NEW RECORDS OF LEPTACANTHICHTHYS GRACILISPINIS AND MICROLOPHICHTHYS MICROLOPHUS (ACTINOPTERYGI: 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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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 expatriates 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 (Bahon 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 oneirodidae 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 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.

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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.

**Cox1 DNA barcoding sequences.** In order to support a more comprehensive comparison of _Cox1_ 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), Möller et al. (2010), Jónsson and Pálsson (2013), and the Global Biodiversity Information Facility (Anonymous 2012). All specimens included for the _Cox1_ 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 _Cox1_ barcodes related to the genera _Dolopichthys_, _Cryptopsaras_, and _Caulophryne_ are discussed below. Besides that, the _Cox1_ 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 _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 | _Leptacanthichthys gracilispinis_ | _Microlophichthys microlophus_ |
|------------|----------------------------------|--------------------------------|
| Specification | 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 |
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| 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 | | |
| Quadrade 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 |
| Analts | 5 | 5–6 (5) | 5 | 4–6 (5) |
| Pectorals | 20 | 18–21 (21) | 14 | 17–20 |
| Caudals | 9 | 9 | | |
| Vertebral | 22 | | 22 | |
| Dentition Vomer | 5 + 5 | 3+3–6+6 | 5 + 5 | 4–12 |
| Dentition Upper jaw | 40 | 52–154 | 180[1] | 160–320 |
| Dentition Lower jaw | 70 | 44–106 | 100[1] | 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; [1]vertebral counts include the posterior urostyle and the most anterior “half-vertebra” connecting the vertebral column to the cranium, [1]jaw 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.

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**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

*Cox1* 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                 |                      |          |           |            |                         |           |                              |                   |                        |
| Lophius piscatorius       | ZMUC (uncat.)        | JYP#8030 | GLF092    | GC455696   | 62.18°N, 40.49°W       | 615       | SE Greenland 2008            | J.Y. Poulsen       | This study             |
| Lophius piscatorius       | MT02950              | MT02950  | BNSF529-12| KJ04939    | 60.37°N, 02.48°E       | 100       | North Sea off Norway 2011    | T. Knebelsberger    | Knebelsberger et al. 2014 |
| Lophius americanus        | ARC 26420            | 06-764   | SCABFB543-07 | KC015569  | Gulf of St. Lawrence, Canada | D. Archambault | McCusker et al. 2013  |
| Lophius budegassa         | MCFS06-074           | FCFMT074-07 | KJ098804 | 35.57°N, 15.27°E | 250 | Malta, Mediterranean, 2006 | M. Dimech | Landi et al. 2014  |
| Lophius budegassa         | EU683980             | GBGC8825-09 | EU683980 |               |                           |           |                              |                   |                        |
| Ceratiidae                |                      |          |           |            |                         |           |                              |                   |                        |
| Ceratias holboelli        | ZMUC (uncat.)        | JYP#8473 | GLF097    | LC455698   | 63.29°N, 54.24°W       | 1130      | SW Greenland 2008            | J.Y. Poulsen       | This study             |
| Ceratias holboelli        | ZMUB 21907           | JYP#9855 | GLF106    | LC455681   | 65.38°N, 30.19°W       | 410       | SE Greenland 2013            | J.Y. Poulsen       | This study             |
