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Age and Growth of Blue Antimora *Antimora rostrata* (Moridae) in Southwestern Greenland Waters

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Abstract—The results of determination of age and study on growth of blue antimora *Antimora rostrata* from the waters of Southwestern Greenland are presented. The results are based on the analysis of 200 fish otoliths. In the catches, we found specimens of antimora with total lengths of 18–70 cm, body weights of 23–2731 g, at the age of 7–38 years. Minimal age of males (not considering juvenile individuals) was 10 years at body length of 27–33 cm; maximal age was 18 years at 42 cm. Minimal age of females was 9 years at length of 21–27 cm; maximal age was 38 years at 70 cm. The rate of linear growth in blue antimora from Southwestern Greenland waters is comparable to that in the fish from New Zealand and Ross Sea waters but considerably lower than indicated earlier for fish from the waters of Iceland, Greenland, and the Mid-Atlantic Ridge. The age of reaching sexual maturity in males and females is preliminary determined as 15 and 19–20 years, respectively.

Keywords: blue antimora *Antimora rostrata*, otoliths, sizes, age, growth, North Atlantic, Greenland
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INTRODUCTION

Published information on the stages of life cycle and growth of many deepwater fish species is extremely scarce. At the same time, studies on fish age and growth are of great practical importance for organization of rational use of fishery resources.

According to the modern concept, genus *Antimora* (Moridae, Gadiformes) (Small, 1981; Cohen et al., 1990) includes two species: Pacific flatnose *A. microlepis* and blue antimora *A. rostrata*. The species of this genus are distributed almost ubiquitously in the temperate and cold waters, but are absent in the Arctic Ocean, semiclosed seas of Japan and the Mediterranean and in the majority of tropic areas (except for the Gulf of Guinea, probably, Cape Verde, and northwestern coasts of South America) (Small, 1981; Cohen et al., 1990; Gonzalez et al., 2010). Pacific flatnose *A. microlepis* dwells in the Northern Pacific; blue antimora *A. rostrata* inhabits the remaining parts of the World Ocean. The mode of life of the latter species is bentho-pelagic; it may form aggregations and is harvested as by-catch at fishing with bottom trawls and longlines (Iwamoto, 1975; Kulka et al., 2003; Fossen and Bergstad, 2006; Horn and Sutton, 2015). This species is considered as a perspective target for commercial fishery (Novikov and Timokhin, 2009; Novikov et al., 2010).

Published data on the specific features of *A. rostrata* lifecycle are extremely scarce and fragmentary (Iwamoto, 1975; Wenner and Musick, 1977; Gordon and Duncan, 1985; Collins et al., 1999; Kulka et al., 2003; Novikov and Timokhin, 2009). Despite widespread distribution in the World Ocean and high occurrence in catches, the growth and age of blue antimora have been studied only in the waters of Iceland (Magnússon, 1998, 2001), the Ross Sea (Antarctic), and New Zealand (Horn and Sutton, 2015) as well as in some regions of the North Atlantic, including the waters of both coasts of Greenland and the Mid-Atlantic Ridge (MAR) (Fossen and Bergstad, 2006). The latter of the referred papers contains the results of the studies on age and growth of blue antimora obtained during the analysis of integrated data on trawl and longline catches in 1992–2004 in five regions of the North Atlantic: western and eastern coastal waters of Greenland, the northern part of MAR (Reykjanes Ridge), the central part of MAR (Charlie-Gibbs Fracture Zone), and the southern part of MAR (off northern part of Azores). This analysis did not account for the sex of fish making it impossible to assess the sex-related and regional differences in the

