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## Lost in the North: The first record of *Diretmichthys parini* (Post and Quéro, 1981) in the northern North Sea

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### Abstract :

In June 2015, an individual of *Diretmichthys parini* (Post and Quéro, 1981) was trawled at 530 m depth, in the North Sea off Norway and donated to research. This capture, the first for this species in the North Sea was the northernmost recorded so far, and provided an opportunity to document some aspects of the biology and ecology of this data-poor species. This individual was a female, 331 mm total length of 33 years old, with low mercury content in muscle and liver (~ 0.2 µg g<sup>-1</sup> wet mass). Stable isotope ratios (C and N) in muscle and liver were consistent with the planktonic diet expected for this species. The capture of this fish at the northern latitude known so far would be consistent with the extension of the home range and the latitudinal shift hypothesized for this species in the 1990's.

**Keywords :** *Diretmichthys parini*, Diet, North Sea, Latitudinal shift, Mercury

Opportunistic captures by fishermen can provide useful insight about the ecology and life history traits of rare species and document their occurrence in unexpected locations (e. g. Arronte and Heredia, 2006; Lyons et al., 2015). In the present paper, we used the catch of a specimen of *Diretmichthys parini* (Beryciformes: Diretmidae) by a bottom trawler operating in the North Sea to document some aspects of the biology and ecology of this unknown species. Most records are located the Pacific and Indian oceans, at tropical and subtropical latitudes but never at latitudes higher than 59° and never in the North Sea (GBIF, 2016; Fig. 1). This species is thus considered to have affinity for warm waters (Quero et al., 1998). Like all species of the beryciformes order, *D. parini* is a bathypelagic species, classically caught between 500 and 2000 meters depth (Maurin and Quero, 1981; Kotlyar, 2002; Arronte and Heredia, 2006; GBIF, 2016; Tab. S1). This species has a pelagic larval and juvenile phase and seems to belong to a pelagic trophic web, since it is considered a plankton eater (Paxton, 1999), even if it should be confirmed by dedicated analyses.

In June 2015, a bottom trawler operating off Norway (62°15N, 01°03 N; 530 m depth) captured a fish of an unknown species. Specimen was stored frozen on-board. The fish was then donated to Ifremer institute for identification and analyses.

Fish was determined as *Diretmichthys parini* based on external morphology (Fig. 2) following reference documents (Post and Quero, 1981; Maurin and Quero, 1981). Several morphological parameters were measured to the nearest mm: total, standard and fork lengths, body width, mouth opening and eye diameter. Body width was measured with a caliper placed upon both opercula. Mouth opening was measured with a standard cone the diameter of which gradually increases by 1 mm. Fish was weighed (total and eviscerated masses, to the nearest 0.01 g). A sample of muscle was collected for stable isotope and mercury (Hg) analysis. All dissection steps were performed with special care, in order to maintain the morphological integrity of the specimen and to include it in the collection of the French Museum National d'Histoire Naturelle (collection number MNHN-IC 2016-0022).

Digestive tract (oesophagus to anus) was dissected and measured (total length, to the nearest mm). Intestine was not considered afterwards. Stomach was weighed before and after the removal of its content for diet analysis. Fullness index was visually evaluated. Sex and maturity status were determined by a macroscopical observation of the gonads that were weighed. Liver was also dissected, weighed and collected for stable isotope and Hg analysis. Total mercury (hereafter Hg) concentration in muscle and liver was determined by a semi-automated atomic absorption spectrophotometer (AMA-254, Altec Ltd., Praha, Czech Republic) in three steps following the protocol previously used (see Cresson et al., 2014, 2015 for details about the analytical procedure). Briefly, the sample is burnt and mercury is volatilized, then captured by a gold trap and swept into the flow cell by heating (800°C) the trap. Hg content is determined by spectrophotometric atomic absorption. Each sample was analysed twice. The accuracy of the analyses is assessed with a standard certified material (DORM-4, National Research Council of Canada). Measured values were within the confidence limits of certified material (measured value: 0.416 µg g<sup>-1</sup>; certified values: 0.41 ± 0.055 µg g<sup>-1</sup>). C and N stable isotope ratios were measured with a continuous flow mass spectrometer (Delta V Advantage, Thermo Scientific) interfaced to a NC2500 elemental analyser. Results are expressed with the classical δ notation  $\delta X = \left( \frac{R_{sample}}{R_{standard}} - 1 \right) \times 10^3$ , where X is <sup>13</sup>C or <sup>15</sup>N and R the isotopic ratio <sup>13</sup>C/<sup>12</sup>C or <sup>15</sup>N/<sup>14</sup>N, respectively). Standards were V-PDB for carbon and atmospheric N<sub>2</sub> for nitrogen. To ensure the accuracy of the instrument, an in-house mink standard is analysed every ten sample, with standard deviation of 0.12 ‰ for δ<sup>15</sup>N and 0.08 ‰ for δ<sup>13</sup>C. Each sample (liver and muscle) was analysed once.

