallow-water benthic frog- and toadfishes (Pietsch and Orr 2007, Miya et al. 2010). Ceratioids exhibit extraordinary adaptations to the deep-sea pelagic habitats. All females of the 169 ceratioid species (Bañón et al. 2019), with the exception of two species in the family Caulophrynidae and the monotypic *Neoceratias spinifer* Pappenheim, 1914, are mimetic aggressive anglers showing a modified first dorsal fin that have evolved into a long shaft (the illicium) with a distal bioluminescent bulb (the esca) (Lütken 1871, Bertelsen 1951, Pietsch 2009). The esca of metamorphosed females contains bioluminescent-producing bacteria (Hansen and

Herring 1977, Munk et al. 1998) that have co-evolved with the host ceratioid species (Haygood et al. 1992). As a consequence, the co-evolving bacteria possess reduced genomes as compared to free-living relatives (Hendry et al. 2018). Both illicium and esca vary between the majority of species and therefore are important taxonomic characters (Parr 1927) and represent the basic knowledge needed to comprehend communication biology of these fishes. Bioluminescence in ceratioids is not fully understood although it is believed to function at least in attracting prey as well as in reproductive signalling (Pietsch 2009). However, as males are usually levels of magnitudes smaller than the females, and possess large olfactory organs, pheromones working within close range could be as important as the light for the latter function.

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** Operational taxonomic unit.

The extraordinary sexual reproductive system in ceratioids varies between deep-sea anglerfish lineages;

- Males never attach to females,
- Males attach temporarily,
- Males are facultative or obligate “parasites”.

When “parasitism” is noted, a fusion of the two sexes is taking place and the male is attached for life and nourished by the female (Pietsch 1976, 2005, Pietsch and Orr 2007). Males showing temporary attachment (or pre-fusion if facultative “parasites”) have a “denticular apparatus” suitable for attachment and feeding (Bertelsen 1951).

Ceratioid anglerfishes in the subarctic North Atlantic are, in general, rare occurrences with the majority of species registered and known only from a single or a few stray specimens (Jónsson and Pálsson 1999, 2013, Møller et al. 2010). Many more ceratioid species have been observed south of the Sub Polar Front (SPF), e.g., in the western central Atlantic (Pietsch 2002). The SPF is an important topographic and oceanographic species barrier between the temperate and subarctic North Atlantic (Sutton et al. 2013) although depth dependent (Vecchione et al. 2015). In fact, Sutton et al. (2017) defined the subarctic western Atlantic as a distinct mesopelagic eco-region that holds primarily cold-water biodiversity assemblages. New records of anglerfishes, and other mid-water taxa could, therefore, provide important information on distributional shifts although the rarity of ceratioids and insufficient knowledge of their true distributions at present makes any trends difficult to detect.

This study describes new records of *Leptacanthichthys gracilispinis* (Regan, 1925) and *Microlophichthys microlophus* (Regan, 1925) from the subarctic Atlantic, including a description of their morphologies. Barcoding *Cox1* molecular data is included for all available subarctic oneirodid taxa with many newly constructed as part of the Greenland fishes barcoding program (Poulsen et al. 2018). Barcoding data indicate taxonomic issues in some ceratioid genera. In addition, a large crustacean parasite, rarely observed in ceratioid anglerfishes, is reported herewith. The new records and molecular data presented are part of a larger continuous taxonomic and monitoring effort off Greenland, a region that has witnessed many new species distributions the last 10 years, with the caveat that deep-sea pelagic waters are poorly known and difficult to monitor.

MATERIALS, METHODS

Material. One specimen of *Leptacanthichthys gracilispinis* was caught by *R/V Pâmiut*, Greenland Institute of Natural Resources (GINR), leg 6, haul 33, 23 September 2009, in the Davis Strait off south-western Greenland at 64.04°N, 057.37°W. It was deposited at the Zoological Museum University of Copenhagen (ZMUC) as ZMUC P922698 (tissue/field JYP#8126). Coll./ID J.Y. Poulsen. The bottom and fishing depth was within 942–950 m, with a bottom temperature of 3.74°C, although the actual catch depth is uncertain due to non-closing trawls. The specimen was barcoded (GLF140)

as part of the Greenland Fishes (GLF) barcoding project (Poulsen et al. 2018) at BOLD* (Ratnasingham and Hebert 2007).

One specimen of *Microlophichthys microlophus* was caught also by *R/V Pâmiut*, leg 4, haul 14, 24 July 2017, on the Irminger Sea slopes off south-eastern Greenland at 61.57°N, 40.16°W. It was deposited as ZMUC P922698 (tissue/field JYP#1862). Coll./ID J.Y. Poulsen. The bottom and fishing depth was within 1454–1465 m and the bottom temperature was 3.45°C. This specimen was also caught during a routine survey with a non-closing Alfredo III trawl probing Greenland halibut abundances and the real catch depth uncertain. Barcode GLF319.

The specimens were X-rayed at the Australian Museum (AMS) and ZMUC and examined under stereomicroscopes. The morphological measurements were taken using a digital calliper to the nearest 0.1 mm and compared to all previous specimens recorded by Pietsch (1976, 1978, 2009) (Table 1).

The copepod parasite attached to *L. gracilispinis* (Fig. 1B) was photo-identified as a taxon within the Pennellidae family, possibly *Sarcotretes scopeli* Jungersen, 1911 by Geoffrey A. Boxshall at the British Museum of Natural History (BMNH).

