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The first record of *Pseudanthobothrium hanseni* Baer, 1956 (Cestoda: Echeneibothriidae) in the White Sea

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ABSTRACT: Cestodes are fairly common in teleost fishes in the White Sea but have never been previously recorded there in elasmobranchs. We found seven individuals of the cestode *Pseudanthobothrium hanseni* in a single specimen of the starry ray *Amblyraja radiata* caught in the White Sea. Molecular analysis based on partial 28S rDNA sequence confirmed that our specimens belonged to this species. Their morphological and morphometric features were compared with the descriptions of *P. hanseni* available in the literature. Specimens of *P. hanseni* from the White Sea were smaller than those from the other areas, had fewer testes, and the vitelline follicles in their mature terminal proglottids did not reach the proglottid's posterior end. The reasons of these differences are unclear, but the low salinity of the White Sea may play a certain role. To sum up, in this study we provided the first record of a cestode in an elasmobranch in the White Sea and added a new point to the distribution of *P. hanseni*.

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KEY WORDS: tapeworm, skate, White Sea, 28S rDNA, helminth, Arctic.

Первая находка *Pseudanthobothrium hanseni* Baer, 1956 (Cestoda: Echeneibothriidae) в Белом море

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РЕЗЮМЕ: Цестоды являются одними из наиболее распространенных паразитов костистых рыб в Белом море, однако ранее ни разу не были найдены у хрящевых рыб этой акватории. В данной работе мы приводим сведения о первой находке семи особей *Pseudanthobothrium hanseni* в Белом море у ската *Amblyraja radiata.* Филогенетический анализ по 28S подтвердил видовую принадлежность наших цестод. Проведено сравнение их морфологических и морфометрических признаков с описаниями *P. hanseni*, имеющимися в литературе. Особи *P. hanseni* из Белого моря меньше, чем в других районах, имеют меньшее количество семенников, а желточные фолликулы в зрелых терминальных проглоттидах не доходят до заднего края проглоттиды. Причины этих различий неясны, но определенную роль в этом может играть пониженная соленость Белого моря. Таким образом, в данной работе мы приводим первые сведения о цестодах — паразитах хрящевых рыб в Белом море и новую точку распространения *P. hanseni*.

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КЛЮЧЕВЫЕ СЛОВА: цестоды, скаты, Белое море, 28S рДНК, гельминты, Арктика.

Introduction

Cestodes are broadly distributed helminths parasitizing as adults a broad range of hosts including various fishes. The fauna of cestodes parasitizing teleost fishes in the White Sea is studied fairly well. It is rather poor, comprising only a few common species such as *Diplocotyle olrikii* Krabbe, 1874, *Bothriocephalus scorpii* (Müller, 1776) Cooper, 1917 species complex, *Pyramicocephalus phocarum* (Fabricius, 1780) Monticelli, 1890, *Schistocephalus solidu*s (Müller, 1776) Steenstrup, 1857, *Proteocephalus filicollis* (Rudolphi, 1802) Weinland, 1858; *Eubothrium crassum* (Bloch, 1779) Nybelin, 1922 and *Proteocephalus longicollis* (Zeder, 1800) Nufer, 1905, as well as various cestode larvae of uncertain generic affiliation (Shulman, Shulman-Albova, 1953; Glukhova, 1956; Timofeeva, Marasaeva, 1984; Tchesunov *et al*., 2008). However, no cestodes from elasmobranchs have ever been reported in the White Sea.

Elasmobranchs are rare in the White Sea. Only two species of rays (the starry ray *Amblyraja radiata* (Donovan, 1808) and the thornback ray *Raja clavata* Linnaeus, 1758) and two species of sharks (the picked dogfish, *Squalus acanthias* Linnaeus, 1758 and the Greenland shark *Somniosus microcephalus* (Bloch et Schneider, 1801)) inhabit its cold low-salinity waters (Tchesunov *et al*., 2008). The salinity in the White Sea has sharp seasonal fluctuations, dropping below 15‰ in some shallow areas (Babkov, 1998).

In this paper we report a finding of the cestode *Pseudanthobothrium hanseni* Baer, 1956 in the starry ray *A. radiata* in the White Sea, thus adding a new point to the distribution of this parasite in the Arctic. We also provide morphometric data on our specimens and confirm their species affiliation with the help of molecular analysis based on the partial 28S rDNA sequence.