C:N ratios were calculated from the %C and %N measured with the elemental analyser. High C:N ratios (> 4) reflect a high lipid content, a potential bias of δ<sup>13</sup>C measurement (Post et al., 2007; Hoffman and Sutton, 2010). Carbon isotopic ratios measured were thus normalized to correct for the effect of high lipid content, following the protocol specifically developed for deep fish by Hoffman and Sutton (2010).

Sagittal otoliths were extracted from the cranial cavity to determine fish age, using transverse section (TS). The right sagittal otolith was used for morphometric measurement and age estimation. Otolith was then embedded in epoxy resin and TS were prepared from a precision saw. Two transverse sections were examined using 50 x magnification connected to a video camera and an image-analysis system (TNPC software, [www.tnpc.fr](http://www.tnpc.fr)). Increments were counted following the ventral otolith *radius* from the *nucleus* to the otolith edge. It was assumed that one annular growth increment consisted of one opaque and one translucent band by taking account of the presence of split increment.

All morphological measurements are detailed in Table I, and meristic details in Table II. This individual was a 331 mm long (total length) female acquiring sexual maturity (IIA sexual stage). Gonads represented ~1% of the eviscerated body mass. To our knowledge, sex of the sampled individuals was only investigated in two other studies that observed males (Kotlyar, 2002; Arronte and Heredia, 2006). Liver weighed 24.15 g, *i.e.* 3.3 % of the eviscerated body mass.

The collection of this sample provided an useful opportunity to question the trophic ecology of this species, that is considered plankton-eater (Paxton, 1999) but without actual results to support this assumption. Unfortunately, the stomach of this individual was empty, as denoted by the low mass difference between full and emptied stomach. Emptiness of the stomach was previously observed for one other *D. parini* sample (Arronte and Heredia, 2006). Stomach content analysis suffers from drawbacks for deep species, notably since stomach is commonly devaginated due to rapid pressure change and feeding is sporadic (Drazen and Haedrich, 2012). Stable isotope ratios measured for this individual (muscle  $\delta^{13}\text{C} = -23.97 \text{ ‰}$ ,  $\delta^{15}\text{N} = 12.33 \text{ ‰}$ ; liver:  $\delta^{13}\text{C} = -24.57 \text{ ‰}$ ,  $\delta^{15}\text{N} = 11.79 \text{ ‰}$ ) can thus provide some information about this specimen's diet. Carbon isotopic ratio is commonly used as a proxy of the main food source of an organism, since pelagic and benthic primary production differ in their  $\delta^{13}\text{C}$  values. But the high lipid content of both samples, confirmed by the high C:N ratios measured (14.7 for muscle, 22.4 for liver) represent a large bias and preclude from the use of raw