RESULTS

Oneirodidae Gill, 1878

Leptacanthichthys Regan et Trewavas, 1932

Leptacanthichthys gracilispinis (Regan, 1925)

(Table 1, Fig. 1A–E)

Description. (Based on specimen ZMUC P922698): First radial shorter than second and pectoral-fin lobe long, narrow, longer than longest fin ray (dorsally positioned); short and broad suboperculum; pharyngobranchials II and III showing 8 long slender teeth; frontals relatively straight; sphenotic spines large, appearing vertical when viewed from anterior, with posterior slant when viewed from side; lower jaw broken at symphysis although small symphyseal spine present ventrally, larger knob present dorsally; maxillomandibular ligament 9.8 mm (15.8% SL); posterior part of lower jaw showing “*Leptacanthichthys*” configuration: long mandibular spine present, shorter quadrate spine and angular bone without distinct spine (Fig. 1); bases of mandibular and quadrate spines broken off left and right sides, however, spines still present although rotated compared to their correct positions; multiple teeth in lower jaw, highly variable in size, some fang-like and almost straight; fewer upper jaw teeth, much smaller, less variable in size, fang-like teeth absent; vertebral column strong and ossified; large neural spines present, anterior four particularly large; haemal spines present, anterior two large; pre-caudal vertebrae 3; caudal vertebrae 17; ribs, epipleurals and epineurals absent (Fig. 1C); caudal fin rays 9: 2 simple + 4 bifurcated + 3 simple; pterygiophore of illicium 3.2 mm (5.2% SL), wider than illicium, originating between anterior part of frontals; illicium slender, especially at midpoint, and flexible; esca with pigmented streak on dorsal margin

* <http://boldsystems.org>.

and single posterior compressed appendage containing no bioluminescent dark tissue (Fig. 1D). Reproductive state: Ovaries 6 mm in lengths, flaccid, suggesting spent or previous larger eggs present now gone; minute eggs present, largest 0.1 mm diameter in ovary walls along its entire length.

Microlophichthys Regan et Trewavas, 1932
Microlophichthys microlophus (Regan, 1925)
 (Table 1, Fig. 2A–E)

Description. (Based on specimen ZMUC P2395464): Sphenotic spines present, large symphysial spine present ventrally, no discernible spine dorsally on lower jaws; quadrate spine robust; opercle notched posteriorly; pectoral fin lobe large, approximately equal in length to fin rays or slightly shorter, that are situated somewhat dorsoposterior on lobe; dorsal fin in advance of anal-fin origin; teeth on lower jaws variable in size on whole jaw; teeth on premaxillaries in multiple rows, variable in size only in the anterior parts; skin smooth, although most skin lost on specimen; subopercle distally expanded and rounded; esca with appendage without bioluminescent tissue, red bulb under bioluminescent tissue in esca (Fig. 2D); stomach content white mass, items indiscernible. Morphological characters similar to those described by

Pietsch (2009) and not included for further descriptions (Table 1). Reproductive state: Ovaries 6.2 mm in lengths, red coloured, no eggs visible.

CoxI DNA barcoding sequences. In order to support a more comprehensive comparison of *CoxI* barcodes of ceratioids in general, I included here all subarctic Atlantic taxa that have barcoding data available. Ceratioid observations in the subarctic regions are based on the presently reported study, Pietsch (2009), Møller et al. (2010), Jónsson and Pálsson (2013), and the Global Biodiversity Information Facility (Anonymous 2012). All specimens included for the *CoxI* barcode in this study are metamorphosed females. A Kimura-2-Parameter (K2P) (Kimura 1980) model was employed for the analysis of the dataset consisting of 55 specimens including a total of 22 subarctic Atlantic distributed taxa (Table 2). The resulting topology is shown in Fig. 3. Three taxonomic results based on *CoxI* barcodes related to the genera *Dolopichthys*, *Cryptopsaras*, and *Caulophryne* are discussed below. Besides that, the *CoxI* barcoding results are not discussed further due to the inclusion of only subarctic Atlantic taxa and the focus on molecular taxonomy of ceratioids in the subarctic Atlantic.

The copepod parasite attached to *L. gracilispinis* (Fig. 1B) was photo-identified as a taxon, within the family

Table 1

Morphometric and meristic data of *Leptacanthichthys gracilispinis* and *Microlophichthys microlophus*, caught off south-western and south-eastern Greenland respectively during the presently reported study (ZMUC specimens), compared to specimens examined by Pietsch (2009)

Parameters	<i>Leptacanthichthys gracilispinis</i>			<i>Microlophichthys microlophus</i>		
	ZMUC P922698	Pietsch (2009) 24 specimens		ZMUC P2395464	Pietsch (2009) 94 specimens	
Distribution	64.04°N, 057.37°W		Circumglobal	61.57°N, 040.16°W		Circumglobal
	[mm]	[%SL]	Count	[mm]	[%SL]	Count
SL [mm]	62.1		22.0–56.0	112.7		11.5–112
Head	38.5		29.1–33.3	43.7		31.1–39.2
Lower jaw	27.4		26.7–34.1	29.2		34.9–46.8
Premaxillary	23.3		22.0–24.6	23.3		28.8–31.9
Illicium	20.0		19.2–24.1	9.7		8.3–10.3
Pectoral lobe	7.7		7.7–10.0			
Sphenotic spine	4.3		3.6–4.9			
Quadrate spine	4.8		2.8–4.5			
Mandibular spine	6.9		4.6–6.8			
Head depth	28.5		30.9–34.9	39.0		35.8–43.2
Dorsals	5		4–6 (5)	7		5–7
Anals	5		5–6 (5)	5		4–6 (5)
Pectorals	20		18–21 (21)	14		17–20
Caudals	9			9		9
Vertebrae ^U	22			22		
Dentition Vomer	5 + 5		3+3–6+6	5 + 5		4–12
Dentition Upper jaw	40		52–154	180 ^U		160–320
Dentition Lower jaw	70		44–106	100 ^T		100–180

ZMUC = Zoological Museum University of Copenhagen; SL = standard length of fish; numbers in parentheses are the most common meristic counts for the particular characters; ^Uvertebral counts include the posterior urostyle and the most anterior “half-vertebra” connecting the vertebral column to the cranium, ^Tjaw teeth counts are approximate as numerous small teeth are present.