Material and Methods

A single specimen of *A. radiata* (female, total length 11.2 cm, disk width 8.8 cm) was caught in the Velikaya Salma strait (66°32′12″N; 33°14′60″E) near the White Sea Biological Station of Lomonosov Moscow State University on July 2, 2019, during trawling with a small bottom dredge. The ray was kept in an aquarium with running seawater for several days after capture and then was dissected using standard methods (Bykhovskaya-Pavlovskaya, 1985; Klimpel *et al*., 2019). Cestode specimens for further molecular analysis were fixed in 96% ethanol and stored at –18°C. The worms for morphological study were fixed in 70 ethanol, hydrated, stained with Harris's hematoxylin, differentiated in tap water, destained in ethanol, dehydrated, cleared in methyl salicylate, and finally mounted in Canada balsam (Jensen *et al*., 2011). All mounts of *P. hanseni* Baer, 1956 (7 vouchers: Reg. No. 1291.C.3m.v1 — whole-mounted mature worm; 1292.C.3m.v2 — whole-mounted mature worm; 1293.C.3m.v3-7 — 5 scolex and proglottids; 2 hologenophores:

1294.C.3m.v8 — separate strobila; 1295.C.3m.v9 — separate strobila) were deposited in the collection of marine parasites in the A.O. Kovalevsky Institute of Biology of the Southern Seas (IBSS), Sevastopol; sample data are available at http://marineparasites.org (Dmitrieva *et al*., 2015). Parasitological indices follow Bush et al. (1997).

DNA extraction, amplification, sequencing, alignment and phylogenetic analysis

The total DNA was extracted from 96% ethanol-fixed adult worm using Wizard SV Genomic DNA Purification System (Promega), as recommended by the manufacturer. The nuclear 28S rRNA gene was amplified using the polymerase chain reaction (PCR) with the primers ZX-1 (5'-ACCCGCTGAATTTAAGCATAT-3'), 1500R (5'-GCTATCCTGAGGGAAACTTCG-3'), LSU_300F (5'-CAAGTACCGTGAGGGAAAGTTG-3'), 1090F (5'-TGAAACACGGACCAAGG-3'), LSU_1200F (5'-CCCGAAAGATGGTGAACTATGC-3'), ECD2 (5'-CTTGGTCCGTGTTTCAAGACGGG-3'), which were described earlier (Waeschenbach, Littlewood, 2017). The initial PCR was performed in a total volume of 20 µl that contained 0.25 mM of each primer pair, 1 µl DNA in water, 1× Taq buffer, 1.25 mM dinucleotide triphosphates (dNTPs), 1.5 mM MgCl2 and 1 unit of Taq polymerase. The amplification was carried out by CJSC *Eurogen* (Moscow) with a 3-min denaturation hold at 94 °C, 40 cycles of 30 s at 94 °C, 30 s at 55 °C and 2 min at 72 °C, and a 10-min extension hold at 72 °C. Negative and positive controls were amplified using all primers. The PCR products were directly sequenced using the ABI Big Dye Terminator v.3.1 Cycle Sequencing Kit, as recommended by the manufacturer, with the PCR primers. The PCR products were analyzed by CJSC *Eurogen* (Moscow). The obtained sequence of *P. hanseni* has been submitted to GenBank (NSBI) with accession number MT777179.

Partial sequence of the 28S rRNA gene, used in our study to evaluate the phylogenetic connections of our specimen, were assembled using the Geneious ver. 10.0.5 software and aligned with sequences retrieved from the Genbank database (Table 1) using the ClustalW DNA weight matrix within the MEGA 10.0.5 software alignment explorer (Kumar *et al*., 2018). Phylogenetic analysis of the nucleotide sequences was undertaken using the maximum likelihood (ML) and Bayesian (BI) methods. Phylogenetic trees using ML and BI methods were reconstructed using the MEGA 10.0.5 (Kumar *et al*., 2018) and MrBayes v. 3.6.2 software (Ronquist, Huelsenbeck, 2003), respectively. Best nucleotide substitution model for the dataset was estimated using jModelTest version 0.1.1 software (Posada, 2008). In both methods, the general time-reversible model GTR+G+I was used based on the Aikake Information Criteria (AIC). A Bayesian algorithm was performed using the Markov chain Monte Carlo (MCMC) option with ngen = 10,000,000, nruns = 2, nchains = 4 and samplefreq = 100. The burnin values were 2,500,000 for the 'sump' and 'sumt' options. The robustness of the phylogenetic relationship was estimated using bootstrap analysis with 1000 replications (Felsenstein, 1985) for ML and with posterior probabilities for BI (Ronquist, Huelsenbeck, 2003). Outgroup choice follows Healy *et al*. (2009).