$\delta^{13}\text{C}$  values. Mathematical correction for high lipid content resulted in 4.7 and 5.2 ‰ increases for muscle and liver respectively (muscle:  $\delta^{13}\text{C}_{\text{corrected}} = -19.27$  ‰, liver  $\delta^{13}\text{C}_{\text{corrected}} = -19.32$  ‰). In addition, the relative nature of stable isotopes - *i.e.* the fact that the ratio measured in a fish is dependent upon the ratio of the primary production at the base of the trophic web - preclude from inferring trophic position directly from isotopic ratios. Comparison with values measured for other species in the zone can nevertheless help addressing this question. In the area, Jennings and Cogan (2015) registered similar  $\delta^{13}\text{C}$  values for *Capros aper* ( $-19.72 \pm 0.82$  ‰) and *Trachurus trachurus* ( $-19.07 \pm 1.16$  ‰), both considered as pelagic species. This similarity may confirm the importance of pelagic organic matter sources in the food web this individual belongs to. In addition, comparison between liver and muscle is useful here for a data-poor species, since both tissues have different turnover times. Due to its high metabolic rate, liver is thought to reflect more rapidly changes in diet and can be used to track recent diet shift, if liver and muscle differ in their isotopic ratio (MacNeil et al., 2005; Guelinkx et al., 2007). This is particularly true for a deep species, with expected low metabolic activity (Drazen and Haedrich, 2012). The isotopic similarity seems to demonstrate that this individual had a rather constant diet throughout the year, and did not shift its diet recently. Regarding  $\delta^{15}\text{N}$ , used as a proxy of trophic level, ratios measured in liver and muscle were consistent with values recorded for plankton eating species like *Sardina pilchardus* ( $12.09 \pm 1.10$  ‰) or *Sprattus sprattus* ( $12.82 \pm 1.50$  ‰) in this area (Jennings and Cogan, 2015). The slightly lower value measured in liver may reflect a minor diet shift, but may also be linked with a seasonal variation of the isotopic baseline.

In addition, the low Hg content ( $0.29 \pm 0.00$   $\mu\text{g g}^{-1}$  wm for muscle,  $0.23 \pm 0.02$   $\mu\text{g g}^{-1}$  wm for liver) - unexpected for a deep fish - might be consistent with a low trophic position. Life history traits of deep species - low metabolism, low growth rate and long lifespan - as well as the fact that deep environments acts as a sink for contaminants, made deep species at risk for chemical contamination (Cronin et al., 1998; Cresson et al., 2014). Once again, the lack of data concerning *D. parini* precludes from a direct comparison of contamination values, but previous studies reported Hg concentrations

in muscle ranging between 0.11 and 0.86  $\mu\text{g g}^{-1}$  for *Hoplostethus atlanticus* sampled in the mid-Atlantic ridge (Cronin et al., 1998; Julshamn et al., 2011). Interestingly, these authors observed that muscle Hg content of a 237 mm long individual was  $\sim 0.10 \mu\text{g g}^{-1}$  and ranged between 0.20 and 0.29  $\mu\text{g g}^{-1}$  for 350 mm-length individuals. The values measured in the present specimen appeared thus consistent with these trends. In addition, metallic contamination is not as hazardous in the northern part of the North Sea than in other marine environments (Robinson et al., in press), a trend that may also explain why Hg concentration was low in this individual.

Sagittal otoliths shape and size (Tab. 1, Fig. 3a) were consistent with previous reports, whatever the location (Post and Hecht, 1977; Kotlyar, 1988; Lombarte et al., 2006). In addition, to our knowledge, we provide the first calibrated image of *astericii* for this species (Fig. 3b). The large size of sagittal otoliths in Beryciformes was previously proposed as an adaptation to deep and dark environments to increase hearing abilities (Paxton, 1999, 2000). Age estimation based on otolith analysis revealed that this individual was 33 years old (Fig. 3c). To our knowledge, this is the first age estimation for this species. The value was consistent with results obtained for other long-lived deep species of the Beryciformes (Julshamn et al., 2011; Drazen and Haedrich, 2012). As an example, Smith et al (1995) estimated that orange roughy (*Hoplostethus atlanticus*) of 30-32 cm were 25 years old, which is rather similar with the result observed for the present specimen.

