FIRST DATA ON THE DAILY FOOD CONSUMPTION BY ANTARCTIC FISH *TREMATOMUS HANSONI* (ACTINOPTERYGII: PERCIFORMES: NOTOTHENIIDAE) IN CAPTIVITY

Rebecca GORNIAK[1*], Emilio RIGINELLA[2], Nils KOSCHNICK[1], and Vladimir LAPTIKHOVSKY[3]

[1]*Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI)*

[2] *Department of Integrative Marine Ecology, Stazione Zoologica Anton Dohrn Napoli (SZN)*

[3]*Centre for Environment Fisheries and Aquaculture Science (Cefas)*

Gorniak R., Riginella E., Koschnick N., Laptikhovsky V.V. 2020. First data on the daily food consumption by Antarctic fish *Trematomus hansoni* (Actinopterygii: Perciformes: Nototheniidae) in captivity. Acta Ichthyol. Piscat. 50 (1): 121–125.

Abstract. In this study, we present first observations on the feeding behaviour of an Antarctic notothenioid fish, the striped rockcod, *Trematomus hansoni* Boulenger, 1902. During 13 days of feeding experiment onboard RV *Polarstern*, the striped rockcod consumed an average of 1.0% BM · day^{-1} of *Loligo reynaudii* at the temperature around +1.0°C. The daily food ration of *T. hansoni* turned out to be lower than predicted by theoretical equations derived for fish living at higher temperatures but was similar to values observed in other Antarctic fish in captivity.

Keywords: daily ration, Nototheniidae, captivity, temperature, Antarctica

INTRODUCTION

The Antarctic is a unique environment encompassing the Southern Ocean, one of three major centres of origin of marine biodiversity (Briggs 2003). One of the products of such rich diversification are notothenioid fishes that evolved to live at sub-zero temperatures (Eastman 1993, Bargelloni et al. 2000) and therefore have physiological adaptations very different from fishes in other parts of the world's oceans (Kock 2005). Notothenioids represent approximately 90% of the fish biomass occurring on the shelf and upper slope down to 500 m depth in the Southern Ocean (Eastman and Clarke 1998).

The ecology of Antarctic fishes has been under intensive study since the end of the 19th century and to date, a sound set of materials on many aspects of their lifestyle has been collected. Their trophic relations have been the focus of prolific studies. Resource partitioning between coexisting species evolved to mitigate competition for food resources (Ross 1986, La Mesa et al. 2015). Every year increasingly more publications describe individual species' feeding spectra (e.g., Vacchi and La Mesa 1995, Flores et al. 2003, Peck et al. 2008, Vanella et al. 2012).

The information on the daily food requirements of Antarctic fish can be obtained in two ways. One such method would be monitoring stomach fullness and the degree of food digestion in samples collected in the different times of the day with resolution no more than a few hours (La Mesa et al. 1997, Flores et al. 2003, Bushula et al. 2005). In this case, assumptions on temperature (Beers and Jayasundara 2015) and size-dependent digestion rates could be made based on the empirical equations of Elliott and Persson (1978), dos Santos and Jobling (1995), Pennington (1985), and others (Pakhomov and Tseitlin 1991, Pahomov 1993, Olaso et al. 2005).

The second approach is based on direct observations of feeding in captivity (Johnston and Battram 1993, Coggan 1997, Olaso et al. 2004), which requires keeping fish in tanks over extended periods of time, weighing both the delivered food and uneaten leftovers. This method is very difficult technically but provides more reliable results. Because of logistical constraints (experiments having to be done in the Antarctic and involving a closed water circulation system), only a handful of data exists on the actual daily requirements of Antarctic fish. However, in this case, the observed daily rations are likely maximum, because in captivity fish is normally fed *ad libitum*, whereas in a natural environment the food must be found and hunted.

* Correspondence: Rebecca Gorniak, Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung (AWI), Am Handelshafen 12, 27570 Bremerhaven, Germany, phone: (+49)15755992004, e-mail: (RG) *rebecca.gorniak@gmail.com*, (ER) *emilio.riginella@szn.it*, (NK) *nils.koschnick@awi.de*, (VL) *vladimir.laptikhovsky@cefas.co.uk*.

In order to address the paucity of relevant data, the aim of this study was to estimate the daily rations of fish species inhabiting the high Antarctic ecosystem.