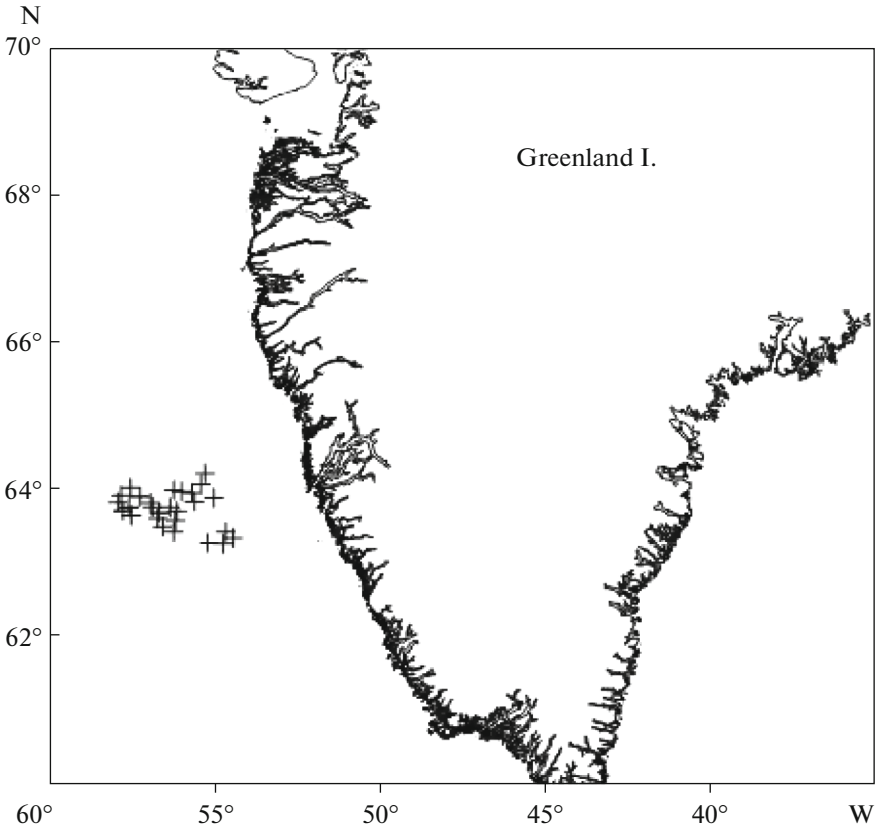

Fig. 1. Locations (+) of sampling of the otoliths of blue antimora *Antimora rostrata* in the waters of Southwestern Greenland in September 2013.

biological parameters. In addition, according to our original determinations, the maximal age of antimora is much higher compared to the data of earlier research (Fossen and Bergstad, 2006). At the same time, it is suggested that this species possesses low productivity due to a long life span and late sexual maturation making it very vulnerable to the effect of fishery (Devine et al., 2006).

The goal of the present paper is to provide the data on the age and growth based on the analysis of otoliths (sagitta) in blue antimora from the Southwestern Greenland waters and to compare the results of this study with earlier published data.

MATERIALS AND METHODS

The materials for the study were sampled in September 2013 in Southwestern Greenland waters during the expedition aboard the RV *Paamiut* (Greenland Institute of Natural Resources, Nuuk, Greenland) (Fig. 1). In total, 200 specimens of blue antimora caught at the depths of 912–1501 m were analyzed. All sampled fish were subjected to full biological analysis according to the standard routine (Laevastu, 1965; Pravdin, 1966); total length (*TL*) was measured.

The otoliths were dissected from the freshly caught fish during the biological analysis aboard the RV and placed into paper envelopes. Fish age was determined in the laboratory. Since the early 1980s, the counting of annual rings in calcined fractured (saw cut) otoliths is widely used in fish age determination (Chugunova, 1959). This method was proven reliable for bottom-dwelling (including deep-water) fish of the United States and Canadian western coastal waters (Beamish and McFarlane, 1987). Considering that antimora, as many other deepwater fish is a long-living species (Devine et al., 2006), its age was determined according to the methods developed specifically for some long-living bottom-dwelling fish (Beamish and Chilton, 1982; Rodríguez Mendoza, 2006).

The otoliths were fractured at the central part, calcined, and polished if necessary. To prepare the otoliths' polished sections, abrasive discs with aluminum-oxide or silicon-carbon covers with 0.1–0.9 μm grain (Buehler, United States) were used. The sections of otoliths were analyzed under a Leica DMLS stereomicroscope at 10 × 4 magnification in glycerol in reflected light (Fig. 2).