Pennellidae, possibly *Sarcotretes scopeli* Jungersen, 1911 by Geoffrey A. Boxshall at the British Museum of Natural History (BMNH).

DISCUSSION

A few morphometric characters of the new subarctic record ZMUC P922698 (*Leptacanthichthys gracilispinis*) show values outside previously reported, such as the mandibular- and quadrate spine lengths (Table 1). However, morphometric values are generally close to the ranges noted by Pietsch (1978). Similarly, the distinct

illicium and esca show similar morphology to what has been reported for other specimens of *L. gracilispinis*: the illicium is very thin compared to other ceratioids and the esca have only one large appendage without bioluminescent tissue (Fig. 1E). A peculiar feature of *L. gracilispinis* is the long pectoral fin lobe showing the fin rays on the dorsal margin (Fig. 1E). This is a unique configuration of the pectoral fins and is only found in a small four-genera subgroup of dreamers in the family Oneirodidae (see Pietsch 1978): *L. gracilispinis*; *Puck pinnata* Pietsch, 1978; *Ctenochirichthys longimanus* Regan et Trewavas,

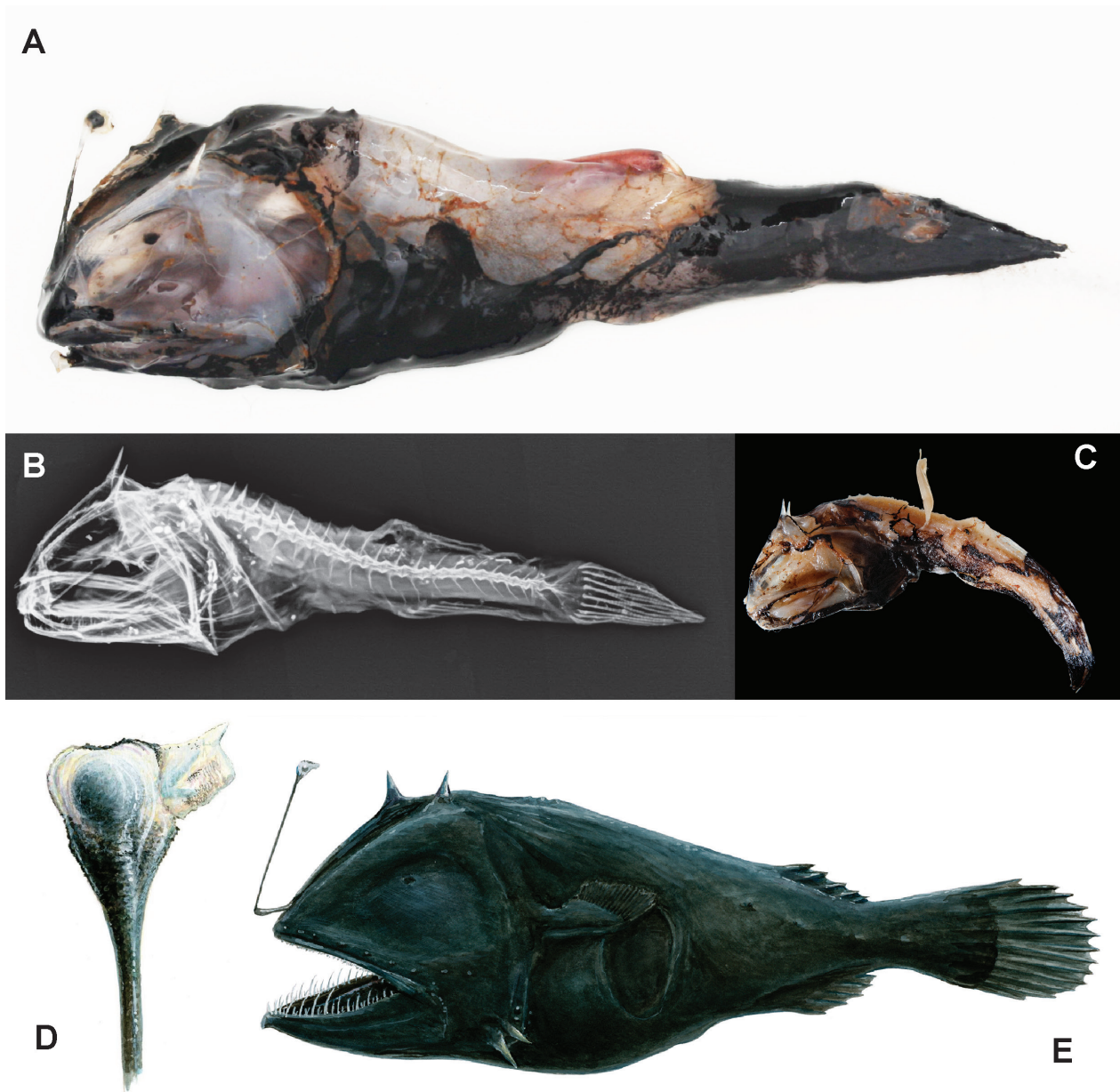


Fig. 1. *Leptacanthichthys gracilispinis* ZMUC P922698: (A) newly caught off south-western Greenland 2009; (B) digital radiograph image; (C) alcohol preserved; note the large mandibular (almost vertical) and quadrate (horizontal) spines designating *Leptacanthichthys* although base broken and both spines are rotated compared to their natural positions; a large copepod parasite can be seen on the freshly caught and the alcohol preserved specimen; (D) illustration of esca (Redrawn based on the Greenland specimen and based on R. Nielsen in Pietsch 2009); (E) illustration of the specimen; note the slender illicium on the specimen and the dark streak on the dorsal margin including a large flattened appendage containing no bioluminescent tissue on the esca

Table 2
Cox/ DNA barcoding data of subarctic Atlantic ceratioid (suborder Ceratioidei of Lophiiformes) taxa used in the presently reported study