Changes in species distribution and extension of the habitat are commonly considered as one of the major effects of climate change for marine species with tropical affinities. Average water temperature in the North Sea increased by  $\sim 1^\circ\text{C}$  between 1997 and 2001, with major effects on species distribution (Perry et al., 2005). Regarding *D. parini*, this species was included in a list of tropical species observed northwards along European Atlantic coast as a result of water warming (Quero et al., 1997, 1998). These authors reported catches of this species off Scotland ( $55^\circ\text{N}$ ) in 1993 and then off Faeroe Island ( $59^\circ 5' \text{N}$ ) in 1996, suggesting this species may expand following a trajectory around British Isles. A similar expansion was proposed to explain the recent increase of hake

(*Merluccius merluccius*) in the warming North Sea (Cormon et al., 2014). These distribution shifts may also be driven by the current system in the zone, and notably the presence of the warm northern Atlantic current, that flow along British coasts, and diverged then in two channels, one of which flows along Norwegian coasts (Krause et al., 2003). Nevertheless, *D. parini* was not observed before in the North Sea, suggesting that it is not established but may migrate away from the boundary of its habitat, as a response to change in environmental conditions (Rose, 2005). This hypothesis was previously proposed to explain captures of Mediterranean species in the English Channel (Mahé et al., 2012, 2014).

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## Figures captions

Figure 1: Map of the world observation of *D. parini*, registered in the Global Biodiversity Information facility (GBIF, 2016- squares) and in other references non-included in this database and listed in Tab. S1 (triangles). The dot represents the sampling position of the individual used in the present study.

Fig. 2: Picture of the specimen of *Diretmichthys parini* sampled in the northern North Sea. The grid in the background is 1 cm square.

Fig. 3: Pictures of *D. parini* otoliths: (a) whole sagitta, (b) asterici and (c) transverse section of the sagittal otolith, with dots representing the annual growth increments. This individual was 33 years old.

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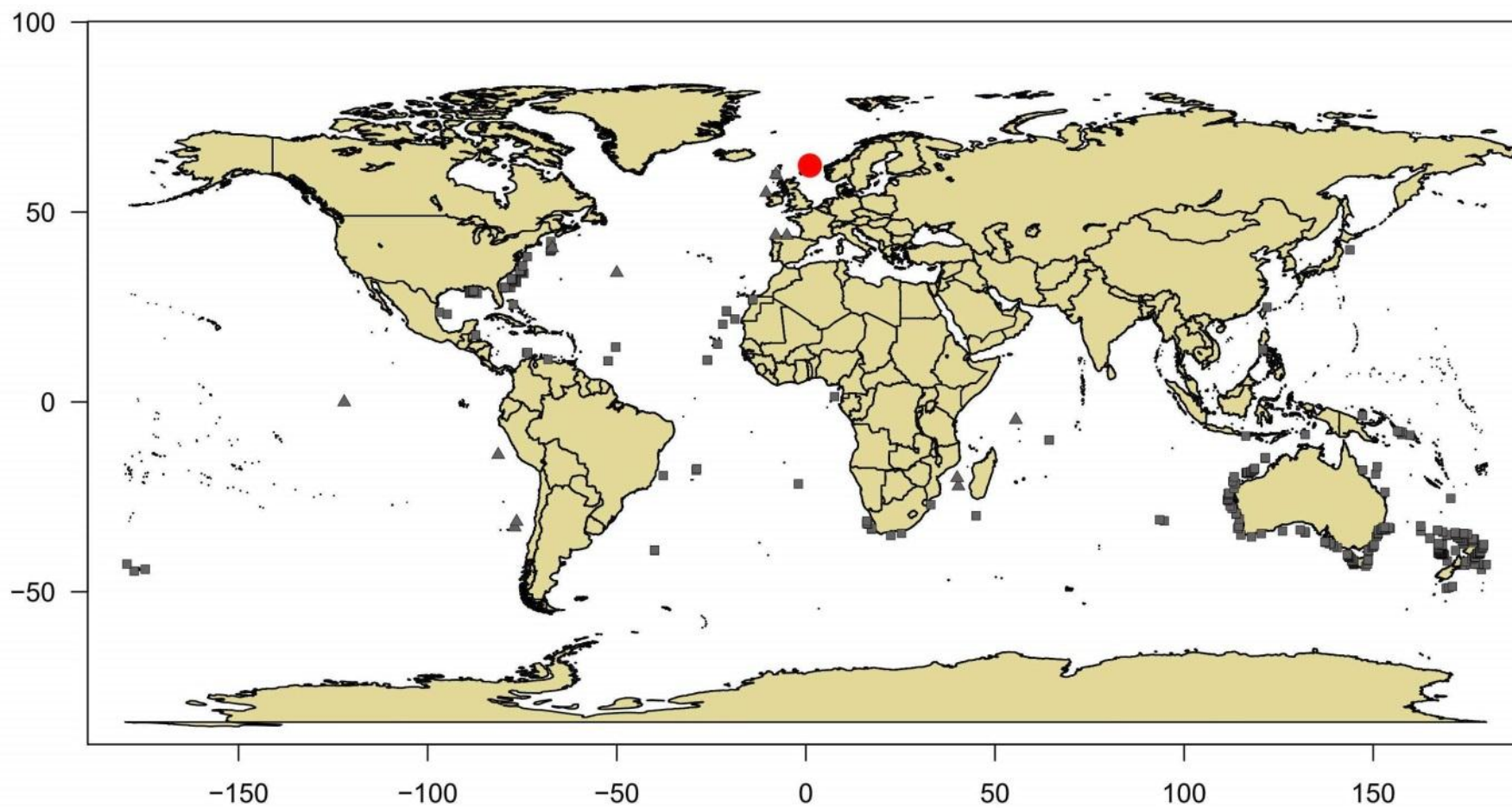