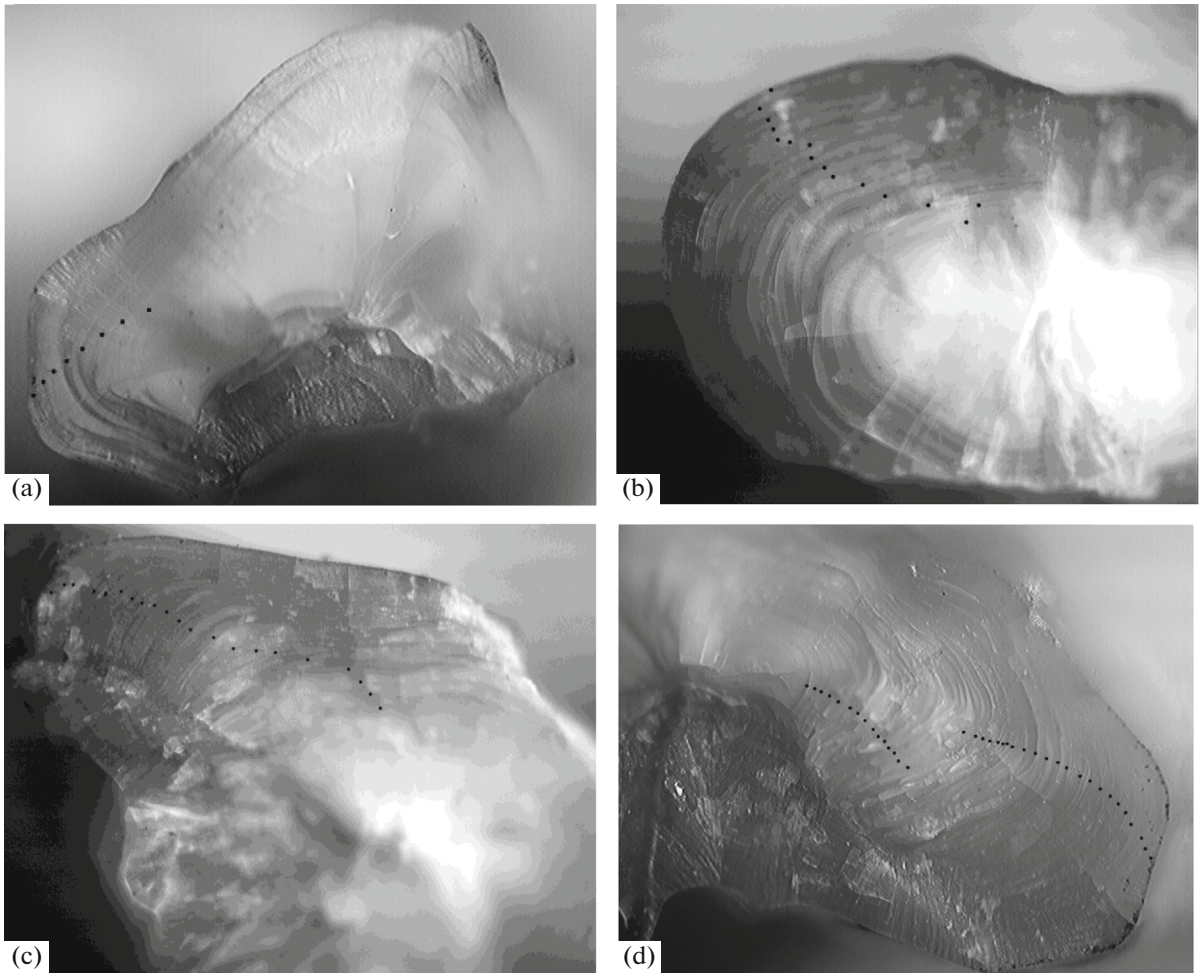

Fig. 2. Microsections of otoliths of blue antimora *Antimora rostrata* from the waters of Southwestern Greenland: (a) *TL* 19 cm, body weight 34 g, age 8 years; (b) *TL* 41 cm, body weight 407 g, age 15 years; (c) *TL* 52 cm, body weight 1167 g, age 21 years; (d) *TL* 70 cm, body weight 2731 g, age 38 years; (·) annual growth zones.

The parameters of the Bertalanffy growth equation were calculated using PAST, ver. 3.14 software (Hammer et al., 2001).

RESULTS

Trawl catches of antimora in the Southwestern Greenland waters consisted of the individuals with *TL* 18–70 cm and body weight of 23–2731 g. Males accounted for 38.5% of catches; females, 46.0%; 15.5% were juvenile specimens. The *TL* of juvenile fish ranged from 18 to 42 cm, at body weight of 23–420 g. In all males, the testes were at I and II maturity stages. In the males, the minimal body length was 27 cm; the maximal, 46 cm; minimal body weight, 95 g; maximal, 612 g. Without histological examination of the gonads, it was difficult to judge which portion of the fish was immature with others being at the stage of postspawning recovery. The majority of females (90.2%) had ovaries at I and II stages of maturity; the gonads of the rest (9.8%) were at VI–II stages of maturity. The lengths in the sampled females varied from 21 to 70 cm; body weight, 71 to 2731 g.