Species	Museum	Field ID	BOLD	NCBI	Coordinates	Depth [m]	Region/date	Sampler/ identifier	Reference
Lophiidae									
<i>Lophius piscatorius</i>	ZMUC (unecat.)	JYP#8030	GLF092	LC455696	62.18°N, 40.49°W	615	SE Greenland 2008	J.Y. Poulsen	This study
<i>Lophius piscatorius</i>	MT02950	MT02950	BNSF529-12	KJ204993	60.37°N, 02.48°E	100	North Sea off Norway 2011	T. Kneibelsberger	Kneibelsberger et al. 2014
<i>Lophius americanus</i>	ARC 26420	06-764	SCAFB543-07	KC015569			Gulf of St. Lawrence, Canada	D. Archambault	McCusker et al. 2013
<i>Lophius americanus</i>			GBMTG293-16	AP004414					Miya et al. 2010
<i>Lophius budegassa</i>		MCFS06-074	FCFMT074-07	KJ098804	35.57°N, 15.27°E	250	Malta, Mediterranean, 2006	M. Dimech	Landi et al. 2014
<i>Lophius budegassa</i>		EU683980	GBGC8825-09	EU683980			Off Scotland	M.O. Sullivan	Espiñeira et al. 2008
Ceratiidae									
<i>Cerattias holboelli</i>	ZMUC (unecat.)	JYP#8473	GLF097	LC455698	63.29°N, 54.24°W	1130	SW Greenland 2008	J.Y. Poulsen	This study
<i>Cerattias holboelli</i>	ZMUB 21907	JYP#9855	GLF106	LC455681	65.38°N, 30.19°W	410	SE Greenland 2013	J.Y. Poulsen	This study
<i>Cerattias holboelli</i>	ZMUB (unecat.)	JYP#1531	GLF207	LC455682	62.03°N, 40.19°W	1408	SE Greenland 2014	J.Y. Poulsen	This study
<i>Cryptosararus cotesii</i>			GBMTG1715-16	AB282850			Off Shikoku Island, Japan		Miya et al. 2010
<i>Cryptosararus cotesii</i>	ZMUB 17873	ME-6992	MAECO417-09		49.20°N, 28.72°W		Mid-Atlantic Ridge 2004	MAR-ECO	Unpublished
Caulophryniidae									
<i>Caulophryne jordani</i>	ZMUC P922691	JYP#8155	GLF100	LC455691	65.49°N, 30.04°W	345	SE Greenland 2009	J.Y. Poulsen	This study
<i>Caulophryne jordani</i>	HUMZ 189336		GBMTG296-16	AP004417		739	Off Peru	T.W. Pietsch	Miya et al. 2003
<i>Caulophryne pelagica</i>	CBM-ZF 12209		GBMTG2488-16	AB282836				T.W. Pietsch	Miya et al. 2010
<i>Caulophryne pelagica</i>		ADC10-738	DSLGA439-10		30.33°S, 30.75°W	13	Off South Africa 2010	A.D. Connell	Unpublished
Himantolophidae									
<i>Himantolophus groenlandicus</i>	MNHN-2003-1066	BPS-0114	GBMTG1732-16	AB282840	56.45°N, 13.00°W	930	North Atlantic 2003	T.W. Pietsch	Miya et al. 2010
<i>Himantolophus albinares</i>	MCZ 138064	2004-055	HIAL GBMTG1727-16	AB282839	39.09°N, 72.46°W	1098	Atlantic U.S.		Miya et al. 2010
Oncirodidae									
<i>Chaenophryne draco</i>	ZMUC (unecat.)	JYP#1667	GLF315	LC455688	64.20°N, 57.23°W	813	SW Greenland 2015	J.S. Sorensen	This study
<i>Chaenophryne draco</i>	ZMUC P922696	JYP#8129	GLF247	LC455694	63.51°N, 57.02°W	1172	SW Greenland 2009	J.Y. Poulsen	This study
<i>Chaenophryne draco</i>	ZMUB (unecat.)	JYP#1591	GLF226	LC455683	65.01°N, 34.32°W	458	SE Greenland 2014	J.Y. Poulsen	This study
<i>Chaenophryne longiceps</i>	ZMUC P2394154	JYP#1653	GLF301	LC455687	64.48°N, 33.35°W	1426	SE Greenland 2015	J.Y. Poulsen	This study
<i>Dolopichthys karsteni</i>	ZMUB 16707	ME-7651	MAECO423-09		51.92°N, 30.42°W		Mid-Atlantic Ridge 2004	MAR-ECO	Unpublished
<i>Dolopichthys karsteni</i>	MCZ 165969	KUT 8149	UKFPBJ1167-08	KFP29827	39.76°N, 67.54°W	2477	George Bank, NW Atlantic 2006	K. Hartel	Unpublished
<i>Dolopichthys karsteni</i>	MNCN_ ICTIO 291.453		ACRAT007		47.80°N, 43.82°W	959	Flemish Cap 2017	R. Bañón	Unpublished
<i>Dolopichthys karsteni</i>	MNCN_ ICTIO 291.465		ACRAT019		45.03°N, 48.80°W	1001	Grand Banks 2015	R. Bañón	Unpublished
<i>Dolopichthys cf. karsteni</i>	ZMUC P922539	#7201	GLF268	LC455684	65.11°N, 56.32°W		SW Greenland 2004	P.R. Moller	This study
<i>Dolopichthys cf. karsteni</i>	ZMUC P922544	#8703	GLF270	LC455685	64.02°N, 56.10°W	784	SW Greenland 2005	S.W. Knudsen	This study

Table continues on next page.

Table 3 cont.

