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BRIEF REPORT

Length–weight relationships and condition factors of six notothenioid fish species occurring off King George Island and Northern Victoria Land (Antarctica)

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Abstract
This research was conducted to study length–weight relationships (LWR) and condition factors of six Antarctic notothenioidei fish species including blackfin icefish (*Chaenocephalus aceratus*), single-angle icefish (*Chionodraco hamatus*), marbled rockcod (*Notothenia rossii*), black rockcod (*Notothenia coriiceps*), emerald rockcod (*Trematomus bernacchii*), and dusky rockcod (*Trematomus newnesi*) from the King Sejong Station on King George Island and Jang Bogo Station on the Northern Victoria Land. A total of 232 specimens were collected by fishing on the icebreaking research vessel ARAON from December 2020 to February 2021. The LWR parameters and condition factors differed depending on species, which can be affected by their distribution, species characteristics, and gravidity status. The exponent *b* values in LWR ($W = aL^b$) ranged from 2.593 to 5.184. Four species including *C. aceratus*, *C. hamatus*, *N. rossii*, and *T. bernacchii* followed positive allometric growth, *T. newnesi* followed negative allometric growth, and only *N. coriiceps* showed isometric growth. These results can be helpful in understanding the ecological and growth conditions of six fish species living in the Antarctic Ocean, providing more information for future research on Antarctic fish.

Keywords Notothenioidei · Length–weight relationships · Condition factors · Antarctic fish

Introduction

Notothenioidei have a unique morphological and physiological range of adaptations to live in cold water, accounting for approximately 45% of all known fish species in the Antarctic region. The suborder accounts for approximately 95% of the total fish biomass in the shelf zone (Eastman 2005; Stefanov 2022). The importance of notothenioids in the Antarctic food web has been widely studied (Eastman 1985; Barrera-Oro 2002; Stefanov 2022). Approximately 140 species of fish live in the Antarctic Ocean. Antarctic fish species were exploited through commercial fishing activities in the Southern Ocean in the late 1970s and early 1980s (Kock et al. 2000; Kock 2007). As a result of this commercial exploitation, these stocks declined rapidly, raising significant concerns due to the potential environmental impacts and the vulnerability of these species, characterized by long lifespans and slow growth rates. In order to regulate and control the exploitation of Antarctic fish, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) was founded in 1982 (Kock 2007). Since then, ongoing efforts have been made to recover the Antarctic fish biomass. The length–weight relationships (LWR) is an useful parameter in ecology, physiology, and biology (Bolognini et al. 2013) and is one of the methods frequently used in fisheries management to determine the growth pattern and nutritional conditions of fish resources in an aquatic ecosystem and to predict the weight of fish with a given length when evaluating fisheries yields (Froese 2006; Hossain et al. 2006; Torres et al. 2012; Froese et al. 2014). This parameter also provides information about fish habitats and an approach for comparing various populations of fish in similar or different ecosystems (Stergiou and Moutopoulos 2001; Odat 2003; Thomas et al. 2003; Ouahb et al. 2021) and is indispensable data for stock assessment (Tsoumani et al. 2006; Torres et al. 2012). The condition factor allows

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the collection of appropriate information on the status of fish in terms of their allometric size, with the assumption that for a given length, the fish are in better condition if they are heavier (Froese 2006; Paugy et al. 2017). Many studies have used condition factors to compare the general physiological status of populations following seasons or locations with similar or different ecological conditions (Le Cren 1951; Lizama and Ambrósio 2002; Pervin and Mortuza 2008; Gupta et al. 2011; Dan-Kishiya 2013; Sarkar et al. 2013; Pouladi et al. 2020). However, there are not many information on the condition factors of Antarctic fish in the Antarctic Ocean, as well as a scarcity of data comparing and analyzing the variations in fish length–weight relationships across different regions and years. Study on the condition factors of Antarctic fishes in various locations and over multiple years is essential for understanding the varying patterns, growth rates, biomass of biological populations, and the relationship between environmental changes and the growth patterns of Antarctic organisms. This information helps obtain the necessary data for sustainable fish resource management and conservation. Therefore, this study could provide valuable insights into the recovery and management of exploited populations, as well as fundamental data to extend the understanding of the ecosystem of the Southern Ocean and species-specific relationships among components, including fish.