In blue antimora, the otoliths are hard and at the same time fragile, which makes their processing and further age determination difficult. The weight of otoliths was 0.052–0.534 g (0.204 g on average). The correlation between the weight of an otolith (W_o, g) and fish length (*TL*, cm) is well approximated ($R^2 = 0.915$) by the exponential equation: $W_o = 0.0004 \times TL^{1.6694}$ (Fig. 3a).

According to our data, minimal age of sampled antimora was 7 years in the individuals with *TL* 18 cm. At the age of 10 years, they reached length of 28.5 cm, 39.5 cm at 15 years, 51.3 cm at 20 years, 54.5 cm at 25 years, 58.2 cm at 30 years. Maximal age recorded in our catches was 38 years in the specimen with *TL* 70 cm (Table 1). The majority of fish in the catches (82%) consisted of the fish at the age of 10–17 years. The age

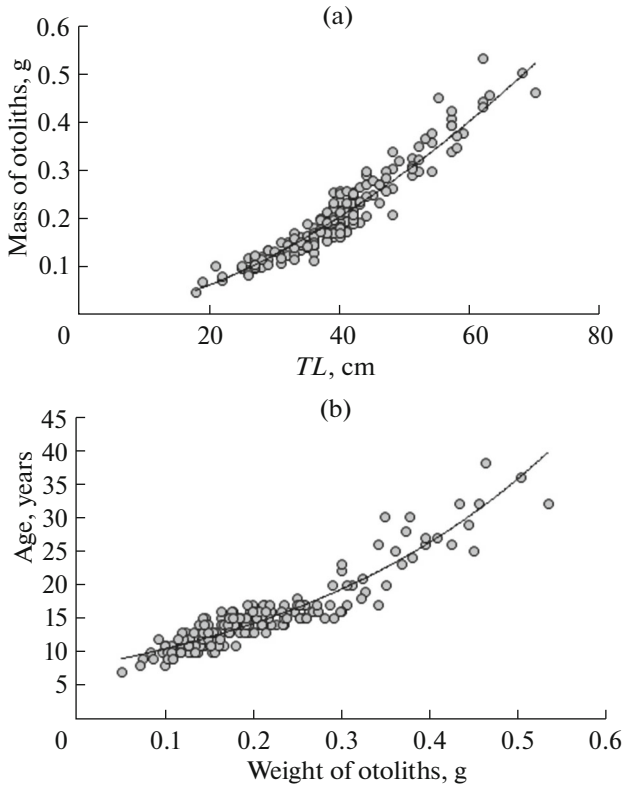

Fig. 3. Relationships between length (*TL*) of blue antimora *Antimora rostrata* and weight of their otoliths (a) and between weight of otoliths and age (b).