<i>Dolopichthys karsteni</i>	1490		DPND1530	27.46°N, 87.47°W	1500	Mexican Gulf 2015	DEEPEND	Unpublished
<i>Dolopichthys pullatus</i>	22862	G133	PS2654_G133	27.01°N, 90.00°W	1305	Mexican Gulf 2011		Unpublished
<i>Dolopichthys pullatus</i>		P41681	FNZ221-06			New Zealand		Unpublished
<i>Leptacanthichthys gracilispinus</i>	ZMUC P922698	JYP#8126	GLF140	64.04°N, 57.37°W	942	SW Greenland 2009	J.Y. Poulsen	This study
<i>Leptacanthichthys gracilispinus</i>	MNCN_ ICTIO 291466		ACRAT020	46.42°N, 46.22°W	859	Flemish Cap 2017	R. Bañón	Unpublished
<i>Lophodolos acanthognathus</i>	ZMUB 21443	JYP#10045	GLF027	65.12°N, 32.54°W	1324	SE Greenland 2012	J.Y. Poulsen	This study
<i>Lophodolos acanthognathus</i>	ZMUB 16719	ME-1269	MAECO463-09	42.81°N, 27.88°W		Mid-Atlantic Ridge 2004	MAR-ECO	Unpublished
<i>Microlophichthys microlophus</i>	ZMUC P2395464	JYP#1862	GLF319	61.57°N, 40.16°W	1454	SE Greenland 2017	J.Y. Poulsen	This study
<i>Microlophichthys microlophus</i>	MCZ 164214			39.97°N, 67.38°W	1640	Atlantic US		This study
<i>Microlophichthys microlophus</i>	ZMUB 18902	ME-5707	MAECO487-09	42.79°N, 29.39°W		Mid-Atlantic Ridge 2004	MAR-ECO	Unpublished
<i>Microlophichthys microlophus</i>	20576	G051	PS1310-G051	27.94°N, 88.59°W	1448	Mexican Gulf 2011	DEEPEND	Unpublished
<i>Oneirodes cf. macrosteus</i>	ZMUB 23271	JYP#1642	GLF290	65.XX°N, 39.52°W	1311	SE Greenland 2015	J.Y. Poulsen	This study
<i>Oneirodes cf. macrosteus</i>	ZMUC P922695	JYP#8128	GLF139	63.52°N, 56.47°W	1088	SW Greenland 2009	J.Y. Poulsen	This study
<i>Oneirodes cf. eschrichtii</i>	CSIRO 7343-02		BW-A12221					Unpublished
<i>Oneirodes cf. eschrichtii</i>	CSIRO 7344-01		BW-A12222					Unpublished
<i>Oneirodes cf. eschrichtii</i>	ZMUC P922758	JYP#8140	GLF080			SE Greenland	J.Y. Poulsen	This study
Gigantactinidae								
<i>Gigantactis vanhoeffeni</i>	ZMUC P239358	JYP#1888	GLF328	64.15°N, 54.57°W	1020	SW Greenland 2017	J.Y. Poulsen	This study
<i>Gigantactis vanhoeffeni</i>	UW 047213		GBMTG1731-16	39.09°N, 72.46°W	1098	Atlantic US	E.O. Wiley	Miya et al. 2010
Linophryinidae								
<i>Haplophryne mollis</i>	ZMUC (uncat.)	JYP#1669	GLF327	63.16°N, 54.38°W	1315	SW Greenland 2015	J.S. Sorensen	This study
<i>Haplophryne mollis</i>	MNHN 2004 0811	NC-045	GBMTG1729-16					Miya et al. 2010
<i>Linophryne bicornis</i>	ZMUC P922693	JYP#8131	GLF096	63.07°N, 54.04°W	1422	SW Greenland 2009	J.Y. Poulsen	This study
<i>Linophryne bicornis</i>			ANGBF021-12					Miya et al. 2010
<i>Linophryne brevibarbata</i>		DPND2645	PS2749-G184			Gulf of Mexico	DEEPEND	Unpublished
<i>Linophryne pennibarbata</i>	14695	DPND2647-17	PS0315-T-053	27.66°N, 88.41°W	339	Gulf of Mexico 2010	DEEPEND	Unpublished
Melanocetidae								
<i>Melanocetus johnsonii</i>	ZMUC (uncat.)	JYP#8474	GLF098	64.32°N, 56.09°W		SW Greenland 2008	J.Y. Poulsen	This study
<i>Melanocetus johnsonii</i>	HUMZ 185908		GBMTG1728-16		976	Off Peru		Miya et al. 2010
<i>Melanocetus murrayi</i>	ASIZP0914893		GBMINI20376-17			Taiwan		Chang et al. 2016
<i>Melanocetus murrayi</i>			GBMTG297-16		AP004418			Miya et al. 2003

The table contains only valid names of fishes, which may sometimes differ from names listed in individual papers; the *Cox1* DNA sequences were either determined for the presently reported study (GLF records), downloaded from public accessible BOLD barcoding projects, or granted use from unpublished barcoding projects; metadata included if known; the taxonomic identification of ceratioids is difficult, hence the identifiers are included for specimens if known.

1932; and *Chirophryne xenolophus* Regan et Trewavas, 1932. The specimen observed off Greenland shows 100% *Cox1* DNA sequence similarity to a specimen from the Flemish Cap (table 2 and fig. 3 of Bañón et al. 2019). The *L. gracilispinis* shows an uncorrected DNA sequence distance of 97% to several species within the Oneirodidae (data not shown), supporting a close association of long-pectoralated dreamers within this family as already noted from morphology (Pietsch 1974, 1978, Pietsch and Orr 2007) and mitogenomic data (Miya et al. 2010). A currently unresolved phylogenetic relation of the long-pectoralated genus *Puck* to *Thaumatichthys* as found by Miya et al. (2010) needs verification with additional taxa. The latter study also found multiple non-coding regions in the mitogenomes of oneirodids—characters proved very

useful in elucidating phylogenetic relation (Poulsen et al. 2013). New unpublished mitogenomic data (J.Y. Poulsen data, data not shown) confirms this feature in some oneirodids.

