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Age and growth of *Antimora rostrata* (Moridae, Gadiformes, Teleostei) from the Kerguelen and Crozet Islands in the southern Indian Ocean

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Abstract

Age and growth of blue antimora *Antimora rostrata* were examined for the first time in the waters of Kerguelen and Crozet Islands (southern Indian Ocean, sub-Antarctic). The longline catches were represented by fish ranging from 39 to 72 cm in total length with weights between 400 and 3310 g, aged 16– 41 years. A minimum age of 16 years was observed in a fish 39 cm long, while a maximum age of 41 years was recorded for an individual of 70 cm in length and 3310 g in weight. The age classes with the greatest numbers were represented by fish aged 34 years (9%), 28 years (9%) and 29 years (8%), which together accounted for 26% of the total catch. The blue antimora in the southern Indian Ocean shows similar growth rates to those of individual fish from the Ross, Lazarev and Weddell Seas and southeastern Greenland, which may indicate the population unity of the species within the Antarctic and sub-Antarctic waters or similar habitat conditions in these areas.

Introduction

The genus *Antimora* (Moridae, Gadiformes) includes two species: Pacific flatnose (*Antimora microlepis*) Bean, 1890 and blue antimora (*Antimora rostrata*) (Günther, 1878) (Cohen, Inada, Iwamoto, & Scialabba, 1990; Orlov, Grigorov, & Lazareva, 2018a; Small, 1981). *Antimora microlepis* inhabits the North Pacific Ocean, while *A. rostrata* is found in many other parts of the world. *Antimora rostrata* is most abundant in temperate and cold waters but is not present in the Arctic Ocean and semi-enclosed seas (i.e. the Sea of Japan and the Caribbean and Mediterranean seas) or in most tropical and subtropical areas (with the exception of the Gulf of Guinea, the Canary Islands and Madeira, the Indian Ocean underwater ridges, Hawaii, Taiwan, the Gulf of California and the northern coast of South America) (Cohen et al., 1990; Orlov et al., 2019; Small, 1981). Blue antimora is a bentho-pelagic deep-sea species that is capable of forming dense concentrations. It is caught as bycatch in bottom trawl and longline fisheries (Fossen & Bergstad, 2006; Horn & Sutton, 2015; Iwamoto, 1975; Kulka, Simpson, & Inkpen, 2003) and considered as a promising commercial target (Priede, 2017).

Published information about the life cycle of *A. rostrata* is limited and fragmentary (Collins, Priede, & Bagley, 1999; Gordon & Duncan, 1985; Iwamoto, 1975; Kulka et al., 2003; Novikov & Timokhin, 2009; Wenner & Musick, 1977). The age and growth of blue antimora have been studied in the waters of Iceland (Magnússon, 2001), the Ross Sea and New Zealand waters (Horn & Sutton, 2015) and the Lazarev and Weddell seas (Vedishcheva, Korostelev, Gordeev, & Orlov, 2019), as well as in several areas of the North Atlantic, including the waters of both coasts of Greenland and the Mid-Atlantic Ridge (Fossen & Bergstad, 2006; Orlov, Vedishcheva, Trofimova, & Orlova, 2018b). However, no age validations were provided in publications documenting those studies.

The purpose of this paper is, for the first time, to report the data on the age and growth of blue antimora from the waters of the Kerguelen and Crozet Islands (southeastern Indian Ocean) and to compare those results with previously published data regarding other parts of range.

Materials and methods

Blue antimora otoliths (sagitta) were collected from bycatch specimens of commercial longline fishing targeting Patagonian toothfish *Dissostichus eleginoides* off the French Kerguelen and Crozet Islands Exclusive Economic Zone (Fig. 1), a part of the Convention area of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). Otoliths were collected by French fishery observers on six different longliners operating in these areas during the 2016/2017 and 2017/2018 fishing campaigns and dry-stored in paper envelopes