MATERIALS AND METHODS

The Antarctic fish used in this study were captured on board the RV *Polarstern* (expedition PS117 15 December 2018 to 7 February 2019) in the King Haakon VII Sea, which is located between the Weddell Sea in the West and the Lazarev Sea in the East. The water temperature often drops under zero degrees and the surface is usually ice covered in winter (Spreen et al. 2008). A fish trap of six independent nets (Fig. 1), each baited with defrosted trawl-captured *Loligo reynaudii* (see Roper et al. 1984) freely suspended, was deployed on 11 January 2019 (70°32.14′S, 008°52.25′W, depth 406–420 m) and recovered five days later, on 16 January 2019.

Two fishes were captured alive, the striped rockcod, *Trematomus hansoni* Boulenger, 1902 (see Dewitt et al. 1990) and the long-fingered icefish, *Cryodraco antarcticus* Dollo, 1900 (see Iwami and Kock 1990). They were immediately transferred into separate tanks situated in a constant room temperature (0–2°C) and enclosed in a circulation system containing 2 m^3 of air-saturated seawater. The circulating seawater was pumped through an ultraviolet lamp to eliminate bacteria and a skimmer to remove the proteins. To protect the fishes' eyes from damage and to avoid stress, that could potentially alter the feeding habit, only dimmed red light was used inside the room during working operations (feeding and cleaning). Otherwise, tanks were kept in complete darkness.

In between capture and start of the experiment the fish had four days for recovery from the strain resulting in the capture.

The fish were fed once a day with common squid*, L. reynaudii* at approximately 0945 h (UTC) *ad libitum*. The defrosted squid was prepared fresh and was weighed with an accuracy of ±0.1 g ("M2000 Series" scales; Marel). Each day tanks were simultaneously checked twice for the presence of uneaten food. The second check took place 12 h after the first at approximately 2145 h (UTC). If the fish had eaten the squid during the day, another portion was dispensed in the evening. Otherwise, uneaten food was replaced with fresh food the next morning.

During the 13 days of observation, *T. hansoni* was offered a total of 192.1 g of food ranging from 7.8 g to 15.2 g per piece, mean 3.0% ± 0.5% drawn to its BM · day^{-1}. *Cryodraco antarcticus* was fed with a total of 162.5 g ranging from 11.7 g to 14.7 g per piece, mean 1.9% ± 0.2% expressed in its BM · day^{-1}. The pieces were small enough to have no doubts that they fit into the fish mouth opening.

The daily check of water parameters consisted of measuring the salinity, the temperature, and the concentration of ammonium. When the ammonium concentration reached the threshold of 0.4 mg · L^{-1} due to the presence of uneaten food, the water was exchanged immediately. The water was exchanged on a daily basis regardless of the ammonium concentration.

The feeding experiment lasted 13 days. Afterward, the individual fish were anesthetized with MS-222 (0.2 g · L^{-1}). The total length (TL) and standard length (SL) of the fish were measured to the nearest mm and body mass (BM) as