| Ceratias holboelli        | ZMUB (uncat.)        | JYP#1531 | GLF207    | LC455682   | 62.03°N, 40.19°W       | 1408      | SE Greenland 2013            | J.Y. Poulsen       | This study             |
| Cryptopsaras couesii      | GBMTG1715-16         | AB282850 |           |            |                         |           | Off Shikoku Island, Japan    | Miya et al. 2010  |                        |
| Cryptopsaras couesii      | ZMUB 17873           | ME-6992  | MAECO417-09 | 49.20°N, 28.72°W | Mid-Atlantic Ridge 2004 | MAR-ECO | Unpublished                   |                   |                        |
| Caulophrynidae            |                      |          |           |            |                         |           |                              |                   |                        |
| Caulophryne jordani       | ZMUC P922691         | JYP#8155 | GLF100    | LC455691   | 65.49°N, 30.04°W       | 345       | SE Greenland 2009            | J.Y. Poulsen       | This study             |
| Caulophryne jordani       | HUMZ 189336          | GBMTG296-16 | AP004417 | 739 | Off Peru            | T.W. Pietsch | Miya et al. 2003  |
| Caulophryne pelagica      | CBM-ZF 12209         | GBMTG2488-16 | GB282836 | 13 | Off South Africa 2010 | T.W. Pietsch | Miya et al. 2010  |
| Caulophryne pelagica      | ADC10-738            | DSLAG439-10 | 30.33°S, 30.75°W | 13 | Off South Africa 2010 | A.D. Connell | Unpublished                   |                   |                        |
| Himantolophidae           |                      |          |           |            |                         |           |                              |                   |                        |
| Himantolophus groenlandicus | 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  |
| Himantolophus albinares   | MCZ 138064           | 2004-055_HAL | GBMTG1727-16 | AB282839 | 39.09°N, 72.46°W | 1098 | Atlantic U.S. | Miya et al. 2010  |                        |
| Oneirididae               |                      |          |           |            |                         |           |                              |                   |                        |
| Chaenophryne draco        | ZMUC (uncat.)        | JYP#1667 | GLF315    | LC455688   | 64.20°N, 57.23°W       | 813 | SW Greenland 2015            | J.S. Sorensen       | This study             |
| Chaenophryne draco        | ZMUC P922696         | JYP#8129 | GLF247    | LC455694   | 63.51°N, 57.02°W       | 1172      | SW Greenland 2009            | J.Y. Poulsen       | This study             |
| Chaenophryne draco        | ZMUB (uncat.)        | JYP#1591 | GLF226    | LC455683   | 65.01°N, 34.32°W       | 458       | SE Greenland 2014            | J.Y. Poulsen       | This study             |
| Chaenophryne longiceps    | ZMUC P2394154        | JYP#1653 | GLF301    | LC455687   | 64.48°N, 33.35°W       | 1426      | SE Greenland 2015            | J.Y. Poulsen       | This study             |
| Dolopichthys karsteni     | ZMUC 16707           | ME-7651  | MAECO423-09 | 51.92°N, 30.42°W | Mid-Atlantic Ridge 2004 | MAR-ECO | Unpublished                   | K. Hartel | Unpublished  |
| Dolopichthys karsteni     | MCZ 165969           | KUT 8149 | UKFB1167-08 | 39.76°N, 67.54°W | George Bank, NW Atlantic 2006 | Unpublished |                        |                   |                        |
| Dolopichthys karsteni     | MNCN_ICTIO 291.453   | ACRAT007 | GBMTG1732-16 | 47.80°N, 43.82°W | Falmouth Cap 2017 | R. Bañón | Unpublished                   |                    |                        |
| Dolopichthys karsteni     | MNCN_ICTIO 291.465   | ACRAT019 | GBMTG1727-16 | 45.03°N, 48.80°W | Grand Banks 2015 | R. Bañón | Unpublished                   |                    |                        |
| Dolopichthys cf. karsteni | ZMUC P922539         | #7201    | GLF268    | LC455684   | 65.11°N, 56.32°W       | 784       | SW Greenland 2004            | P.R. Moller        | This study             |
| Dolopichthys cf. karsteni | 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.