The new subarctic record of *Microlophichthys microlophus* off south-eastern Greenland shows most characters within the ranges noted by Pietsch (2009) and are therefore not given much discussion. However, head length and measurements of the jaws fall outside the ranges noted in Pietsch (2009; table 1, fig. 2). The Greenland specimen is relatively large compared to previous observations (Table 1) and the small differences could be due to allometric growth changes. The *Cox1* barcode shows the Greenland specimen to have 100% DNA sequence similarity to specimens from the Mid-

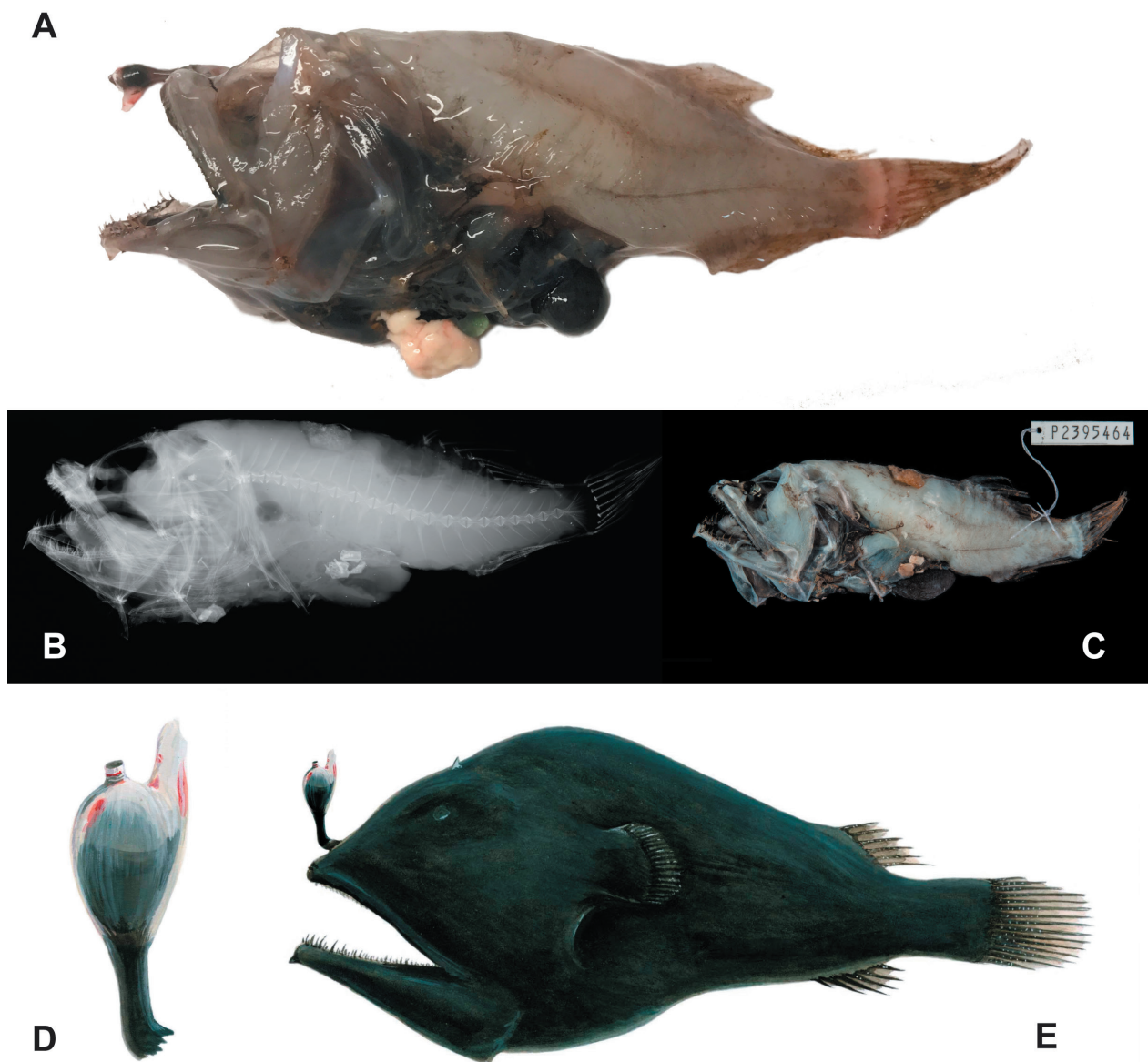


Fig. 2. *Microlophichthys microlophus* ZMUC P922698: (A) newly caught off south-eastern Greenland 2017; (B) digital radiograph image; (C) alcohol preserved; (D) illustration of esca; redrawn based on the Greenland specimen and based on Bertelsen (1951; cited by Pietsch 2009); (E) illustration of the specimen; note the short illicium and many minute teeth in the jaws