Fig.2: Picture of the specimen of *Diretmichthys parini* sampled in the northern North Sea. The grid in the background is 1 cm square.

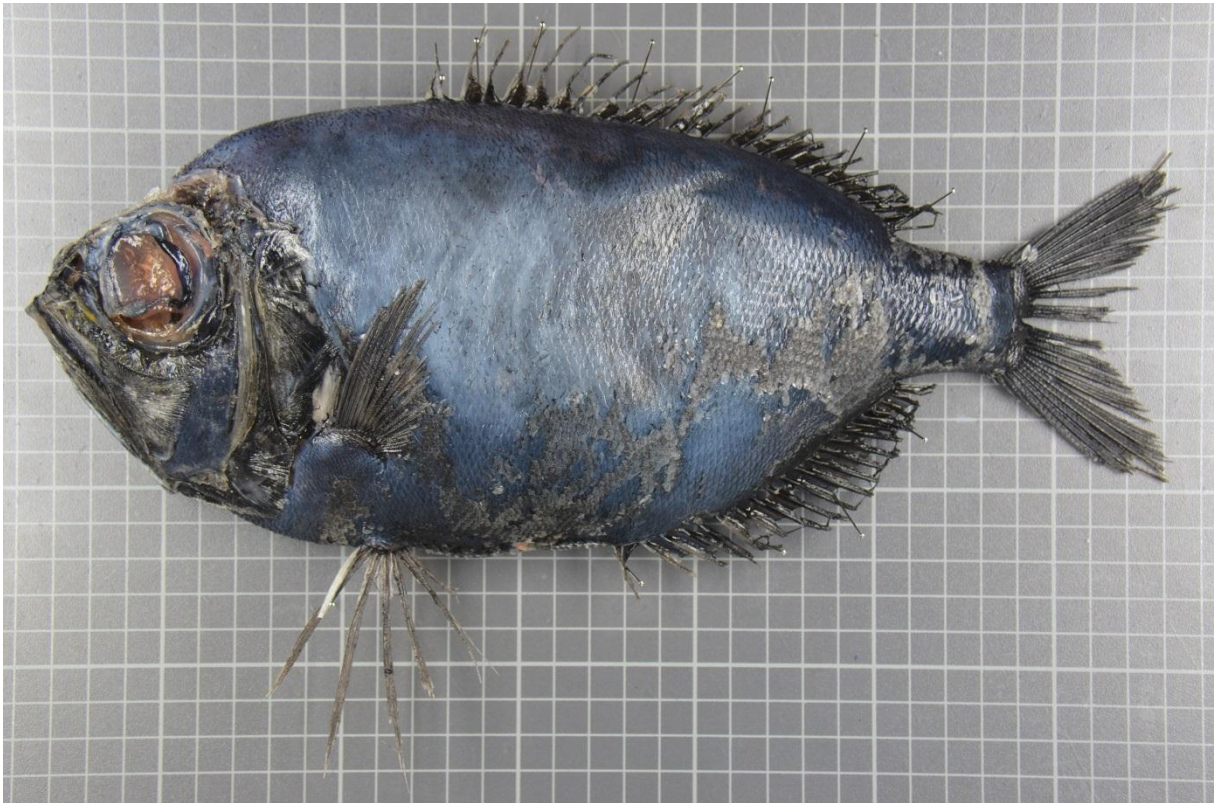


Fig. 3: Pictures of *D. parini* otoliths: (a) whole sagitta, (b) asterici and (c): transverse