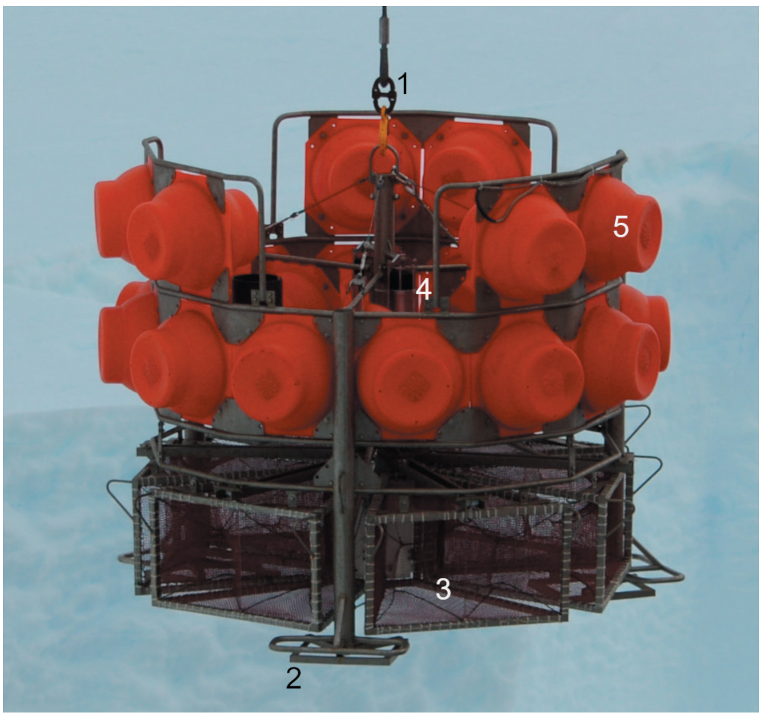

Fig. 1. Fish trap with (**1**) a hook for deploying and recovering the device and (**2**) feet, on which a set of weights (350 kg in total) are attached to keep the trap on the seabed after the deployment. Bait was placed into the creels (**3**) to attract the fish. An acoustic signal induces the detachment of the fish trap from the weights by the releaser (**4**) and its rise to the surface by means of several floats (**5**)

well as the gutted mass (GM) were measured to the nearest 0.1 g. Their stomachs were also checked for the presence of undigested food.

Statistical analysis. The results of the environmental variability and the biological observations (Table 1) bear the arithmetic mean with its standard deviation (SD), calculated with MS Excel.

RESULTS

Environmental variability. During the experiment the water temperature in the system ranged from 0.6 to 1.4°C (mean ± SD = 1.0 ± 0.3°*C*). The salinity varied between 33.2 µS · cm^{-1} and 34.2 µS · cm^{-1} (mean ± SD = 33.7 ± 0.3 µS · cm^{-1}) and the ammonium concentration varied between 0.10 mg · L^{-1} and 0.44 mg · L^{-1} (mean ± SD = 0.28 ± 0.10 mg · L^{-1}).

Biological observations. The total length of *Trematomus hansoni* was TL = 31.5 cm and the standard length, SL = 26 cm. Its body mass was BM = 358.5 g, and gutted mass at the end of the experiment was GM = 295 g. *Trematomus hansoni* was an immature female, the maturity stage II was assessed according to the five-point scale proposed for notothenioids (Kock and Kellermann 1991).

Trematomus hansoni began to eat food on the fourth day after capture (20 January 2019) and then took three more portions, the last one on 25 January 2019 (Table 2). Upon dissection, on 31 January 2019, the fish stomach was found to contain two pieces of partially digested squid, indicating that the fish was probably still not hungry and food digestion in the Antarctic waters might take up to a week or even longer. The total mass of eaten food was 46.1 g, which corresponds to 1.0% BM · day^{-1} for the period of this study.

Cryodraco antarcticus had a TL = 49 cm and a SL = 47.5 cm. Its body mass was BM = 668 g (GM = 489 g). *Cryodraco antarcticus* was a mature male, stage IV (Kock and Kellermann 1991). During the experiment, it did not eat anything. Its stomach was found to be empty after dissection.

DISCUSSION

The maximum daily ration of approximately 1.0% BM · day^{-1} observed in *Trematomus hansoni* at temperatures of around +1.0°C represents the first observation for this species. This fish is known as an opportunistic feeder (La Mesa et al. 1997), eagerly consuming whatever is available including fishery discards, which represent half of its diet in the Cosmonaut Sea (Pakhomov and Tseitlin 1991, Pakhomov 1998, La Mesa et al. 1997). The daily ration of *T. hansoni* was similar to estimations for the sub-Antarctic "warmer-water" fish *Champsocephalus gunnari* Lönnberg, 1905 and *Chaenocephalus aceratus* (Lönnberg, 1906) based on stomach fullness and the degree of food digestion, that also resulted in estimation of approximately 1.0% BM · day^{-1} mean daily feeding ration for fish with the length of TL = 30.0–34.0 cm (Flores et al. 2003). Our results are also similar to the feeding rates of other Antarctic fish in captivity. A study of diet and growth of the demersal notothenioid *Notothenia coriiceps* Richardson, 1844 at temperatures around 0°C demonstrated that with a daily ration of approximately 1.0% of BM · day^{-1} the fish did not grow, at < 0.5% BM · day^{-1} they lost mass, and with 1.5%–2.0% BM · day^{-1} they grew by approximately 0.1–0.2 percentage points BM · day^{-1} (Coggan 1997). A similar consumption rate of 1.3% BM · day^{-1} was observed in *Harpagifer antarcticus* Nybelin, 1947, showing zero growth under winter conditions, but growing in summer by 2.5 percentage points BM · day^{-1}, when food was supplied *ad libitum* (Johnston and Battram 1993 and references within). The daily ration of *Pleuragramma antarctica* Boulenger, 1902 collected in the same area as our study of the East Weddell Sea resulted in estimation of 1.133% BM in immature fish and 0.484% BM in mature fish (Olaso et al. 2004).