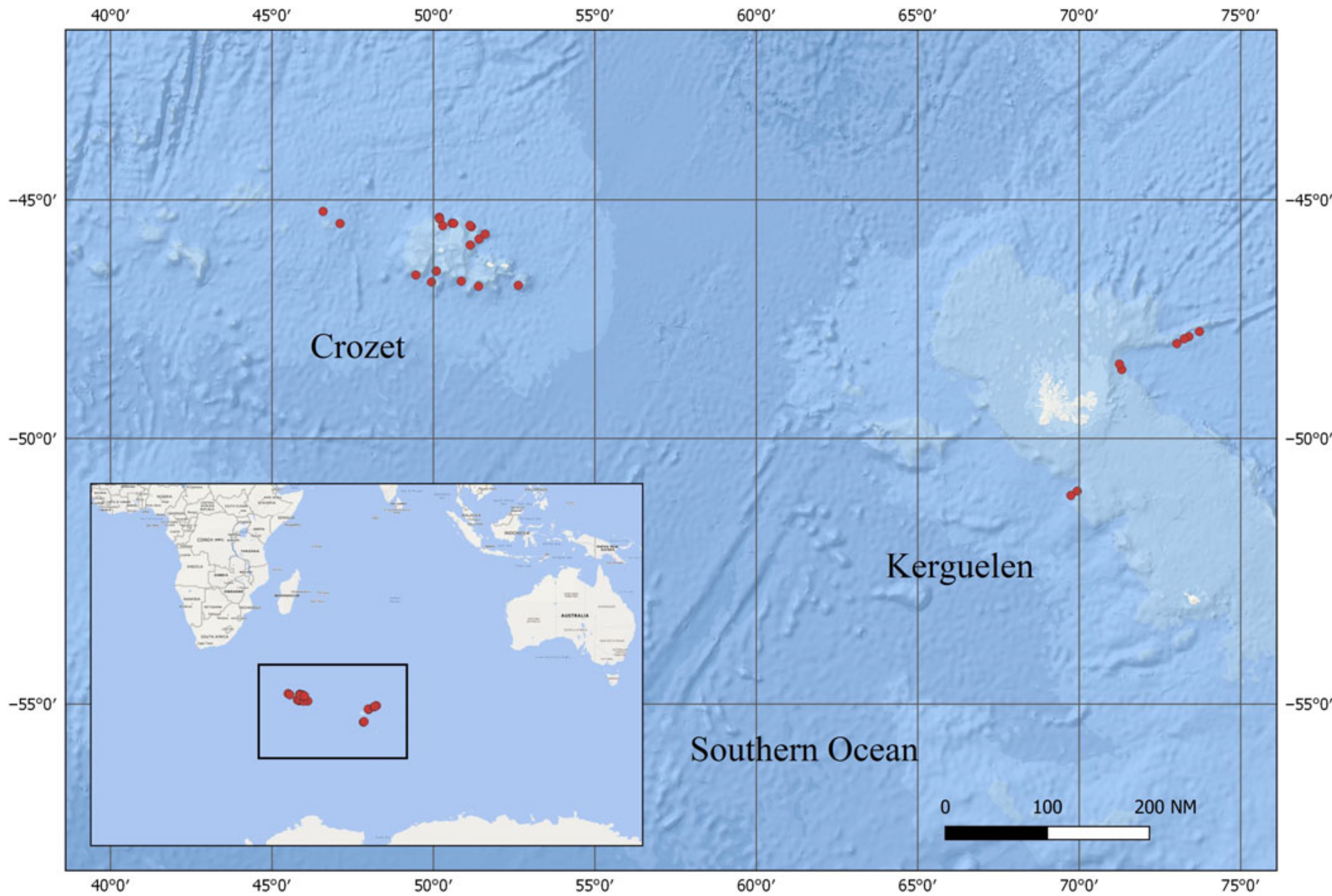

Fig. 1. The sites (circles) where otoliths of blue antimora *Antimora rostrata* in the waters off Kerguelen and Crozet Islands were sampled.

with labels on the catch (date, set number and depth) to be linked to the fishing master logbook. The fishing method is described in Cherel, Weimerskirch, and Duhamel (1996) and Duhamel (1992).

A total of 164 individuals caught from depths of 515–1745 m were analysed. All the fish were analysed using standard methods (Laevastu, 1965; Pravdin, 1966). Measurements included total body length (TL) and body weight, and sex was registered when possible. Of the 164 fish caught, sex was determined in 97 specimens (76 females and 21 males); the other 67 specimens were unsexed; gonadal maturity was also not examined by observers.

Otoliths were extracted from freshly caught fish during the biological analyses onboard the ship. The measuring and weighing of otoliths and age determinations were carried out in the VNIRO laboratory. The length was measured in 133 otoliths using an electronic calliper (Kraftool GmbH, Löningen, Germany) with accuracy of 0.01 mm; the weight of these 133 otoliths was determined on an electronic scale (Sartorius GmbH, Goettingen, Germany) with accuracy of 0.001 g.

Since the beginning of the 1980s, when determining the age of fish, a "break and burn" method of age determination on otoliths has been widely used, which has proved to be good for demersal (including deep-water) fish of the west coast of the USA and Canada (Beamish & McFarlane, 1987). Taking into account that blue antimora, like many deep-sea fish, is probably a long-lived species (Fossen & Bergstad, 2006; Horn & Sutton, 2015; Magnússon, 2001; Orlov et al., 2018b; Vedishcheva et al., 2019), age was determined in accordance with the methods developed specifically for some long-lived deep-sea fish (Beamish & Chilton, 1982).