Results

Seven cestode specimens were found in the spiral valve of the dissected starry ray. As evidenced by 28S gene-based phylogenetic analysis, all of them belonged to *P. hanseni* (intensity of infection, 7) (Fig. 1). Many morphological characteristics of our specimens (Fig. 2) corresponded to the redescription of *P. hanseni* from *A. radiata* collected in the Western Passage (Bay of Fundy, Canada) (Randhawa *et al*., 2008). However, after an analysis of morphological and morphometric features of the White Sea specimens some differences were also revealed (Table 2). It is important to note that the cestodes at our disposal were mature, being represented by proglottids with a formed uterus but without eggs, while the descriptions of *P. hanseni* in the literature are based on gravid speci-

Table 1. Data on the 28S rDNA sequences used in the phylogenetic analysis.
Таблица 1. Данные о последовательностях 28S рДНК, использованных в филогенетическом анализе.

GenBank ID	Parasite	Host	Locality	Reference
MT525320	*Pseudanthobothrium hanseni*	*Amblyraja radiata*	White Sea	this study
MH688744	*Pseudanthobothrium hanseni*	*Malacoraja senta*	Canada: Passamaquoddy Bay	Beer *et al.*, 2019
MH688743	*Pseudanthobothrium hanseni*	*Amblyraja doellojuradoi*	Atlantic Ocean: Falkland Islands	Beer *et al.*, 2019
MH688745	*Pseudanthobothrium hanseni*	*Amblyraja radiata*	North Sea	Beer *et al.*, 2019
MH688741	*Pseudanthobothrium purtoni*	*Leucoraja erinacea*	Canada: Passamaquoddy Bay	Beer *et al.*, 2019
MH688740	*Pseudanthobothrium purtoni*	*Leucoraja ocellata*	Canada: Passamaquoddy Bay	Beer *et al.*, 2019
KF685750	*Pseudanthobothrium* sp.	*Leucoraja erinacea*	Canada: St. Andrews, New Brunswick	Caira *et al.*, 2014
MH913263	*Phormobothrium affine*	*Zearaja nasuta*	New Zealand	Bennett *et al.*, 2019
MH688748	*Echeneibothrium multiloculatum*	*Zearaja chilensis*	Atlantic Ocean: Falkland Islands	Beer *et al.*, 2019
MH688750	*Echeneibothrium vernetae*	*Leucoraja erinacea*	Canada: Passamaquoddy Bay	Beer *et al.*, 2019
MH688751	*Echeneibothrium canadensis*	*Amblyraja radiata*	Canada: Passamaquoddy Bay	Beer *et al.*, 2019
KF685901	*Scyphophyllidium* cf. *giganteum*	*Galeorhinus galeus*	New Zealand: Chatham Rise	Caira *et al.*, 2014
AF286930	*Litobothrium janovyi*	*Alopias superciliosus*	Mexico	Waeschenbach *et al.*, 2007

mens (Williams, 1966; Randhawa *et al*., 2008). Therefore, only the morphology of mature proglottids was taken into account in our further analysis.

Discussion

Both molecular and morphological analyses confirmed that our specimens belonged to *P. hanseni*. However, some differences from the descriptions of *P. hanseni* available in the literature were also found. To note, in this study we used only some of the numerous sequences of *P. hanseni* and other representatives of the family Echeneibothriidae available in GenBank (Fig. 1).Therefore, our tree cannot be used for discussing the systematics of the genus *Pseudanthobothrium*.

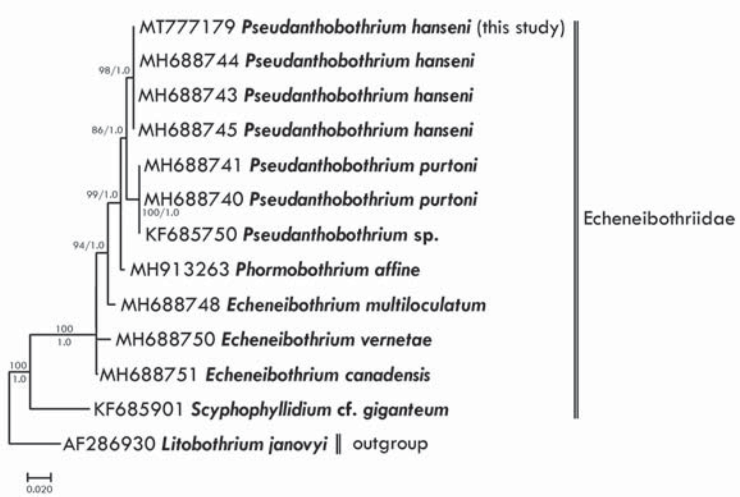

Fig. 1. Phylogenetic relationships of *Pseudanthobothrium hanseni* based on 1499 bp 28S rDNA sequence (GTR + G+I model). Numbers at nodes indicate bootstrap values/Bayesian posterior probabilities.
Рис. 1. Филогенетические отношения *Pseudanthobothrium hanseni*, построенные на основании частичных последовательностей 28S рДНК (1499 п.н.), модель GTR + G+I. Число в узлах обозначают поддержку бутстрепа/байесовские апостериорные вероятности.