All these observed values were much lower than estimated from theoretical assumptions and using Pennington formula with a range for the different demersal Antarctic fish being some 1.0%–4.0% of BM, mostly 2%–4% BM (Pakhomov and Tseitlin 1991, Pakhomov and Shumatova 1992).

Daily rations of 4.5%–5.2% of the body dry mass were theoretically calculated for relatively "warm water" fish, *Lepidonotothen larseni* (Lönnberg, 1905) and *Gobionotothen marionensis* (Günther, 1880), in Prince

Table 1

Water parameters during the feeding experiment of *Trematomus hansoni*

Date	Temperature [°C]	Salinity [µS · cm^{-1}]	Ammonium [mg · L^{-1}]
19 January 2019	1.3	34.2	0.10
19 January 2019	1.4	34.1	0.10
20 January 2019	1.3	34.0	0.20
21 January 2019	1.3	34.1	0.22
22 January 2019	1.3	33.8	0.30
23 January 2019	1.2	33.9	0.30
24 January 2019	1.1	33.6	0.44
25 January 2019	0.8	33.6	0.28
26 January 2019	0.6	33.7	0.38
27 January 2019	0.8	33.5	0.32
28 January 2019	0.9	33.7	0.36
29 January 2019	1.0	33.4	0.26
30 January 2019	1.0	33.3	0.38
31 January 2019	0.8	33.2	0.24
1 February 2019	0.8	33.2	0.32

Table 2

The relative food consumption of *Trematomus hansoni* during the reported experiment; food amounts expressed as the percentage of fish body mass (BM)

Date	Feed ration [%BM]
20 January 2019	3.1
20 January 2019	2.2
23 January 2019	3.4
25 January 2019	4.2

Edward Island's water, sub-Antarctic, using Baikov's relation (Bushula et al. 2005). However, these rations are calculated for warm water fish and are not applicable to cold water ones.

The approach of calculating the fish daily food requirement by monitoring stomach fullness and the degree of food digestion would work well only if Antarctic fish would have a strong diurnal feeding activity and digestion time would not exceed 24 h. However, for Antarctic fish, the time intervals between feeding events often exceeded the supposed 36–48 h (Kock 1992). This is even the case in captivity, where fish have constant fresh food access (Pakhomov 1998) what puts the possibility of using these theoretical approaches under doubt. The unreliability of theoretical methods might be caused by the fact that these formulas were derived from using data of fishes living in much warmer latitudes.

The two species that were captured for this study have different hunting methods. Browsers and scavengers (La Mesa et al. 2004), like *T. hansoni,* do not need their prey moving and therefore could be easily fed in captivity. Bottom icefishes, like *Cryodraco antarcticus* Dollo, 1900—judging from their body morphology—are ambush predators (Kock and Jones 2002), that detect the prey by its movement. It might be possible that this provoked difficulties regarding the feeding of this specimen. The fact that it entered the trap does not necessarily mean that it was attracted by the bait: the icefish might look for shelter or target small scavengers like amphipods inside the trap.

Assumptions regardless of how well they are backed, are still assumptions and we think that only primary observations might give a clue what occurs in nature. In this respect every single piece of reliable information on actual feeding rates matters, even the observations on single fish.

CONCLUSION

Overall, our results in comparison to other field studies demonstrate that food rations of Antarctic fish are likely overestimated by the traditional formula of Pennington, which derived from data based on relatively warm water species. A new theoretical approach is required to solve this disparity.

ACKNOWLEDGEMENTS

We express our gratitude to the crew of RV *Polarstern* for all their excellent support on board. We would also like to thank Carina Engicht, Rainer Graupner, Jakob Allerholt, and Moritz Krusenbaum who helped to deploy and release the fish trap. Furthermore, we are thankful to Isabel Diercks for taking the picture used in Fig. 1. We would like to thank M. Lucassen and S. Hain from AWI , M. La Mesa from CNR of Ancona for their support, and C. Papetti and L. Zane from the University of Padua, founded by the PNRA16_00307 project (ER on board). The projects were enabled by Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI).