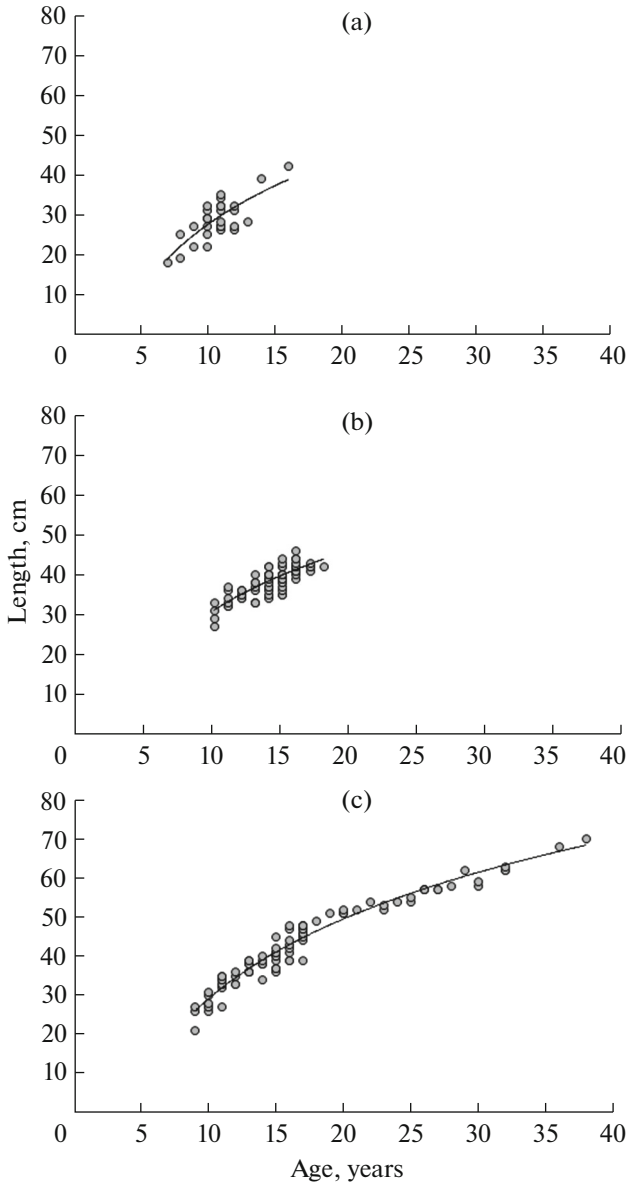

Fig. 4. Linear growth of blue antimora *Antimora rostrata* in the waters of Southwestern Greenland: (a) juvenile specimens ($R^2 = 0.5802$), (b) males ($R^2 = 0.6705$), (c) females ($R^2 = 0.9536$).

of juvenile fish was 7–16 years at *TL* 18–42 cm (Fig. 4a). The males in the catches were with *TL* 27–42 cm at the age of 10–18 years (Fig. 4b). In females, minimal recorded age (9 years) was in the fish with *TL* 21–27 cm; maximal (38 years), in the specimens with *TL* 70 cm (Fig. 4c). Spawned females were presented in the catches by the fish with *TL* 52–70 cm at the ages of 23–38 years.

The relationship between fish age (*A*, years) and weight of otoliths (W_o, g) (Fig. 3b) is well approximated ($R^2 = 0.859$) by the following exponential function: $A = 7.627 \times e^{3.0812W_o}$. The presence of reliable statistical correlation between the weight of otoliths and fish age and body weight allows for the development of age-size keys making much easier the studies on the size-age structure of the exploited fish aggregations. These studies are very important practically for the assessment of fishery resources.

Comparison of body lengths and weights in males and females shows that these parameters in males are slightly larger than in females at the age of 10–12. At the age of 13 years, the rates of linear and weight growths in females start to be a bit higher than in males. At the age of 15–16 years, the growth rate in females retards and mean lengths and weights of the specimens of both sexes of the same age become similar. Starting from the age of 17 years, the rates of linear and weight growth in females are considerably higher than in males. In our catches, we found no males older than 18 years.

During its life span, the growth rate of blue antimora is extremely uneven. In general, high increments (1.0–5.5 cm/year) are observed until the age of 19 years. After this, the rate of linear growth and annual increments of length noticeably decrease even to negative values.

Table 1. Total body length (*TL*) and body weight of blue antimora *Antimora rostrata* of various age groups in west Greenland waters