Pseudanthobothrium hanseni is recorded in the North Atlantic from the starry ray *A. radiata* and *Malacoraja senta* in the Atlantic waters of Canada (Randhawa *et al*., 2007; Randhawa *et al*., 2008; Randhawa, Burt, 2008), and the spinytail skate *Bathyraja spinicauda* (Jensen, 1914) in the north-eastern Norwegian Sea (Rokicki *et al*., 2001). *Pseudanthobothrium purtoni* Randhawa, Saunders, Scott & Burt, 2008 was primarily described from the same area in the North Atlantic, but according to our own data on helminths of *Bathyraja* sp. ('*Bathyraja sexoculata*') in the Simushir Island area (Gordeev, Polyakova, 2020), it also inhabits the North Pacific. Thus, the distribution area of the genus *Pseudanthobothrium* seems to be underestimated. It may be broadly present in the bottom ecosystems in the Arctic seas and elsewhere.

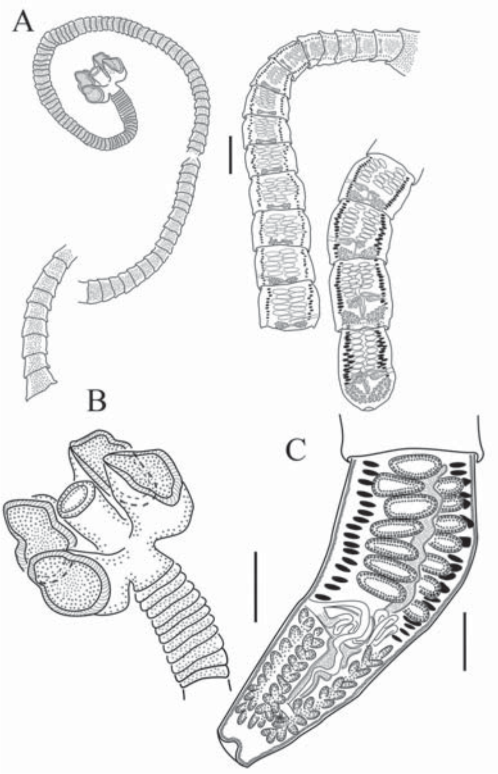

Fig. 2. *Pseudanthobothrium hanseni* ex *Amblyraja radiata* from the White Sea. A — whole worm; B — scolex; C — mature, terminal proglottid. Scale bars: A — 200 µm; B–C — 100 µm.
Рис. 2. *Pseudanthobothrium hanseni* от *Amblyraja radiata* из Белого моря. A — общий вид; B — сколекс; C — зрелая, терминальная проглоттида. Масштаб: A — 200 мкм; B–C — 100 мкм.

Table 2. Morphological characteristics of *Pseudanthobothrium hanseni* Baer, 1956 ex *Amblyraja radiata* (Donovan, 1808) from different areas.
Таблица 2. Морфологические характеристики *Pseudanthobothrium hanseni* Baer, 1956 от *Amblyraja radiata* (Donovan, 1808) из разных районов.

Source:		Present study	Baer, 1956	Williams, 1966	Randhawa *et al.*, 2008
Locality:		White Sea	Disko Bay, West Greenland	North Sea	Bay of Fundy, Canada
Total length (mm)[1]		8.2–9.1	4	Up to 20	5.1–25.8
Maximum W[2]		340	250	400	195–600
No. of proglottids		135–148	40	200	39–131
Bothridia	L	108–167	–	1000	140–380
	W	56–103	–	800	135–306
Myzorhynchus	L	58–110	–	1000	45–440
	d	50–63	55	150	60–175
Stalk	L	55–85	–	60–210	60–210
	W	50–85	–	–	65–160
Neck	L	32–35	–	–	60–335
	W	53–71	–	–	40–150
Mature proglottids	L	508–642	–	–	–
	W	231–323	–	–	–
Gravid proglottids	L	–	–	1500	475–1645
	W	–	–	400	205–600
No. of testes		13–16	Few	16–20	19–32
Size of testes	L	86–105	Large	–	50–150
	W	17–28		–	38–90
Cirrus-sac	L	94–114	–	280	140–255
	W	52–59	–	140	60–105
Vitelline follicles	L	16–29	Large	–	16–55
	W	10–24		–	15–35

[1] All measurements in micrometres unless otherwise indicated.
[2] Abbreviations: No. — number; L — length; W — width, d — diameter.