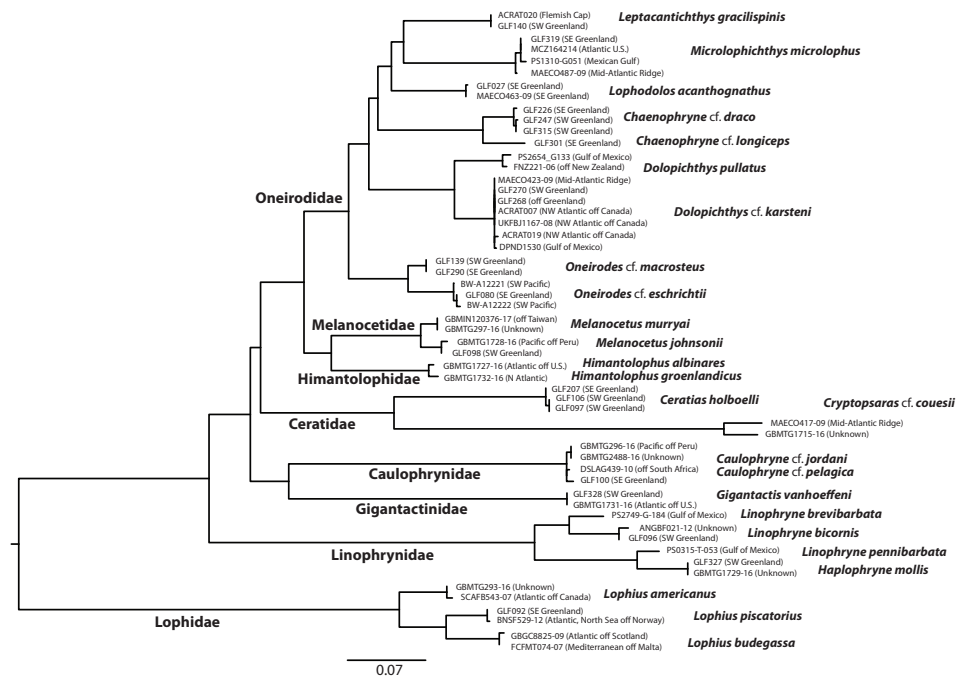


Fig. 3. K2P topology of subarctic Atlantic ceratioids based on the *CoxI* barcoding DNA sequences; three species of *Lophius* were employed as the operational outgroup; all subarctic Atlantic species in the suborder Ceratioidei with barcoding data available are included (many produced as part of the Greenland fishes barcoding program; Poulsen et al. 2018); note the one OTU in *Dolopichthys karsteni* and *Caulophryne* contrary to two OTUs in *Cryptopsaras cf. coesii*

Atlantic Ridge. My personal observations combined with barcoding data produced as part of the Greenland fishes barcoding project (Poulsen et al. 2018), has shown that oneirodid identification (and hence onboard sampling of specimens) off Greenland problematic for an extensive period of time. The two new records presented in this study are possible examples of such past sampling and identification errors, and the word expatriate is trivial at best at the moment.

The new *L. gracilispinis* specimen off Greenland provides one of approximately 35 female specimens recorded, from both the Atlantic and Pacific (Anonymous 2012), and extends the distribution into the western subarctic Atlantic at 64°N close to the Arctic Circle. The most northern Atlantic record previously observed was caught during pelagic trawling during the MAR-ECO cruises in 2004 at 52.89°N, 030.59°W (ZMUB 16711) that also showed several more records from approximately 50°N (I. Byrkjedal, MAR-ECO data). Previously, *R/V Walter Herwig* fishing in 1982 at similar latitudes as the MAR-ECO cruises, has a record at 48.90°N, 027.48°W (ISH 619) measuring 60 mm (R. Thiel data). Expatriate specimens are often showing large body size (Poulsen 2015a), and even though the Greenland specimen is 62 mm SL and therefore relatively large compared to presently described material, *L. gracilispinis* can apparently grow to 103 mm SL (Pietsch 2009). However, a status as expatriate of *L. gracilispinis* in the subarctic Atlantic is by no means substantiated, as the pelagic deep-sea realm in this region is poorly known due to a variety of factors

(Bertelsen and Krefft 1965, Poulsen 2015b, Poulsen et al. 2018). The four long-pectored taxa show circumglobal distributions, although not observed in the Indian Ocean as yet (Pietsch 2009). *Leptacanthichthys gracilispinis* is the most commonly observed of the four long-pectoral anglerfishes and indications are that it is widely distributed in the North Atlantic. The new record of *M. microlophus* off Greenland is unsurprising as it is relatively common in all major oceans and the temperate Atlantic (Pietsch 2009).

Greenland waters are considered too cold for ceratioid reproduction, based on comprehensive data by Bertelsen (1951) and Pietsch (2009). However, several ceratioid species are regularly observed off south-western and south-eastern Greenland (J.Y. Poulsen, personal observation): *Ceratias holboelli* Krøyer, 1845; *Oneirodes eschrichtii* Lütken, 1871; *Oneirodes macrosteus* Pietsch, 1974; *Chaenophryne longiceps* Regan, 1925; *Lophodolos acanthognathus* Regan, 1925; and *Melanocetus johnsonii* Günther, 1864. The species *Linophryne coronata* Parr, 1927 appears to be more common off Iceland than Greenland (Bertelsen 1976, Bañón et al. 2006, Jónsson and Pálsson 2013), although this knowledge is based on few specimens only. The remaining 31 species registered in the subarctic waters of the North Atlantic are, on the contrary, rare occurrences, known only from one or a few stray specimens (Møller et al. 2010, Jónsson and Pálsson 2013). In fact, 2009 witnessed yet another rare ceratioid specimen off south-western Greenland, the sixth specimen of *Linophryne bicornis* Parr, 1927 known,

ZMUC P922693, Coll./ID J.Y. Poulsen, presented in Møller et al. (2010) with barcode GLF096 and caught at a bottom temperature of 3.64°C. *Leptacanthichthys gracilispinis*, *M. microlophus*, and *L. bicornis* are the only three new ceratioid records that have been observed in the region for over a decade, owing to an increased sampling and taxonomic effort onboard including integrative taxonomy. Yearly fluctuations in warm North Atlantic drift waters are potentially a factor concerning observations of ceratioids in this region (Gaemers and Poulsen 2017). The large volume pelagic deep-sea water masses off the Labrador Sea (south-western Greenland) and the Irminger Sea (south-eastern Greenland) remain poorly studied, and deep-sea pelagic fishing efforts would certainly result in many new discoveries in these regions considering that benthic distributions are continuously being extended (Poulsen et al. 2018) and new recent pelagic species discovered (Poulsen 2015b). Future fish records in these regions should elucidate the subarctic north-western eco-region as delimited by Sutton et al. (2017). Few ceratioid species with males attached (Pietsch 2009), such as, for example, *Linophryne lucifer* Collett, 1886 observed in 1967 by Jónsson (1967) in the Denmark Strait off south-eastern Greenland (Bertelsen 1976, 1986), have been observed north of the SPF. Free-living male ceratioids seem restricted to the tropical and subtropical zones between 40°N and 40°S (Bertelsen 1951, Pietsch 1974, 2009). No attached males or signs of previous attachment were found on the new records. The *L. gracilispinis* specimen caught off Greenland showed only tiny eggs present and clearly not close to reproducing at the time of capture. Contrary to the yearly observations of some ceratioid species off Greenland, these results support that reproduction is not taking place at these latitudes.