Age, years	Males			Females			Males, females and juvenile specimens		
	TL, cm	body weight, kg	*n*	*TL*, cm	body weight, kg	*n*	*TL*, cm	body weight, kg	*n*
7	–	–	–	–	–	–	18.0	0.023	1
8	–	–	–	–	–	–	19.0–25.0 22.0 ± 4.24	0.034–0.08 0.057 ± 0.032	2
9	–	–	–	21.0–27.0 24.7 ± 3.21	0.082–0.88 0.357 ± 0.452	3	21.0–27.0 24.6 ± 2.88	0.044–0.88 0.243 ± 0.356	5
10	27.0–33.0 30.0 ± 2.58	0.095–0.205 20.140 ± 0.04	4	26.0–31.0 28.2 ± 1.94	0.071–0.173 0.10 ± 0.036	6	22.0–33.0 28.5 ± 2.71	0.042–0.202 0.117 ± 0.041	18
11	32.0–37.0 34.0 ± 2.1	0.164–0.3 0.213 ± 0.05	6	27–35 32.9 ± 2.58	0.113–0.257 0.199 ± 0.046	8	26.0–37.0 31.7 ± 3.31	0.082–0.3 0.177 ± 0.059	25
12	34.0–36.0 35.0 ± 0.9	0.223–0.271 0.242 ± 0.019	6	33.0–36.0 34.3 ± 1.5	0.163–0.253 0.207 ± 0.043	4	26.0–36.0 33.1 ± 3.17	0.079–0.271 0.199 ± 0.06	14
13	33.0–40.0 36.0 ± 2.72	0.178–0.420 0.274 ± 0.078	8	36.0–39.0 37.1 ± 1.36	0.234–0.348 0.294 ± 0.035	9	28.0–40.0 36.1 ± 2.88	0.11–0.42 0.275 ± 0.07	18
14	34.0–42.0 38.6 ± 2.38	0.219–0.466 0.357 ± 0.083	15	34.0–40.0 37.8 ± 2.04	0.213–0.387 0.304 ± 0.059	6	34.0– 42.0 38.4 ± 2.21	0.213–0.466 0.341 ± 0.077	22
15	35.0–44.0 39.35 ± 2.41	0.21–0.505 0.383 ± 0.081	20	36.0–45.0 39.9 ± 2.58	0.274–0.555 0.389 ± 0.079	11	35.0–45.0 39.5 ± 2.44	0.21–0.555 0.385 ± 0.079	31
16	39.0–46.0 42.08 ± 1.92	0.359–0.612 0.487 ± 0.074	12	39.0–48.0 42.9 ± 3.35	0.361–0.622 0.49 ± 0.093	8	39.0–48.0 42.4 ± 2.47	0.359–0.622 0.485 ± 0.079	21
17	41.0–43.0 42.0 ± 0.7	0.417–0.529 0.475 ± 0.052	5	39.0–48.0 45.8 ± 2.74	0.356–0.892 0.657 ± 0.157	10	39.0–48.0 44.5 ± 2.89	0.356–0.892 0.596 ± 0.156	15
18	42.0	0.49	1	49.0	0.797	1	42.0–49.0 45.5 ± 4.94	0.49–1.287 0.643 ± 0.217	2
19	–	–		51.0	0.706	1	51.0	0.706	1
20	–	–		51.0–52.0 51.3 ± 0.5	0.804–0.976 0.871 ± 0.079	4	51.0–52.0 51.3 ± 0.5	0.804–0.976 0.871 ± 0.079	4
21	–	–		52.0	1.167	1	52.0	1.167	1
22	–	–		54.0	1.163	1	54.0	1.163	1
23	–	–		52.0–53.0 52.5 ± 0.7	1.08–1.138 1.109 ± 0.04	2	52.0–53.0 52.5 ± 0.7	1.08–1.138 1.109 ± 0.041	2
24	–	–		54.0	1.175	1	54.0	1.175	1
25	–	–		54.0–55.0 54.5 ± 0.7	1.287–1.366 1.326 ± 0.055	2	54.0–55.0 54.5 ± 0.7	1.287–1.366 1.326 ± 0.055	2
26	–	–		57.0–57.0 57.0 ± 0	1.298–1.418 1.358 ± 0.098	3	57.0–57.0 57.0 ± 0	1.298–1.494 1.403 ± 0.098	3
27	–	–	–	57.0–57.0 57.0 ± 0	1.455–1.522 1.488 ± 0.047	2	57.0–57.0 57.0 ± 0	1.455–1.522 1.488 ± 0.047	2
28	–	–	–	58.0	1.534	1	58.0	1.534	1

Table 1. (Contd.)

Age, years	Males			Females			Males, females and juvenile specimens		
	TL, cm	body weight, kg	*n*	*TL*, cm	body weight, kg	*n*	*TL*, cm	body weight, kg	*n*
29	–	–	–	62.0	1.935	1	62.0	1.935	1
30	–	–	–	58.0–59.0 58.2 ± 0.7	1.328–1.376 1.352 ± 0.033	2	58.0–59.0 58.2 ± 0.7	1.328–1.376 1.352 ± 0.033	2
31	–	–	–	–	–	–	–	–	–
32	–	–	–	62.0–63.0 62.3 ± 0.57	1.973–2.098 2.051 ± 0.068	3	62.0–63.0 62.3 ± 0.57	1.973–2.098 2.051 ± 0.068	3
33	–	–	–	–	–	–	–	–	–
34	–	–	–	–	–	–	–	–	–
35	–	–	–	–	–	–	–	–	–
36	–	–	–	68.0	2.479	1	68.0	2.479	1
37	–	–	–	–	–	–	–	–	–
38	–	–	–	70.0	2.731	1	70.0	2.731	1

Top—limits of the parameter variation; bottom—means and standard deviation; *n*—number of examined fish, ind.