Beer *et al.* (2019) recorded two species of *Pseudanthobothrium* in *Amblyraja doellojuradoi* (Pozzi, 1935) caught in the Falkland Islands area. Apparently, this genus tends to be associated with the polar and sub-polar waters.

Amblyraja radiata is a very common ray in the North Atlantic and the seas adjacent to the Arctic Ocean (Last *et al.*, 2016). Throughout this extensive area, it serves as a host of at least 19 species of onchoproteocephalidean, phyllobothriidean, rhinebothriidean, diphyllidean, and trypanorhynchean cestodes (Pollerspöck, Straube, 2019). The freshened environment of the White Sea makes possible the presence of the euryhaline species in marine communities (Tchesunov *et al.*, 2008), while truly marine fish come from the Barents Sea mostly through poorly studied bottom recesses, in which normal oceanic salinity is preserved. This may be the reason why a parasite of an elasmobranch in the White Sea was recorded in our study for the first time.

Ecological and biological features of the elasmobranchs such as feeding behavior, age, size, depth and geographical distribution, play an important role in their co-evolution with cestodes (Caira, Bardos, 1996; Klimpel *et al*., 2003; Palm, 2004; Beer *et al*., 2019). In this study, we cannot explain with certainty the morphometric differences between *P. hanseni* from the White Sea and other areas (Table 2). Some role may be played by salinity, which in the White Sea (Babkov, 1998) could be twice or more lower than in habitats of the previously studied hosts of *P. hanseni* (Baer, 1956; Williams, 1966; Randhawa *et al*., 2008). The White Sea is not isolated from the ocean, but the capture of rays there is quite rare. This might mean that the environmental conditions there are on the verge of tolerance of marine rays. This, in turn, is likely to affect their parasites.

The length of the strobila of cestodes in the present study could not be used as a diagnostic sign, since the specimens were at different stages of development. However, the mature cestodes from the White Sea in our study had a greater number of proglottids (135–148) than gravid *P. hanseni* (39-131) (Randhawa *et al*., 2008). Our specimens also had fewer testes, 13–16 vs. 19–32 in Randhawa *et al*. (2008) vs. 16–20 in Williams (1966). In the mature proglottids of worms under study, the yolk follicles were located in two lateral bands extending from the anterior end of the proglottid to the anterior end of the ovary, without reaching the posterior end of the proglottid (Fig. 2). Moreover, in the figures of mature proglottids in the description of *P. hanseni* in the work of Williams (1966: fig. 95), as well as in mature and gravid proglottids in the work of Randhawa *et al*. (2008: figs 2, 3), yolk follicles extend from the anterior to posterior end of the proglottids, without interruption at the level of the ovary. However, according to the redescription of *P. hanseni* in Randhawa *et al*. (2008) "Vitelline follicles ... .., arranged in 2 paired lateral bands anterior to ovary, extending as 2 single lateral bands posterior to anterior margin of the ovary along length of proglottis (Fig. 2A)." Thus, the location of yolk follicles in the text of the description of *P. hanseni* are somewhat inconsistent with the details shown in Figure 2 (see Randhawa *et al*., 2008). In our specimens the yolk vitelline follicles reached the posterior margin of proglottids only in immature proglottids. A relatively low intensity of infection (7 worms/host) must be associated with the small size and, accordingly, age of the examined host specimen. As elasmobranchs grow, their diet changes, and their infection with cestodes increases as a result (Randhawa *et al*., 2008; Gordeev, Polyakova, 2020). All other cestode species recorded in the White Sea (Tchesunov *et al*., 2008; see above) parasitize at the adult stage teleosts, birds, and mammals which, unlike rays, are common in the White Sea. It is therefore unsurprising that the starry ray examined in our study harbored only a few individuals of a single parasite species.

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Compliance with ethical standards

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

Ethical approval: This article does not contain any studies with animals performed by any of the authors.

Sampling and field studies: All necessary permits for sampling and observational field studies have been obtained by the authors from the competent authorities and are mentioned in the acknowledgements, if applicable.

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