Accordingly, otoliths were broken transversely in half with a lancet and baked, then polished if necessary. Otoliths were burned in the flame of an alcohol burner. For the preparation of polished cross-sections of the otoliths, abrasive discs with aluminium-oxide- or silicon-carbide-coated grit of 0.1–0.9 μm (Buehler, USA) were used. The readiness of each otolith for further analysis was determined individually on the basis of visual observations. We used a trinocular microscope (Olympus SXZ12) with a DFPLAPO 1×PF lens to view the cross-sections at 1×20–40 magnification. Otolith cross-sections were coated with glycerine and illuminated with reflected light (Fig. 2). In total, 164 otoliths were analysed based on the readings made by 3 independent readers. The average percent error (APE) index was calculated according to the methods proposed by Beamish and Fournier (1981) for comparison of age determinations by different readers. Age for an individual fish was determined as a mean age based on the three independent readings. Between-reader age determinations were based on pairwise comparisons and were considered consistent if APE values were less than 10% (Arkhipkin et al., 2008).

Fisher's exact tests were used to assess relationships between the TL and body weight, length and weight of the otolith, TL and otolith weight, as well as age and otolith weight. Test outputs were calculated in MS Excel®.

Age curves were plotted and the coefficients of von Bertalanffy growth equations were calculated using PAST version 3.14 software (Hammer, Harper, & Ryan, 2001).

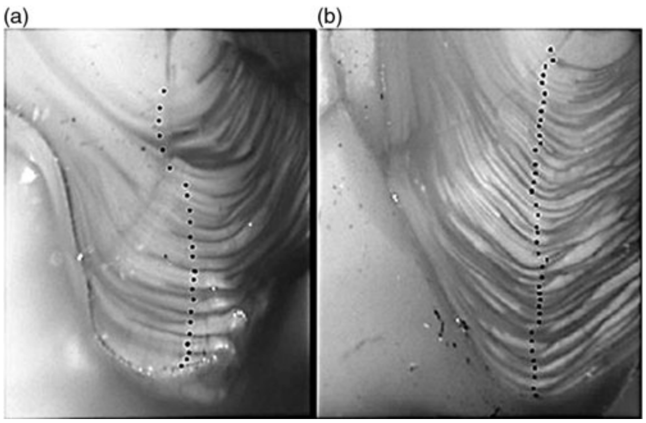

Fig. 2. Cross-sections of otoliths of blue antimora *Antimora rostrata* from waters of Kerguelen and Crozet Islands: (a) TL 40.3 cm, 24 years; (b) TL 66.9 cm, 40 years. Dots are annual growth zones, TL = total length.

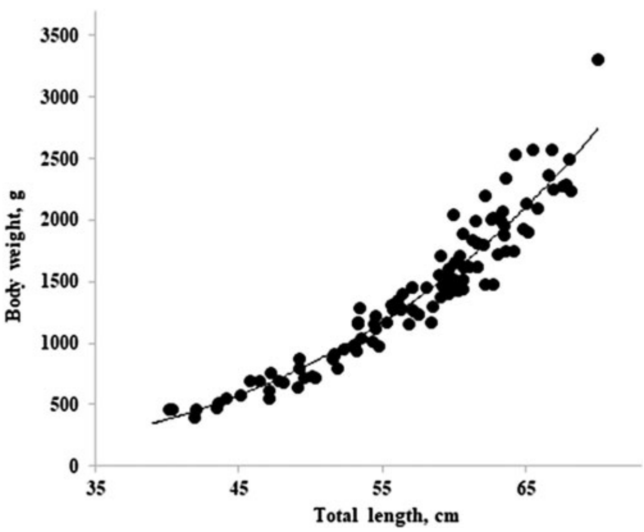

Fig. 3. Relationship between the total length and body weight of blue antimora *Antimora rostrata* from waters of Kerguelen and Crozet Islands.

Results

Otoliths were collected from representative samples of commercial catches of bottom longlines, in which blue antimora was represented by specimens with a TL ranging from 39 to 70 cm (smaller fish were not observed in catches due to selectivity of longlines that caught larger specimens). Fish with a TL of 55–65 cm (56%) dominated with a mean length of 57.0 ± 6.9 (SE) cm. The mean weight of fish in catches was 1434 ± 566 g with minimum and maximum values of 400 and 3310 g, respectively. Individuals weighing 1200–1700 g accounted for 42% of the total number of fish; there were smaller numbers in other weight groups in catches.

The relationship between the length and weight of blue antimora was better described (R^2= 0.94, statistically significant at $p < 0.01$) by a power function (Fig. 3):

$$BW = 0.0008 \times TL^{3.5793}$$

where BW = body weight (g) and TL = total length (cm).