Materials and methods

Fish were collected using a rod and line and fish traps on board of the icebreaker vessel, Araon, around the two Korean Antarctic Research Stations: The King Sejong Station on King George Island and Jang Bogo Station on the Northern Victoria Land, from December 2020 to February 2021. A total of 232 individuals from six species of fish were caught during this period. Among the Notothenoidei, four species of the Nototheniidae family, including *Notothenia rossii*, *Notothenia coriiceps*, *Trematomus bernacchii*, and *Trematomus newnesi* and two species of the Channichthyidae family, *Chaenocephalus aceratus* and *Chionodraco hamatus* were recorded for this study. A summary of the collected fish is shown in Online Resource 1. The collected fish were transported live in a cold water aquarium of the Araon and frozen at − 20 °C immediately in case of death. To calculate the LWR of frozen fish, the total length (TL) and total weight (TW) of 232 fish samples were measured using a fish measuring board and an electronic scale.

The LWR was calculated using the equation $W = aL^b$ (Le Cren 1951) and its logarithmic form equation $\log W = \log a + b \log L$, which gives the linear equation to estimate the parameters a and b by linear regression where W = total weight, L = total length, a = constant, and b = slope of line. Among the factors, the b value determines the allometric growth pattern of fish. When the b value is 3, it means isometric growth that as the length increases, its weight also increases in direct proportion. When the b value is higher than 3, it suggests positive allometric growth which means that its weight increases at a faster rate than length and becomes relatively heavier as it grows. When the b value is less than 3, it indicates negative allometric growth, which shows that fish become relatively lighter with increasing length. LWR were estimated using regression analysis within Microsoft Excel based on weight and length data. To check for significant differences between the calculated b values and isometric values ($b = 3$), a t-test was performed. If there was a statistically significant difference between the b value and 3 ($p < 0.05$), positive allometric growth ($b > 3$), or negative allometric growth ($b < 3$), the b value was not statistically different from 3, which indicated isometric growth ($b = 3$) (Eastman and Sidell 2002; Eastman et al. 2011; Park et al. 2017).

Fulton's condition factor was estimated using the equation $K = 100 \times W/\mathrm{TL}^3$ (Nash et al. 2006), where K is the condition factor, the constant 100 is employed to normalize K toward unity, W is the total body weight, TL is the total body length, and 3 is a constant. The higher K value means that the fish is in better condition, and their well-being is generally good. The relative condition factor was expressed according to the formula $Kn = W/aL^b$ (Le Cren 1951), where Kn is the relative condition factor, W is the weight, and aL^b is the value calculated from the LWR using the values of length and weight of fish. If the Kn value is greater than 1, it means the fish has a good overall growth condition than the average. If the Kn value is lower than 1, it indicates the fish has a poor growth condition than the average.

Results and discussion

In the present study, we analyzed the LWR values of six species and obtained linear regression equations for each of them. The sampling location, number of specimens, total length, total weight, LWR, and condition factors for six species are presented in Table 1. Our results indicate that four species of *C. aceratus*, *C. hamatus*, *N. rossii,* and *T. bernacchii* followed a positive allometric growth pattern with equations $\log W = 5.1842 \log \mathrm{TL} - 11.0025$ ($R^2 = 0.9486$, $p < 0.05$), $\log W = 3.2335 \log \mathrm{TL} - 5.9014$ ($R^2 = 0.6915$, $p = 0.081$), $\log W = 3.2670 \log \mathrm{TL} - 5.5743$ ($R^2 = 0.9289$, $p < 0.05$), and $\log W = 3.0947 \log \mathrm{TL} - 5.1063$ ($R^2 = 0.9604$, $p < 0.05$), respectively. *N. coriiceps* exhibited an isometric growth pattern, showing and equation of $\log W = 3.0380 \log \mathrm{TL} - 4.9301$ ($R^2 = 0.9148$, $p < 0.05$), while *T. newnesi* displayed a negative allometric growth pattern with and equation of $\log W = 2.5927 \log \mathrm{TL} - 4.0505$ ($R^2 = 0.6490$,