Online databases dedicated to taxonomic assignments of fish species based on barcoding DNA fragments have shown valuable in several respects concerning the distribution, morphology, taxonomy, and, as a consequence, the species diversity of fishes (Ward et al. 2009, Bañón et al. 2013, Barros-García et al. 2018). This study provides barcoding data of all ceratioid species sampled off Greenland for more than a decade and is intended to support comparisons for future discoveries. All records in the Greenland fishes barcoding project are freely available in BOLD (prefix GLF, Poulsen et al. 2018). However, the BOLD database should be used with great caution concerning *Cox1* ceratioid comparisons at present, as many species show almost identical DNA sequences indicating taxonomic identifications problematic. This is evident in, for example, the family Oneirodidae, a difficult group of fishes in which damage is often present in species-defining characters, and therefore difficult to identify. Future works using *Cox1* comparisons should provide and validate identifications and metadata associated with records used (Table 2). Although several ceratioid species recorded from the subarctic Atlantic is missing for their *Cox1* barcode in the presently reported study, many are rare and no tissues available, three taxonomic issues can be noted from the barcoding results in the presently reported

study (Fig. 3). Thorough morphological examinations of these three genera are beyond this study.

Two specimens identified as *Dolopichthys longicornis* Parr, 1927, the only species in the genus noted from the subarctic Atlantic (Møller et al. 2010, Jónsson and Pálsson 2013), show identical *Cox1* DNA sequences to several specimens identified as *Dolopichthys karsteni* Leipertz et Pietsch, 1987 that were collected from different Atlantic localities such as the Mid-Atlantic Ridge and Georges Bank (Table 2). However, Pietsch (2009) noted no presence of either species in the subarctic Atlantic. I leave these results as presented for future studies employing barcoding *Cox1* data and note that *Dolopichthys allector* Garman, 1899 from the North Atlantic Ocean was found to be closely related to *D. karsteni* (Fig. 3).

Cryptopsaras couesii Gill, 1883 show two relatively divergent Operational Taxonomic Units (OTUs) with an uncorrected distance of 5.4% (Kenchington et al. 2017). A total of 37 substitutions are observed in 688 base pairs of the *Cox1* fragment of which only two are not observed in the third codon positions (one synonymous C–T transition and one non-synonymous A–G transition in first codon positions). Seven of the 37 substitutions are transversions and three are non-synonymous. This variation between *C. couesii* specimens is reminiscent of substitutional variations observed in mid-water and deep-sea taxa delimited also from solid morphological characters (Byrkjedal et al. 2011, Poulsen et al. 2016). Unfortunately, no *Cox1* barcode of a *C. couesii* specimen off Greenland could be included, as this species has not been observed for more than a decade in the region, contrary to *Ceratias holboelli* Krøyer, 1845 that is caught annually (J.Y. Poulsen, personal observation, Fig. 3).

Caulophryne jordani Goode et Bean, 1996 and *Caulophryne pelagica* (Brauer, 1902) show highly similar DNA sequences, based on four specimens barcoded from the Atlantic and Pacific Oceans (Table 2). There is no structure in the few substitutions present indicating one OTU (Fig. 3). The few differences observed are mostly associated with fragment end-regions that could be caused by primer attachment artefacts in the replication process during the PCR amplification and sequencing. These primer attachment sites (usually about 20 base pairs in the end regions) are unfortunately not always removed before the *Cox1* DNA sequences are uploaded to the BOLD repository (J.Y. Poulsen, personal observation). This is an issue when comparing *Cox1* barcodes if not assessing the locations of the variations observed. Regardless, and in respect to other ceratioid OTUs (Fig. 3), the variation between *C. jordani* and *C. pelagica* is not supporting two distinct OTUs (see Miya et al. (2010) for specimen identifications).

A plethora of crustacean parasites are found in association with deep-sea fishes (Klimpel et al. 2001) although these types of modified parasites have only been observed once in ceratioid anglerfishes (Prokofiev 2014). Therefore, the copepod parasite attached to *L. gracilispinis* off Greenland is the second external parasite recorded in deep-sea anglerfishes (Fig. 1A, 1C) with a hydroid

(Hydrozoa) *Hydrichthys pietschi*, reported on the skin of *Ceratias holboelli* by Martin (1975). The parasite, presently reported from *L. gracilispinis*, is a copepod in the family Pennellidae and likely represents the species *Sarcotretes scopeli* (see G.A. Boxshall, personal comment) that has also been recorded from various other mid-water fishes. *Sarcotretes scopeli* is a common fish ectoparasite in the North Atlantic showing a low host-specificity (Boxshall 1998). It is reminiscent of the parasite shown by Prokofiev (2014) on *Chaenophryne melanorhabdus* Regan et Trewavas, 1932, although no identification was provided. Copepod parasites are regularly observed in deep-sea fishes (Boxshall 1998). The observation of only few copepod parasites observed in ceratioids is noteworthy (T. Pietsch, personal comment), although demersal species are observed much more frequent to be parasitized than meso- and bathypelagic species in the Arctic (Klimpel et al. 2006). Relatively large mesoparasitic copepod parasites (families Pennellidae and Sphyriidae), featuring an internal holdfast and the majority of the body protruding outside the fish (Piasecki and Avenant-Oldewage 2008), are common observations on various fishes off subarctic Greenland, across phylogenetically independent fish lineages (J.Y. Poulsen, personal observation).

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