Males were caught less often than females (males: 22% vs. females: 78%). Females captured were considerably longer (mean total length 58.77±6.12 vs. 52.00±8.56 cm) and heavier than males (mean weight 1566±552 vs. 1112±586 g).

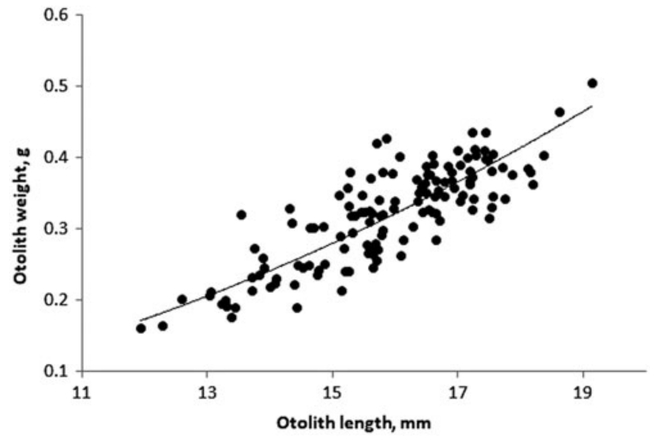

Fig. 4. Relationship between otolith weight and otolith length of blue antimora *Antimora rostrata* from waters of Kerguelen and Crozet Islands.

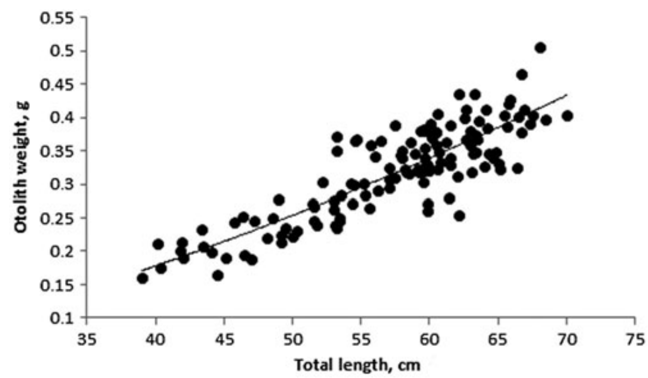

Fig. 5. Relationship between otolith weight and total length of blue antimora *Antimora rostrata* from waters of Kerguelen and Crozet Islands.

The weight of otoliths ranged between 0.161 and 0.505 g, with a mean weight of 0.320±0.070 g, while the length of otoliths ranged between 11.94 and 19.13 mm, with a mean of 15.85±1.40 mm. The relationship between the length and weight of otoliths (Fig. 4) can be described by a power function ($R^2 = 0.719$, $p < 0.001$):

$$W_o = 0.0008 \times L_o^{2.1527}$$

where W_o represents otolith weight (g) and L_o represents otolith length (mm). As our analysis shows, the power function describes this relationship better than linear one ($R^2 = 0.693$). This means that the otolith gets increasingly bulky as it grows.

The otolith weight positively correlated with the total length of the fish ($R^2 = 0.764$, $p < 0.001$), and the relationship between the considered parameters (Fig. 5) can be described by a power function:

$$W_o = 0.0005 \times TL^{1.5904}$$

where W_o represents the weight of the otolith (g) and TL represents total length (cm). The power function describes this relationship better than linear one ($R^2 = 0.726$).

According to our data, in longline catches in the waters off the Kerguelen and Crozet Islands, blue antimora (if the rings in

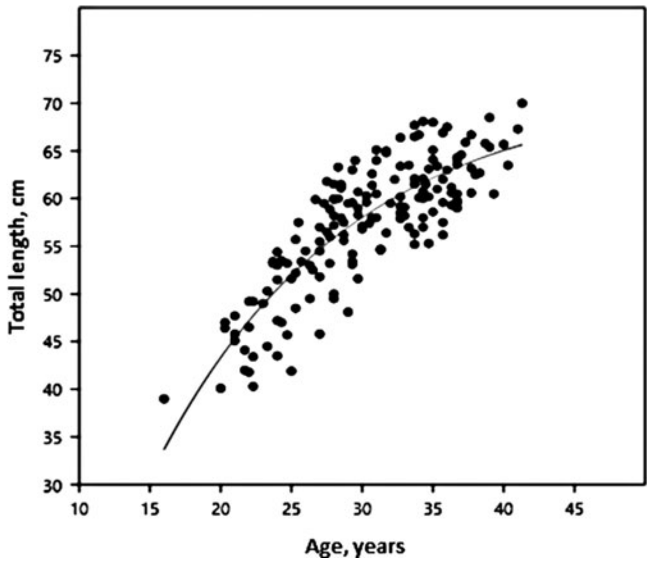

Fig. 6. Fitted von Bertalanffy curve to growth data (sexes combined, $n = 148$) of blue antimora *Antimora rostrata* from waters of Kerguelen and Crozet Islands.