Table 1 Length—weight relationships and condition factors of Antarctic fish

Location	Species	n	Total length (mm)			Total weight (g)			Length–weight relationships				Condition factors	
			Mean	Min	Max	Mean	Min	Max	log a	b	Growth pattern	R^2	K	Kn
King Sejong Station	*Chaenocephalus aceratus* (total)	11	500.5	415.0	560.0	1075.8	374.0	1870.6	−11.002	5.184	A^+	0.9486	0.80	1.00
	Chaenocephalus aceratus (gravid)	7	526.4	480.0	560.0	1349.2	839.4	1870.6	−11.746	5.461	A^+	0.8902	0.90	1.06
	Chaenocephalus aceratus (non-gravid)	4	455.0	415.0	510.0	597.4	374.0	940.0	−7.897	4.008	A^+	0.9227	0.61	1.05
	Notothenia rossii	39	324.7	227.0	390.0	453.3	140.0	794.0	−5.574	3.267	A^+	0.9289	1.25	0.89
	Notothenia coriiceps	11	335.0	205.0	413.0	598.8	113.5	1106.5	−4.930	3.038	A^0	0.9148	1.48	1.19
Jang Bogo Station	*Chionodraco hamatus*	5	367.2	324.0	420.0	258.5	128.3	374.7	−5.901	3.234	A^+	0.6915	0.51	1.28
	Trematomus bernacchii	130	196.4	112.0	280.0	111.2	18.0	331.1	−5.106	3.095	A^+	0.9604	1.30	0.99
	Trematomus newnesi	36	182.2	160.0	212.0	66.4	36.8	121.9	−4.051	2.593	A^-	0.6490	1.08	1.00

A^0 isometric growth, A^+ positive allometric growth, A^- negative allometric growth

$p < 0.05$) (Fig. 1). The average length of the two icefishes was 458.8 mm, which was larger than that of other fish species, with an average length of 224.3 mm ($p < 0.05$).

The regression model of length and weight showed that the b value of *C. aceratus* was much higher than 3 at 5.184 ($p < 0.05$), following allometric growth. This result was different from the average value of 3.680 obtained from Elephant Island, South Orkney Island, and South Shetland Islands (Kock 1986; Kock et al. 2000; Eastman and Sidell 2002), whereas it was similar to Casaux et al.'s (2003) result of 5.578 from the Danco Coast (Casaux et al. 2003) (Fig. 2). The b value for *C. hamatus* was 3.234, similar to the result of 3.496 for fish caught in the Atlantic sector of the Southern Ocean (Wei et al. 2017) (Fig. 2). The regression model of *C. hamatus* was not significant ($p = 0.081$). This could be explained by the small number of specimens ($n = 5$), leading to difficulties in creating a model that is representative of the entire population. However, the data could be accepted with a significance value of 0.1, with the aim of generating a reference for other studies of *C. hamatus* in this area.

N. rossii follows positive allometric growth with b value of 3.267. This result was similar to the results of 3.55 reported from King George Island by Park et al. (2017) and 3.12 by Eastman et al. (2011), and from South Shetland Islands ($b = 3.44$) (Eastman and Sidell 2002), South Orkney Islands ($b = 3.16$) (Kock et al. 2000), and Elephant Island ($b = 3.19$ and 3.30) (Kock 1986; Balguerias and Quintero 1989) (Fig. 2). This result was different from that obtained at Livingston Island ($b = 3.07$) (Fig. 2), which showed an isometric growth pattern (Stefanov 2022).

The b value for *T. bernacchii*, was 3.095 ($p < 0.05$), indicating positive allometric growth. This result shows growth patterns similar to other data reported on the Danco coast ($b = 3.859$) (Casaux et al. 2003). For *T. newnesi*, the b-value was 2.593 ($p < 0.05$), indicating negative allometric growth. This result indicates different growth patterns from other published information on the South Orkey Islands ($b = 4.049$) (Kock et al. 2000) and the Danco Coast (Casaux et al. 2003) (Fig. 2), which showed positive allometric growth.

Regarding the case of condition factors for icefishes, the average K value of *C. aceratus* was 0.80, and the average Kn value was 1.00. As for *C. hamatus,* the average K value was 0.51, and the average Kn value was 1.28. In the case of *Notothenia* species, the average K values for *N. rossii* and *N. coriiceps* were 1.25 and 1.48, respectively; and the average Kn values for these two species were 0.89 and average 1.19, respectively. Similarly, the average K for two fishes of *Trematomus*, *T. bernacchii* and *T. newnesi* were 1.30 and 1.08, and the average values for Kn were 0.99 and 1.00, respectively. The K values of *N. rossii*, *N. coriiceps*, *T. bernacchii*, and *T. newnesi* were greater than 1, suggesting that these species were fattened. The K values of *C. aceratus* and