In males, most intensive growth (1–4 cm/year) is observed until the age of 15 years followed by substantial retardation. Females intensively grow until 18 years (0.7–4.7 cm/year). After this, the rate of linear growth slightly decreases followed by alternating increases and decreases in the annual increments lacking clear periodicity.

DISCUSSION

The specificity of sampling determines the results of our and previous studies on blue antimora to a high extent. The ratio of sexes in the catches directly depends on the depth of fishing, since different sexes dwell within different bathymetric ranges. The dwelling of females at the shallower waters is a characteristic of Northeastern Atlantic antimora (Gordon and Duncan, 1985). In the Northwestern Atlantic, females account for 30–40% of catches at depths less than 500 m and for 60–70% at depths more than 700 m (Kulka et al., 2003). Near the United States North Atlantic coast, males prevail at depths to 1500 but are practically absent deeper than 2000 m (Wenner and Musick, 1977). In the waters of Iceland, females dominate in number in the catches deeper than 1500 m (Magnússon, 2001). In the catches in Ross Sea (Antarctic) at depths of 800–2000 m, females considerably prevail over males (90.3 vs. 9.7%) (Horn and Sutton, 2015). In terms of the parameters noted above, blue antimora from the Indian Ocean differs considerably from the North Atlantic fish. According to Novikov and Timokhin (2009), at the underwater ridges of the Indian Ocean, the ratio of sexes is close to 1 : 1 with some prevalence of females. In our catches, females dominated in number, which may relate to trawling at depths more than 900 m. However, recent studies carried out in the Northeastern Pacific (Frey et al., 2017) on the closely related species Pacific flatnose *A. microlepis* revealed that ratio of sexes in this species may be subject to strong inter-annual fluctuations due to the appearance of numerous replenishment (e.g., the share of females in monitoring catches decreased from 40% in 2013 to 25% in 2015).

Practically full absence of sexually mature fish in our catches is not a unique phenomenon. Earlier the same fact was noted by Gordon and Duncan (1985) at the studies in the Northeastern Atlantic and by Novikov and Timokhin (2009) at the underwater ridges of the Indian Ocean. The authors of the referred papers believe that lack of mature individuals in catches relate to their dwelling outside the depths studied. However, if the former authors relate this fact to spawning of antimora at the deepest parts of the slope, the latter believe that this fish spawns in the water column.

The researchers that studied age of antimora by otoliths (Fossen and Bergstad, 2006; Horn and Sutton, 2015) note the problems related both to the difficulties in preparation of the otoliths' saw cuts for age determination and to the interpretation of obtained data. In the recent study, we faced similar difficulties.

No correlation between body length and weight of otoliths in blue antimora was analyzed in the earlier studies. At the same time, we revealed the correlation providing an additional tool for the determination of age by fish length in the present study. Earlier similar correlations were described in Pacific flatnose from Northwestern (Orlov and Abramov, 2002) and the Northeastern Pacific (Frey et al., 2017). Relevant data

Table 2. Parameters of von Bertalanffy growth equation in blue antimora *Antimora rostrata* and Pacific flatnose *A. microlepis* in various regions of World Ocean

Region and fish sex	*n*, ind.	parameters of growth equation			Reference
		L_∞ (*TL*)	*K*	t_0	
A. rostrata					
Mid-Atlantic Ridge and Greenland:					Fossen and Bergstad, 2006
—males	68	2332.00	0.0016	−1.74	
—females	170	71.86	0.14	1.52	
—both sexes and juvenile specimens	257	81.70	0.10	0.98	
Iceland, both sexes and juvenile specimens	57	61.37	0.089	0.205	Magnússon, 2001
Ross Sea, both sexes	192	82.2	0.047	−0.6	Horn and Sutton, 2015
New Zealand, both sexes and juvenile specimens	48	50.8	0.056	−3.2	Horn and Sutton, 2015
Southwestern Greenland:					Original data, 2013
—males	77	74.17	0.062	1.14	
—females	92	82.58	0.036	0.89	
—both sexes and juvenile specimens	200	76.82	0.057	1.11	
A. microlepis					
Northwestern Pacific (1993–2000), both sexes and juvenile specimens	109	125.9	0.031	0.91	Orlov and Abramov, 2002
Northeastern Pacific (2007–2015), both sexes and juvenile specimens	247	61.2	0.100	−2.69	Frey et al., 2017

on blue antimora are given for the first time in the present study. Mean sizes of blue antimora in various regions were not compared earlier, which is related to the lack of published information of lengths and weights of the specimens of different ages (Magnússon, 2001; Fossen and Bergstad, 2006; Horn and Sutton, 2015). Only single paper (Magnússon, 2001) notes that the individuals of this species in Icelandic waters at the age of 3 years have *TL* 15 cm; after reaching the age of 23, *TL* 54 cm. In our catches of fish aged 23–25 years, body length averaged 52.5–54.5 cm, which is close to the relevant parameters revealed in the antimora from Icelandic waters.