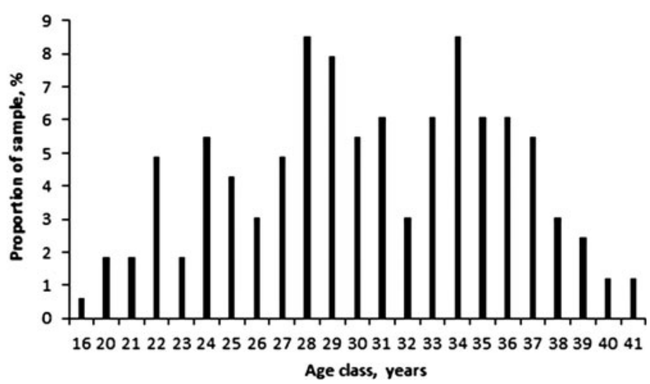

Fig. 7. Age composition of blue antimora *Antimora rostrata* sample from waters of Kerguelen and Crozet Islands.

otoliths of this fish actually represent annual rings) was aged 16–41 years (Fig. 6) with a mean age of 30.4 years. The age determinations might be considered as quite repeatable since the APE indexes for readers 1, 2 and 3 were 6.04%, 5.18% and 5.81%, respectively.

The age classes with the greatest numbers were represented by fish aged 34 years (9%), 28 years (9%) and 29 years (8%), which together accounted for 26% of the total catch (Fig. 7).

The youngest male in the catches was 16 years old with a TL of 39 cm (Fig. 8). The oldest male was aged 37 years with a TL of 68.1 cm and a weight of 2240 g. The mean age of males was 26.8 years. The youngest female in catches was 22 years old with a TL of 43.4 cm and a weight of 480 g, while the oldest age of 41 years was recorded for a female individual with a TL of 70 cm and a weight of 3310 g. The mean age of females was 31.5 years.

The relationship between the age of fish and the weight of otoliths (Fig. 9) can be described ($R^2 = 0.602$) by a power equation:

$$W_o = 0.0118 \times A^{0.9622}$$

where W_o represents otolith weight (g) and A represents age (years).

Discussion

Size composition of blue antimora caught off Kerguelen and Crozet Islands by longlines during 2016/2017 and 2017/2018 fishing campaigns differed from that during the 1995/1996 season (Duhamel, Pruvost, & Capdeville, 1997). Thus, TL of this species in our catches and in 1995/1996 was 39–70 cm and 22–65 cm, respectively, with mode 55–65 vs. 52 cm and mean TL 57 vs. 45.9 cm. The main possible reason of smaller fish caught during 1995/1996 season is shallower depths fished (300–1700 vs. 515–1745 m in 2016–2018), since smaller and younger individuals of this species occur at shallower depths (Cohen et al., 1990).

The sex ratio of blue antimora varies across areas and depths surveyed. Males dominated at depths of 500 m of the northwestern Atlantic, while the proportion of females increased with increasing depth (Kulka et al., 2003). In Greenland waters, depths of over 900 m were also dominated by females (Orlov et al., 2018b). In the waters of the North Atlantic coast of the USA at depths up to 1500 m, the number of males was higher than that of females (Wenner & Musick, 1977). Populations of the Indo-Oceanic blue antimora significantly differ from the North Atlantic in sex ratio. According to Novikov and Timokhin (2009), on the underwater ridges of the Indian Ocean at depths ranged 900–1700 m, the sex ratio was close to 1:1 on the Southwest Indian Ridge with some predominance of females (1:1.2–1.4) in other areas. In the Southern Ocean, the number of males in the Lazarev and Weddell seas was higher than females at depths of 1100–1800 m (Vedishcheva et al., 2019). Furthermore, at depths of 800–2000 m in the Ross Sea, the percentage of females was up to 90% (Horn & Sutton, 2015), which is similar to our data (78% vs. 22%). In our opinion, the sex ratio of blue antimora in different areas is dependent not only on depth surveyed but also on type of fishing gear used. Thus, longlines are more selective gear in relation to size composition and catch larger fish, which in case of blue antimora are dominated by females.

The majority of authors who studied the age of blue antimora using otoliths (Fossen & Bergstad, 2006; Horn & Sutton, 2015; Orlov et al., 2018b; Vedishcheva et al., 2019) note the challenges associated with the difficulty in interpreting the otolith zones, which was quite evident in our studies. In this study, we consider all visible rings as annuli similar to other previous studies where age estimations were unvalidated. Preliminary results from further research suggest that the number of rings placed on otoliths and vertebrae do not differ significantly (Korostelev, Frey, & Orlov unpublished) and we therefore consider the rings on otoliths and vertebrate to be laid annually. Despite the absence of well-defined seasonality at great depths, in high latitudes, seasonal changes on the ocean surface (changes in daylight hours, temperature, etc.) lead to changes in the flow of organic matter into deep-sea layers and thus can affect the overall productivity of deep waters and the availability of food for deep-sea fishes.