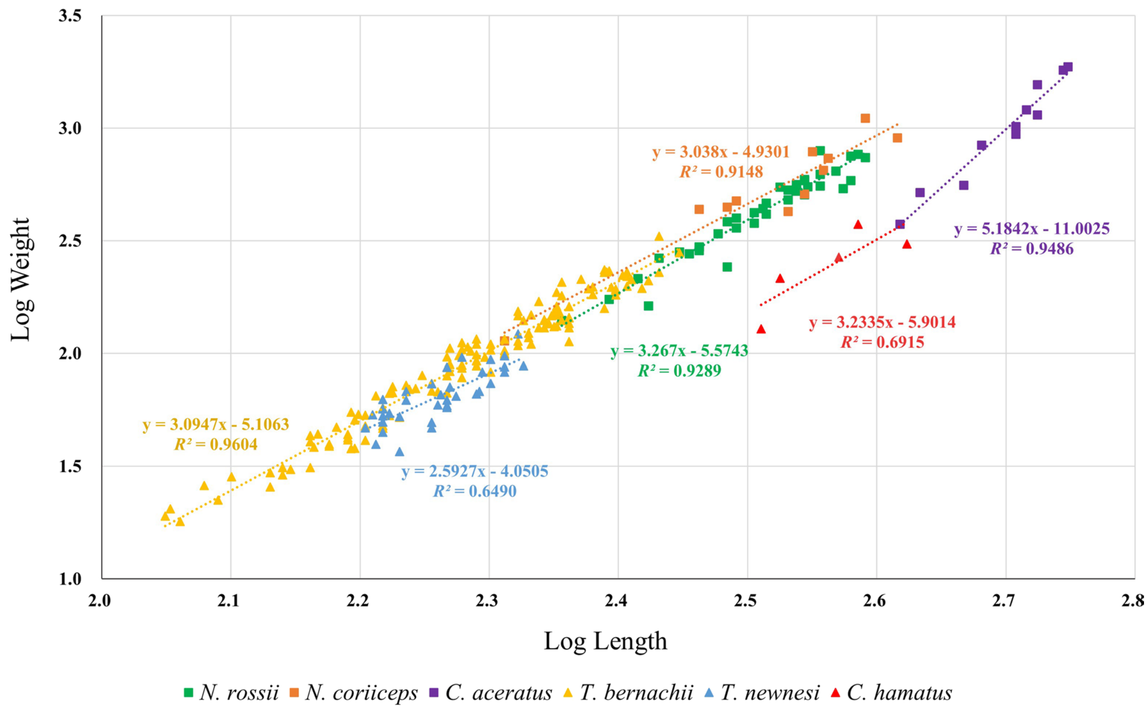

Fig. 1 Logarithmically transformed linear regression of length–weight relationships of Antarctic fishes. The triangle symbols, fishes from King Sejong Station; the square symbols, fishes from Jang Bogo Station