section of the sagittal otolith, with dots representing the annual growth increments. This individual was 33 years old.

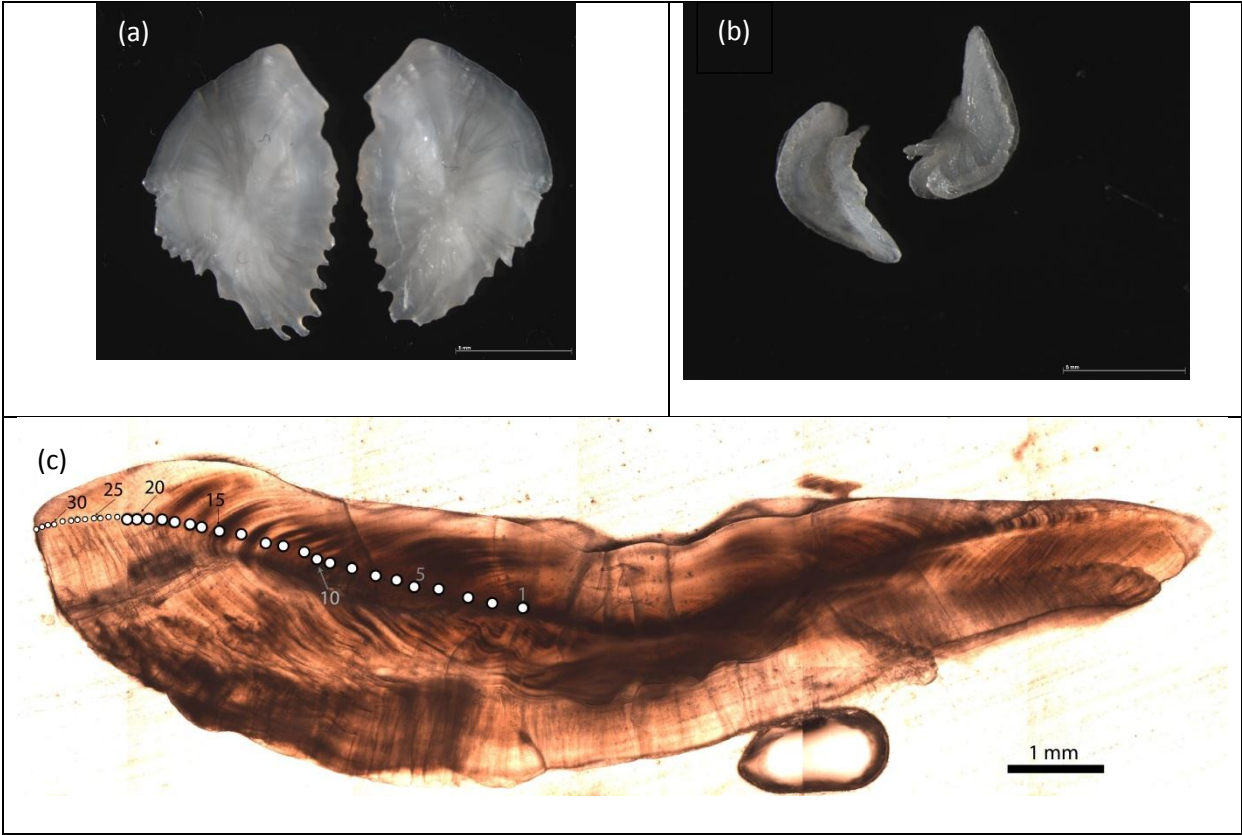


Table 1: Morphological measurements. All lengths are expressed in millimeters, all mass in grams.