Given that commercial longline fishing catches mainly large fish, our samples of blue antimora had a relatively narrow size range, which can explain the low R^2 value for the relationship between the length of the blue antimora and the weight of its otoliths, as well as between the weight and age of otoliths. The example from the waters of southwestern Greenland can serve as confirmation of this (Orlov et al., 2018b): the R^2 value for juvenile individuals with a length of 18–42 cm was equal to 0.58, while for females with a broader size range (21–70 cm), it was 0.95.

The contradictory information available in the literature on the growth rates of female and male blue antimora is probably

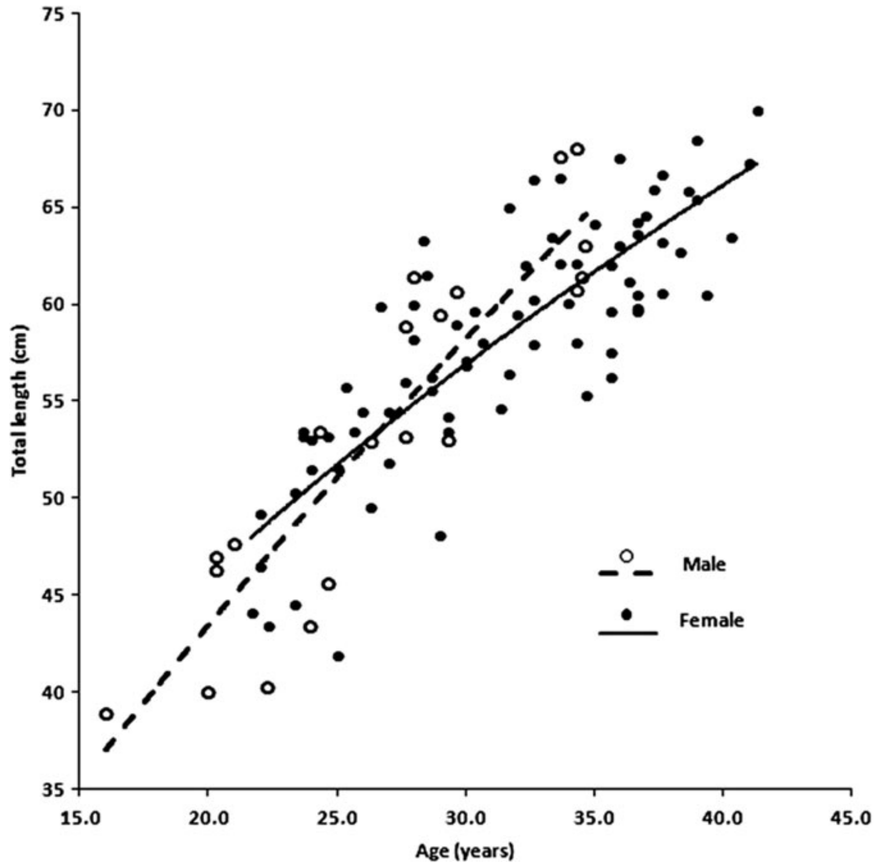

Fig. 8. Growth of male and female blue antimora *Antimora rostrata* from waters of Kerguelen and Crozet Islands.