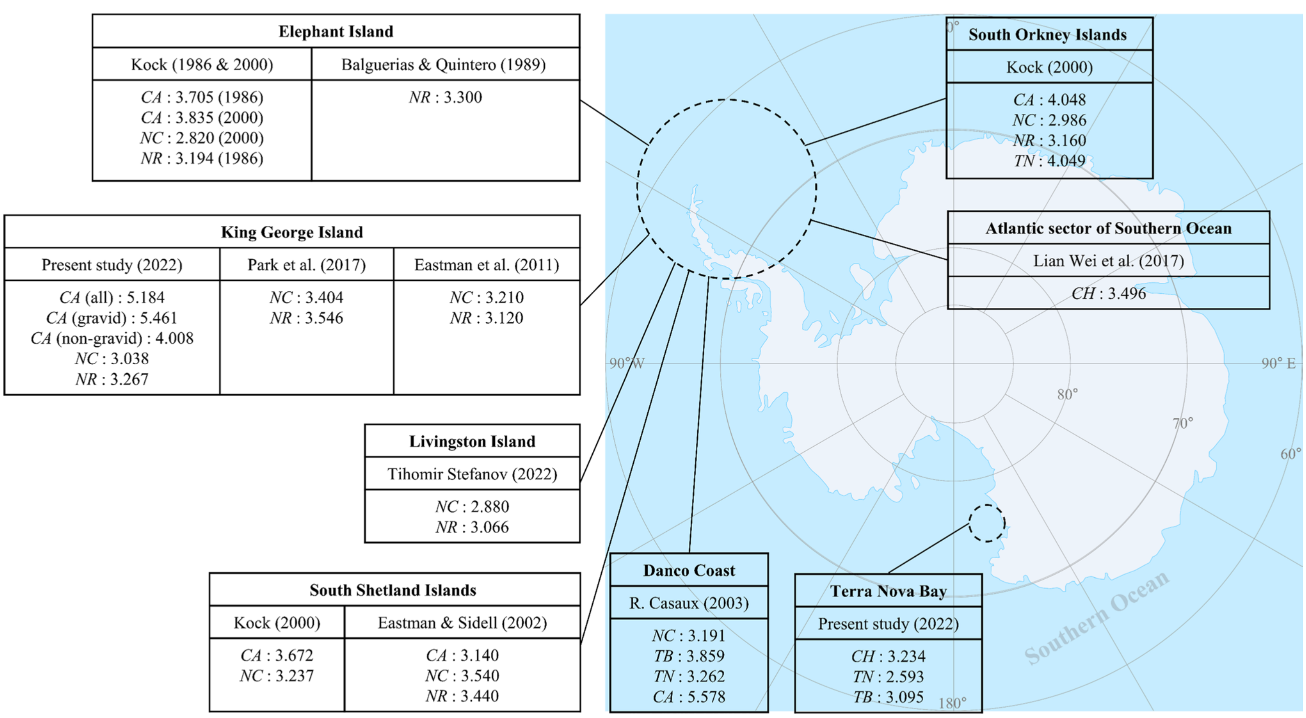

Fig. 2 Map showing LWR of previously reported fish species and fish collected in this study. *CA*, *Chaenocephalus aceratus*; *CH*, *Chionodraco hamatus*; *NC*, *Notothenia coriiceps*; *NR*, *Notothenia rossii*; *TN*, *Trematomus newnesi*; *TB, Trematomus bernacchii*

C. hamatus were less than 1, suggesting that these species were relatively thinner. The *Kn* values of *N. coriiceps* and *C. hamatus* were higher than 1, which suggests that these species were in good growth conditions in their biotopes. The *Kn* values of *N. rossii* and *T. bernacchii* were lower than 1, suggesting that these species were in poor condition in their biotopes. The value of *Kn* for *C. aceratus* and *T. newnesi* was 1, which suggests that these species were in normal conditions in their biotope. In the case of *C. aceratus*, there were seven gravid fish with an average weight of 1349.2 g among the 11 specimens, and the other four non-gravid specimens were much lighter, with an average weight of 597.4 g. This difference in weight leads to a difference in the condition factor of 0.61 in non-gravid fish, compared to 0.9 for gravid fish. There have also been other reports on this parameter. The condition factor of the icefish sampled from the Palmer Station was 0.61 (Eastman and Sidell 2002), a value equal to non-gravid icefish in this study, whereas the result obtained from the Southwest and Northwest of Low Island was 1.05 (Le François et al. 2017), larger than the *K* value of gravid fish in this study.

These results suggest that the blackfin icefish (*C. aceratus*) were in the breeding season from December to January around King Sejong Station and from March to April around the Southwest and Northwest of Low Island, but not in the breeding season around Palmer Station from June to July (Eastman and Sidell 2002; Le François et al. 2017). Most of the 18 Antarctic icefish species spawn between late summer (January and February) and early winter (May and June) (Kock and Kellermann 1991; Duhamel et al. 1993; La Mesa et al. 2003; Kock 2005).

Conclusion

In conclusion, the LWR parameters and condition factors differed depending on species, which can be affected by their distribution, species characteristics, and gravidity status.

The fish caught in Jang Bogo Station tended to be heavier than fish caught near King Sejong Station. The two species of the family Channichthyidae were longer than the four species in the family Nototheniidae. In *C. aceratus*, there were different values of LWR and condition factors according to gravidity status. This study provides more detailed and clear information about the parameters of fish growth, including LWR and condition factors, for six representative Antarctic fishes. In addition, this could be a fundamental base reference for extending further research on fishes living in one of the most extreme environments on Earth.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00300-023-03178-w.

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Data availability All data analyzed during this study are included in this published article [Online Resource 2].

Declarations

Competing interests The authors have declared that no competing interests exist.

Ethical approval All international, national, and institutional guidelines for sampling of organisms in the polar regions have been followed.

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