There is no common opinion concerning the differences in growth rates between males and females of blue antimora. As was noted in antimora from Icelandic waters, males are smaller than the same-aged females (Magnússon, 2001). At the same time, no such differences were revealed in the fish from the MAR and Greenland waters (Fossen and Bergstad, 2006) or in the Ross Sea and off New Zealand (Horn and Sutton, 2015). According to our data, until the age of 14 years, the growth rate in males is higher than in females. At the age of 15–16 years, the fish of both sexes have comparable values of body length and weight and the females are later noticeably longer and heavier than the males of the same age.

The age composition of blue antimora catches differs in various regions. In the MAR water catches, the specimens at ages of 6–25 years with prevalence (86%) of the fish older than 10 years were noted; in the Greenland waters, fish age varied from 1 to 20 years with prevalence (90.7%) of the individuals younger than 10 years (Fossen and Bergstad, 2006). In general, in the catches at both regions, the fish at the age of 7–14 years prevailed. In the Ross Sea catches, blue antimora at the age of 11–41 years was found; in the New Zealand waters, 4–28 years (Horn and Sutton, 2015). In our catches in Southwestern Greenland waters, we registered specimens at the age of 7–38, while the fish at age of 11–21 years dominated in number (74.5%). Increase in size and age with depth is a characteristic of blue antimora (Cohen et al., 1990). This is why it is likely that the described differences in the age composition in catches relate to the fact that different researchers obtained analyzed materials within different bathymetric ranges.

The parameters of the von Bertalanffy growth equation for blue antimora and Pacific flatnose are given in Table 2. The comparison of these parameters shows that the value of K (0.057), parameter characterizing rate of reaching the asymptotic length in our study is close to the value in blue antimora from the Ross Sea (0.047) and waters off New Zealand (0.056) (Horn and Sutton, 2015) as well as in Pacific flatnose (0.031) from Northwestern Pacific (Orlov and Abramov, 2002). At the same time, the K value calculated in the present study is noticeably lower than in blue antimora from Icelandic, MAR, and Greenland waters (Magnússon, 2001; Fossen and Bergstad, 2006) and in Pacific flatnose from Northeastern Pacific (Frey et al., 2017).

The data on the age of sexual maturity in blue antimora are scarce and extremely controversial. In the Indian Ocean, this fish reaches maturation at *TL* 15–20 cm (Novikov et al., 2010). In Icelandic waters, half of males and females reach maturation at *TL* 45.1 and 42.1 cm, respectively (Magnússon, 2001). In our opinion, the data of both referred papers are doubtful. According both to published information (Magnússon, 2001; Fossen and Bergstad, 2006; Horn and Sutton, 2015) and our data of the present study, the body length of 15–20 cm corresponds to the age of 3–8 years in *A. rostrata*. In consideration of maximal length of this species (*TL* 70 cm) and extreme age (40 years), it is unlikely that the specimens with *TL* 15–20 cm reach the stage of beginning of sexual maturation. The data given by Magnusson (2001) also look doubtful, since the males of blue antimora are smaller than the females and, consequently, should mature at lesser body length. In addition, in North Atlantic, the individuals of antimora with $TL > 45$ cm are very innumerous in the catches (Magnússon, 2001; Kulka et al., 2003; Fossen and Bergstad, 2006); in our catches, the maximal length of the males was 46 cm. It is hard to believe that half of the males reach maturation at $TL \approx 45$ cm (practically corresponding to their maximal age), while such specimens in the population are very innumerous owing to natural elimination. According to our data in the females, the body length of 42 cm corresponds to the age of approximately 16 years. Only indirect data, the results of the analysis of annual length increments, allow for the determination of the age of maturation. In the males, considerable retardation of growth rate is observed by the age of 15 years; in females, 19–20. It is likely, that the males and females of blue antimora from Southwestern Greenland waters reach sexual maturation by the ages noted above.

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