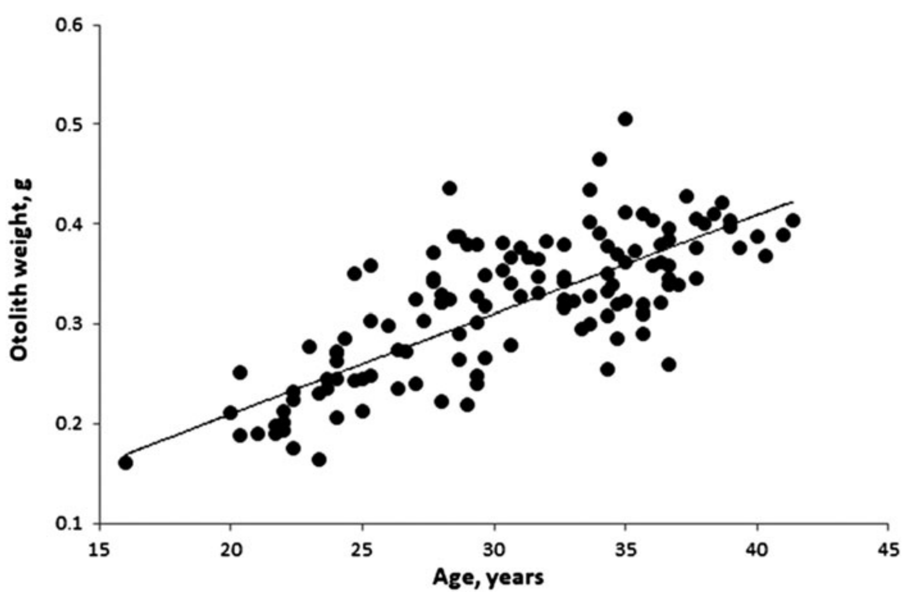

Fig. 9. Relationship between otolith weight and age of blue antimora *Antimora rostrata* from waters of Kerguelen and Crozet Islands.

associated with difficulties that relate to ageing long-lived deep-water fish. In the waters off Iceland, males were smaller than females of the same age (Magnússon, 2001), while no such difference was found off Greenland and the Mid-Atlantic Ridge (Fossen & Bergstad, 2006), as well as in the Ross Sea and off New Zealand (Horn & Sutton, 2015). Male blue antimora (up to the age of 14 years) off southwestern Greenland grow faster than females, whereas 15–16-year-old individuals of both sexes have comparable growth rates in length and weight. In subsequent years, females are noticeably longer and heavier than males of the same age (Orlov et al., 2018b). In our study area, female blue antimora were much larger than males and slightly older (31.9 vs. 27.9 years on average),

Table 1. The parameters of von Bertalanffy growth equation of blue antimora *Antimora rostrata* in different regions.

Parameters	MAR and Greenland (Fossen & Bergstad, 2006) M (68)	F (170)	M+F+J (257)	Iceland (Magnússon, 2001) M+F+J (57)	Ross Sea (Horn & Sutton, 2015) M+F (192)	New Zealand (Horn & Sutton, 2015) M+F+J (48)	Southwestern Greenland (Orlov et al., 2018b) M (77)	F (92)	M+F+J (200)	Lazarev and Weddell seas (Vedishcheva et al., 2019) M (38)	F (29)	M+F+J (110)	Kerguelen and Crozet Islands (our data) M+F+J (148)
$L_\infty(TL)$	2332.00	71.86	81.70	61.37	82.2	50.8	74.17	82.58	76.82	79.90	165.45	82.25	71.5
K	0.0016	0.14	0.10	0.089	0.047	0.056	0.062	0.036	0.057	0.060	0.012	0.050	0.074
t_0	−1.74	1.52	0.98	0.205	−0.6	−3.2	1.14	0.89	1.11	1.23	0.87	1.09	1.72

MAR = Mid-Atlantic ridge, M = males, F = females, J = juveniles, number of fish is given in parentheses.

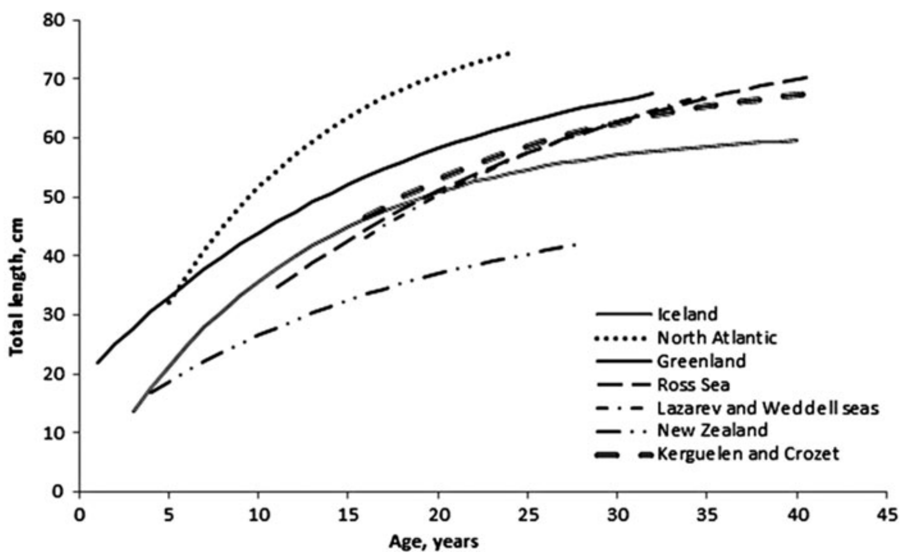

Fig. 10. The growth of blue antimora *Antimora rostrata* in various parts of species' range (Iceland – Magnússon, 2001; North Atlantic – Fossen & Bergstad, 2006; Ross Sea – Horn & Sutton, 2015; New Zealand – Horn & Sutton, 2015; Greenland – Orlov et al., 2018b; Lazarev and Weddell seas – Vedishcheva et al., 2019; Kerguelen and Crozet Islands, our data).

which is probably due to females growing larger than males and the lifespan of males being considerably shorter (Fossen & Bergstad, 2006; Horn & Sutton, 2015).