REFERENCES

Bargelloni L., Marcato S., Zane L., Patarnello T. 2000. Mitochondrial phylogeny of notothenioids: A molecular approach to Antarctic fish evolution and biogeography. *Systematic Biology* 49 (1): 114–129. DOI: 10.1080/10635150050207429

Beers J.M., Jayasundara N. 2015. Antarctic notothenioid fish: What are the future consequences of 'losses' and 'gains' acquired during long-term evolution at cold and stable temperatures? Journal of Experimental Biology **218** (12): 1834–1845. DOI: 10.1242/jeb.116129

Briggs J.C. 2003. Marine centres of origin as evolutionary engines. Journal of Biogeography, 30 (1): 1–18. DOI: 10.1046/j.1365-2699.2003.00810.x

Bushula T., Pakhomov E.A., Kaehler S., Davis S., Kalin R.M. 2005. Diet and daily ration of two nototheniid fish on the shelf of the sub-Antarctic Prince Edward Islands. Polar Biology **28** (8): 585–593. DOI: 10.1007/s00300-005-0729-2

Coggan R. 1997. Growth: Ration relationships in the Antarctic fish *Notothenia coriiceps* Richardson maintained under different conditions of temperature and photoperiod. Journal of Experimental Marine Biology and Ecology **210** (1): 23–35. DOI: 10.1016/S0022-0981(96)02717-7

Dewitt H.H., Heemstra P.C., Gon O. 1990. Nototheniidae. Pp. 279–331. *In*: Gon O., Heemstra P.C. (eds.) Fishes of the Southern Ocean. J.L.B. Smith Institute of Ichthyology, Grahamstown, South Africa.

dos Santos J., Jobling M. 1995. Test of a food consumption model for the Atlantic cod. ICES Journal of Marine Science **52** (2): 209–219. DOI: 10.1016/1054-3139(95)80036-0

Eastman J.T. 1993. Antarctic fish biology: Evolution in a unique environment. Academic Press, San Diego, New York, Boston, London, Sydney, Tokyo, Toronto.

Eastman J.T., Clarke A. 1998. A comparison of adaptive radiations of Antarctic fish with those of non-Antarctic fish. Pp. 3–26. DOI: 10.1007/978-88-470-2157-0_1 *In*: di Prisco G., Pisano E., Clarke A. (eds.) Fishes of Antarctica: A biological overview. Springer-Verlag Italia, Milano, Italy. DOI: 10.1007/978-88-470-2157-0

Elliott J.M., Persson L. 1978. The estimation of daily rates of food consumption for fish. Journal of Animal Ecology **47** (3): 977–991. DOI: 10.2307/3682

Flores H., Kock K.-H., Wilhelms S., Jones C.D. 2003. Diet of two icefish species from the South Shetland Islands and Elephant Island, *Champsocephalus gunnari* and *Chaenocephalus aceratus*. Polar Biology **27** (2): 119–129. DOI: 10.1007/s00300-003-0570-4

Iwami T., Kock K.-H. 1990. Channichthyidae. Pp. 381–389. *In*: Gon O., Heemstra P.C. (eds.) Fishes of the Southern Ocean. J.L.B. Smith Institute of Ichthyology, Grahamstown, South Africa.

Johnston I.A., Battram J. 1993. Feeding energetics and metabolism in demersal fish species from Antarctic, temperate and tropical environments. Marine Biology **115** (1): 7–14. DOI: 10.1007/BF00349380

Kock K.-H. 1992. Antarctic fish and fisheries. Cambridge University Press, Cambridge, UK.

Kock K.-H. 2005. Antarctic icefishes (Channichthyidae): A unique family of fishes. A review, Part I. Polar Biology **28** (11): 862–895. DOI: 10.1007/s00300-005-0019-z

Kock K.-H., Jones C.D. 2002. The biology of the icefish *Cryodraco antarcticus* Dollo, 1900 (Pisces, Channichthyidae) in the southern Scotia Arc (Antarctica). Polar Biology **25** (6): 416–424. DOI: 10.1007/s00300-002-0357-z

Kock K.-H., Kellermann A. 1991. Reproduction in Antarctic notothenioid fish. Antarctic Science **3** (2): 125–150. DOI: 10.1017/S0954102091000172

La Mesa M., Castelli A., Eastman J.T., Riginella E. 2015. Factors involved in prey resource partitioning in the genus *Artedidraco* (Notothenioidei, Artedidraconidae) from the western Ross Sea. Hydrobiologia **761**: 249–259. DOI: 10.1007/s10750-015-2206-4.