| Family           | Genus                  | Species                          | Code     | Location               | Collector | Year | Metadata | Source                  |
|------------------|------------------------|----------------------------------|----------|------------------------|-----------|------|----------|-------------------------|
| Dolopichthys     | karsteni               | 1490 Dolopichthys karsteni       | DPND1530 | 27.46°N, 87.47°W       | DEEPEND   | 2015 |          | Unpublished             |
| Dolopichthys     | pullatus               | 22862 Dolopichthys pullatus      | PS2654_G133 | 27.01°N, 90.00°W       | Mexico    | 2011 |          | Unpublished             |
| Dolopichthys     | pullatus               | 1490 Dolopichthys pullatus       | FN221-06 | New Zealand            |           |      |          | Unpublished             |
| Leptocanthichthys| gracilispinis          | ZMUC P922698 Leptocanthichthys gracilispinis | JYP18126 | 64.04°N, 57.37°W       | Mexican   | 2009 |          | J.Y. Poulsen This study |
| Lophodolos       | acanthognathus         | ZMUB 21443 Lophodolos acanthognathus | JYP10045 | 65.12°N, 32.54°W       | SE        | 2012 |          | J.Y. Poulsen This study |
| Lophodolos       | acanthognathus         | ZMUB 16719 Lophodolos acanthognathus | ME-1269  | 42.81°N, 27.88°W       | MAR-ECO   |      |          | Unpublished             |
| Microlophichthys | microphorus            | ZMUC P2 395464 Microlophichthys microphorus | JYP1862  | 61.57°N, 40.16°W       | SE        | 2017 |          | J.Y. Poulsen This study |
| Microlophichthys | microphorus            | ZMUC 18902 Microlophichthys microphorus | ME-5707  | 42.79°N, 29.39°W       | Mid-Atlantic Ridge | 2004 |          | MAR-ECO Unpublished     |
| Microlophichthys | microphorus            | 20576 Microlophichthys microphorus | G051     | 27.94°N, 88.59°W       | Mexican    | 2011 |          | DEEPEND Unpublished     |
| Oneirodes        | cf. macrosteus         | ZMUB 23271 Oneirodes cf. macrosteus | JYP1642  | 65.12°N, 32.54°W       | MAR-ECO   |      |          | J.Y. Poulsen This study |
| Oneirodes        | cf. macrosteus         | ZMUC P922695 Oneirodes cf. macrosteus | JYP1828  | 63.52°N, 56.47°W       | SW        | 2009 |          | J.Y. Poulsen This study |
| Oneirodes        | cf. eschrichtii        | CSIRO 7 34 3 0 Oneirodes cf. eschrichtii | BW-1 22 2 1 |                          | SW        | 2009 |          | Unpublished             |
| Oneirodes        | cf. eschrichtii        | CSIRO 7 34 4 0 Oneirodes cf. eschrichtii | BW-1 22 2 2 |                          | SW        | 2009 |          | Unpublished             |
| Oneirodes        | cf. eschrichtii        | ZMUC P922758 Oneirodes cf. eschrichtii | JYP1840  | 61.57°N, 40.16°W       | SE        | 2017 |          | J.Y. Poulsen This study |
| Gigantactinidae  | vanhoeffeni            | ZMUC P 2 39358 Gigantactinidae vanhoeffeni | JYP1888  | 64.15°N, 54.57°W       | SW        | 2017 |          | J.Y. Poulsen This study |
| Gigantactinidae  | vanhoeffeni            | UW 047213 Gigantactinidae vanhoeffeni | GBMTG1731-16 | 39.09°N, 72.46°W       | Atlantic  | 2010 |          | E.O. Wiley Miya et al. 2010 |
| Linophrynidae    | mollis                 | ZMUC (uncat.) Linophrynidae mollis | JYP1669  | 63.16°N, 54.38°W       | SW        | 2015 |          | J.S. Sorensen This study |
| Linophrynidae    | mollis                 | MNHN 2004 0811 Linophrynidae mollis | NC-045   | 63.16°N, 54.38°W       | SW        | 2015 |          | Myia et al. 2010        |
| Linophrynidae    | bicornis               | ZMUC P922693 Linophrynidae bicornis | JYP1831  | 63.07°N, 54.04°W       | SW        | 2009 |          | J.Y. Poulsen This study |
| Linophrynidae    | bicornis               | ZMUC P922693 Linophrynidae bicornis | JYP1831  | 63.07°N, 54.04°W       | SW        | 2009 |          | J.Y. Poulsen This study |
| Linophrynidae    | brevibarbata           | DPN2645 Linophrynidae brevibarbata | PS2749-G184 | 27.66°N, 88.41°W       | Gulf of Mexico | 2010 |          | DEEPEND Unpublished     |
| Linophrynidae    | pennibarbata           | DPN2647-17 Linophrynidae pennibarbata | PS0315-T-053 | 27.66°N, 88.41°W       | Gulf of Mexico | 2010 |          | DEEPEND Unpublished     |
| Melanocetidae    | johnsonii              | ZMUC (uncat.) Melanocetida johnsonii | JYP1847  | 64.32°N, 56.09°W       | SW        | 2008 |          | J.Y. Poulsen This study |
| Melanocetidae    | johnsonii              | HUMZ 18 5308 Melanocetida johnsonii | GTMTG1728-16 | 976 Off Peru            | SW        | 2008 |          | Myia et al. 2010        |
| Melanocetidae    | murrayi                | ASIZP0914893 Melanocetida murrayi | GBMIN120376-17 |              | Taiwan   | Chang et al. 2016 |
| Melanocetidae    | murrayi                | GBMTG297-16 Melanocetida murrayi | GBMTG297-16 | 976 Off Peru            | SW        | 2008 |          | Myia et al. 2003        |

The table contains only valid names of fishes, which may sometimes differ for 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 longpectoraled 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 longpectoraled 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-

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**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 (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. couesi.

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-pectoral 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 Kroyer, 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 corona Parr, 1927 appears to be more common off Iceland than Greenland (Bertelsen 1976, Bahón 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,
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specimens is reminiscent of those observed by Collett, 1886, and documented in Goode et Bean, 1996. 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 have been 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), and, for example, Linophryne lucifer Collett, 1886, 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 1976; Bertelsen 1986), have been observed south of the SPF. Most male ceratioids are free-living, although these types of modified parasites have only been observed in association with deep-sea fishes (Klimpel et al. 2001).

Regardless, and in respect to other ceratioid OTUs (Fig. 3), the variation between COI barcode sequences 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 COI 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 COI 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 COI 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 COI 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 COI 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 (Brykjedal et al. 2011, Poulsen et al. 2016). Unfortunately, no COI 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 Krayen, 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 COI DNA sequences are uploaded to the BOLD repository (J.Y. Poulsen, personal observation). This is an issue when comparing COI 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 Miyata 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 *Chaeonophryne 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 (Piascecki 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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