The age composition of the catches of blue antimora in various areas is different. In the waters of the Mid-Atlantic Ridge, catches were represented by individuals aged 6–25 years with a predominance of fish older than 10 years; in the waters off Greenland, the age of fish varied within a range of 1–20 years with a predominance of individuals under 10 years (Fossen & Bergstad, 2006). In general, catches in both areas were dominated by individuals aged 7–14 years. In the Ross Sea, catches of blue antimora ranged in age between 11 and 41 years; and in the waters off New Zealand, they ranged between 4 and 28 years (Horn & Sutton, 2015). In catches from southwestern Greenland, individuals aged 7– 38 years with a numerical dominance of fish aged from 11 to 21 years were observed (Orlov et al., 2018b), while 25–27-year-old individuals of blue antimora were most numerous in catches in the Lazarev and Weddell seas (Vedishcheva et al., 2019). In our catches, the age classes with the greatest numbers were represented by fish aged 34 years (9%), 28 years (9%) and 29 years (8%), which together accounted for 26% of the total catch. Since larger and older individuals of this species are known to generally occur at deeper depths (Cohen et al., 1990), the described differences in the age composition of the catches are likely to be associated with obtaining the studied material from various authors in different bathymetric ranges. Between-area differences can also be influenced by the relative proportions of males and females in each sample, assuming that, in general, females are larger at age than males. The differences observed might also partly be explained by the different fishing gear (trawls and longlines) used in the various research studies. Longlines selectively caught larger and older fish, and therefore, blue antimora from the Ross, Lazarev and Weddell Seas and the waters of Kerguelen and Crozet Islands (Horn & Sutton, 2015; Vedishcheva et al., 2019; our data) were older than fish caught by trawls in the North Atlantic and off Greenland and New Zealand (Fossen & Bergstad, 2006; Horn & Sutton, 2015; Orlov et al., 2018b). A greater proportion of small fish were caught by survey gear with smaller hooks and smaller mesh (Kulka et al., 2003).

A comparison of blue antimora growth in different parts of its range (Fig. 10, Table 1) shows that growth curves for Kerguelen and Crozet Islands (our data) are very similar to those for the Ross Sea (Horn & Sutton, 2015), waters off Greenland (Orlov et al., 2018b), and the Lazarev and Weddell Seas (Vedishcheva et al., 2019). Conversely, our data differ quite substantially from that obtained off the coast of New Zealand (Horn & Sutton, 2015), Iceland (Magnússon, 2001) and the North Atlantic (Fossen & Bergstad, 2006). Blue antimora from

New Zealand waters (Horn & Sutton, 2015) shows slower growth rates compared to our results, while in the North Atlantic (Fossen & Bergstad, 2006), this species demonstrates faster growth than in the waters of Kerguelen and Crozet Islands. In Icelandic waters (Magnússon, 2001), blue antimora grows faster up to about 20 years, followed by a slower growth rate in older individuals compared to our data.

Conclusions

The similarity of blue antimora growth patterns in the Ross, Lazarev and Weddell seas and the waters of Kerguelen and Crozet Islands might indicate that this species forms a single population in the Southern Ocean that might be confirmed by recent molecular genetic study (Orlov, Bannikov, & Orlova, 2020). This study also showed a difference of haplotype composition between blue antimora samples from the Southern Ocean and the North Atlantic. However, the growth pattern of this species in the Southern Ocean and Greenland waters is quite similar and might be due to the similar environmental conditions of both areas (temperature, forage conditions, etc.).

While our results are relatively similar to previous ones (Horn & Sutton, 2015; Orlov et al., 2018b; Vedishcheva et al., 2019), the age determination of *A. rostrata* remains unvalidated and requires further research to validate the annual deposition of rings and confirm the real age. A valid comparison between studies would also require confirmation that all workers used the same otolith zone interpretation method. However, it is necessary to apply validation techniques based on Pb-210/Ra-226 disequilibrium (Cailliet et al., 2001; Smith, Nelson, & Campana, 1991). We recently measured the elemental composition of *A. rostrata* and *A. microlepis* otoliths, and preliminary results suggest that Pb concentrations are sufficient for further age validation research based on the disequilibrium of Pb-210/Ra-226 (Kostelev & Orlov, 2020).

Current fishing methods and depth coverage do not allow for catching the juvenile part of the population, introducing another bias in the growth curves. Therefore, in future research, it is necessary to target juveniles to improve estimations of the younger ages just after nucleus formation.

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Conflict of interest. None.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional guides on the care and use of laboratory animals.

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