La Mesa M., Eastman J.T., Vacchi M. 2004. The role of notothenioid fish in the food web of the Ross Sea shelf waters: A review. Polar Biology **27** (6): 321–338. DOI: 10.1007/s00300-004-0599-z

La Mesa M., Vacchi M., Castelli A., Diviacco G. 1997. Feeding ecology of two nototheniid fishes, *Trematomus hansoni* and *Trematomus loennbergii*, from Terra Nova Bay, Ross Sea. Polar Biology **17** (2): 62–68. DOI: 10.1007/s003000050105

Olaso I., Lombarte A., Velasco F. 2004. Daily ration of Antarctic silverfish (*Pleuragramma antarcticum* Boulenger, 1902) in the eastern Weddell Sea. Scientia Marina **68** (3): 419–424. DOI: 10.3989/scimar.2004.68n3419

Olaso I., Velasco F., Sánchez F., Serrano A., Rodríguez-Cabello C., Cendrero O. 2005. Trophic relations of lesser-spotted catshark (*Scyliorhinus canicula*) and blackmouth catshark (*Galeus melastomus*) in the Cantabrian Sea. Journal of Northwest Atlantic Fishery Science **35**: 481–494. DOI: 10.2960/J.v35.m494

Pahomov [Pakhomov] E.A. 1993. Pitanie i ocenka racjona seroj nototenii *Notothenia squamifrons squamifrons* na podnâtiâh Ob′ i Lena (Indookeanskij sector Antarktiki). [Feeding habitats and estimate of ration of gray notothenia, *Notothenia squamifrons squamifrons*, on the Ob and Lena tablemounts (Indian Ocean sector of Antarctica).] Voprosy ihtiologii **33** (9): 407–416. [In Russian.]

Pakhomov E.A. 1998. Feeding plasticity of the Antarctic fish *Trematomus hansoni* Boulenger, 1902 (Pisces: Nototheniidae): The influence of fishery waste on the diet. Polar Biology **19** (4): 289–292. DOI: 10.1007/s003000050248

Pakhomov E.A., Shumatova A.A. 1992. Feeding and estimation of daily ration of Wilson's glassfish, *Chaenodraco wilsoni*, of the Indian Ocean sector of Antarctica. Journal of Ichthyology **32** (7): 56–70.

Pakhomov E.A., Tseitlin V.B. 1991. Feeding pattern of nine species of Antarctic fish and assessment of their daily food consumption. Selected Scientific Papers, SC-CAMLR-SSP/8 (1991): 321–333.

Peck L.S., Webb K.E., Miller A., Clark M.S., Hill T. 2008. Temperature limits to activity, feeding and metabolism in the Antarctic starfish *Odontaster validus*. Marine Ecology Progress Series **358**: 181–189. DOI: 10.3354/meps07336

Pennington M. 1985. Estimating the average food consumption by fish in the field from stomach contents data. Dana **5**: 81–86.

Roper C.F.E., Sweeney M.J., Nauen C.E. 1984. FAO Species catalogue. Vol 3. Cephalopods of the World. An annotated and illustrated catalogue of species of interest to fisheries. FAO, Rome.

Ross S.T. 1986. Resource partitioning in fish assemblages: A review of field studies. Copeia **1986** (2): 352–388. DOI: 10.2307/1444996

Spreen G., Kaleschke L., Heygster G. 2008. Sea ice remote sensing using AMSR-E 89 GHz channels. *Journal of Geophysical Research* **113** (C2): eC02S03. DOI: 10.1029/2005JC003384

Vacchi M., La Mesa M. 1995. The diet of the Antarctic fish *Trematomus newnesi* Boulenger, 1902 (Nototheniidae) from Terra Nova Bay, Ross Sea. Antarctic Science **7** (1): 37–38. DOI: 10.1017/S0954102095000071

Vanella F.A., Boy C.C., Fernández D.A. 2012. Temperature effects on growing, feeding, and swimming energetics in the Patagonian blennie *Eleginops maclovinus* (Pisces: Perciformes). Polar Biology **35** (12): 1861–1868. DOI: 10.1007/s00300-012-1228-x

Received: 6 June 2019
Accepted: 19 October 2019
Published electronically: 1 March 2020