Morphological measurements	Value
Total length	331
Fork length	304
Standard length	277
Body width	44
Mouth maximal opening	53
Eye diameter	37
Length of the digestive tract	135
Otolith length	12.40
Otolith width	8.51
Otolith perimeter	37.39
Otolith area (mm <sup>2</sup> )	74.51
Total mass	738.97
Eviscerated mass	666.21
Mass of the gonads	11.52
Mass of the liver	24.15
Mass of the stomach (full)	4.19
Mass of the stomach (empty)	3.98

Table 2: Number of soft rays of the different fins

Fin	Number of soft rays
Dorsal	27
Caudal	23
Anal	23
Pelvic	5+2
Pectoral	18

Table SI: List of the observation of *Diretmichthys parini* not included in the GBIF database. TL: total length; SL: Standard length; TM: total mass; nd: data not available

Ocean	Localization	GPS coordinates	Sampling date	Sampling mode	Depth	Sex	Morphological details	Reference
Atlantic	Slope off Georges Banks	40°30'N, 67°05'W	nd	nd	340	nd	47 mm <sup>a</sup>	Moore et al. 2003
Atlantic	Off Scotland - ICES Zone 6A	55°4'N, 10°31'W	Dec. 3, 1993	Bottom Trawler	nd	nd	TL: 350 mm	Quero et al. 1994, 1998
Atlantic	Faroe Island	59°54'N, 7°55'W	1996	Bottom Trawler	900	nd	265 mm <sup>a</sup>	Quero et al. 1994, 1998
Atlantic	Bay of Biscay , Asturian Coast, Spain	43°50'N, 5°2'W	Jan. 26, 2003	Bottom Trawler	637	nd	SL: 293 mm, TM: 865 g	Arronte & Heredia 2006
Atlantic	Bay of Biscay, western of Cabo Estaca de Bares	nd <sup>c</sup>	2006	Pair trawler	nd	nd	nd	Arronte unpubl. data, in Bañón et al. 2010
Atlantic	Sargasso Sea, Corner Rising	34 to 37°N , 47 to 53°W	1976 - 1995	Bottom Trawlers, research vessels	nd	nd	nd	Vinnichenko 1997
Indian	St Paul and Amsterdam Island	37° 37' 1.2" S; 77° 51' 0" E	July 3, 1996	Research vessel	730 -905	nd	nd	MNHN-IC-1998-0327 <sup>b</sup>
Indian	Seychelles Island	nd <sup>c</sup>	2001-2003	Fish remains in swordfish <i>Xiphias gladius</i> ' stomach contents	nd	nd	nd	Potier et al. 2007
Indian	Europa Island	22°20'S, 40°20'E	2002 - 2003	Fish remains in Sooty terns <i>Sterna fuscata</i> ' stomach content	nd	nd	larvae, reconstituted mass : 4 g	Jaquemet et al. 2008
Indian	Mozambique channel	nd <sup>c</sup>	Sept. – Oct. 2002, Nov.– Dec. 2008, Nov. 2009, April 2010	Research vessel, mid-water trawling; fish stomach contents	5 - 200	nd	nd	Potier et al. 2014
Pacific	Off Hawaii	0°03'S, 122°04'W	1978	nd	270	nd	nd	Kotlyar 1978



Pacific	at a submarine mount located between Juan Fernandez Archipelago and Valparaiso	31°31'S, 76°28'W	May 11, 2002	na	668	nd	SL: 216 mm	Pequeño & Olivera 2004
Pacific	Off Peru	13°54'S, 81°21'W	Sept. 7, 1985	Research vessel	200	Male	SL: 182 mm	Kotlyar 2002

a: no information about the type of length measured

b: information about these samples were gathered from MNHN database (<https://science.mnhn.fr/taxon/species/diretmoides/parini>)

c: actual sampling positions are not detailed in the publication but was inferred from the map provided in the publication to place the point in Fig 2 of the present paper.

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