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Study on the relationship between the diameter of the compound eye and the growth of the Antarctic krill

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Abstract Correlation between the body length and the diameter of the compound eye of the Antarctic krill *Euphausia superba* was examined. From the samples collected in the late summer, it shows that there is an apparent exponential relationship between eye diameter and the body length. From the laboratory population, it seems that when the krill shrink, the diameter of the compound eye does not decrease. It is more reliable to use the eye diameter as krill growth index than body length. The ratio of the body length to the diameter of the compound eye offers another method for detecting the effect of shrinking in natural populations of krill.
Key words Antarctic krill, growth, shrinkage, compound eye.

1 Introduction

Antarctic krill (*Euphausia superba* Dana) is growing by successive molts with a renewal of the skeleton each time. Ikeda and Dixon (1982) demonstrated in the laboratory that adult krill could survive more than 200 days in the state of starvation and during this period the krill continued to moult-reducing their body size at each moult. Because krill continues to moult regularly even if being deprived of food, it is difficult to determine their age directly by using classical methods as on calcified structures (e. g. otoliths of fish and shells of mollusc). Krill age has traditionally been estimated by measuring the size (Marr, 1962; Ivanov, 1970; Mackintosh, 1972), because krill can increase or decrease in size, even as adults, there is not a simple relationship between their size and age (Thomas and Ikeda, 1987; Nicol, 1990; Nicol *et al.*, 1992).

This paper is to discuss the relationship between the diameter of the compound eye and the growth of the krill and to make it possible by using the diameter of the compound eyes of krill to determine their age.

2 Materials and methods

Materials examined in this experiment include two parts: living krill and preserved specimens. Samples of preserved krill used for this study were collected during the following two high summer cruises: 19 January～14 February, 1991 and 19 January～7

February, 1993. In addition, samples were also collected during late spring and early summer: 22 November ~ 19 December, 1982. All specimens were preserved in Steedman's solution (Steedman, 1976) for later examination. After the cruises the krill were sorted into juvenile, male or female. Living Antarctic krill were collected from the Prydz Bay region on 3 occasions: 22 February, 1992 (position: 64°59.99′S, 77°39.85′E), 19 March, 1992 (position: 63°45.6′S, 105°10.9′E) and 30 March, 1993 (position: 64°39.0′S, 77°35.6′E). Living krill were randomly collected from the catch and placed in plastic containers containing freshly collected surface sea water. The containers were maintained at 0℃ (the ambient surface sea water temperature was between −1℃ and 1℃) in the dark and were checked daily. After being transferred to the cool room in the Australian Antarctic Division, they were maintained in an aquarium under constant conditions at 0℃. 50 specimens were randomly collected from the catch and preserved in Steedman's solution (Steedman, 1976) for later examination. The aquarium kept krill had been starved, and were known to be shrinking. A sample of the aquarium kept population was removed in July 1993, November 1993 respectively and the animals were preserved in Steedman's solution for later analysis.

The preserved krill were collected using a Rectangular Midwinter Trawl (RMT1+8, Baker *et al.*, 1973) between 19 January and 7 February, 1993 during summer cruise in the Prydz Bay. Sampling stations were located at the area of 65°00.0′~69°00.0′S, 67°00.0′~78°00.0′E, the Prydz Bay, Antarctica.

3506 preserved specimens and 168 aquarium-kept krill were examined. Body length (standard 1, Mauchline 1980) was measured to 0.01 mm. The left compound eye was severed from the krill and the diameter of the eye was measured using an image analysis system, 1×10^{-5} accuracy.

3 Results

3506 krill from high summer collection were measured for body length (BL) and diameter of the compound eye (ED). Fig. 1 shows the relation between ED and BL. Inspection of these data indicated an exponential relationship between ED and BL, i. e.

$$ED = \kappa e^{\lambda BL}$$

An exponential regression gave the following equation:

$$ED = 0.574e^{0.0292BL}, \quad r = 0.9495$$

The high correlation between length and the eye diameter means that the diameter of the compound eye can be considered a proximate measure for the krill growth.

Among the 3506 high summer collected krill, there are 1347 female krill, 1072 juvenile krill and 748 male krill. As the juvenile will be divided into female or male, so the data of the female and that of the juvenile was put together when we analysed the data for the inspection of the relation between the eye diameter and the body length. Fig. 2 shows the relationship between the diameter of the compound eye and the body length of the female krill. It is clear that the eye diameter and the body length of the female krill have an exponential relationship. The following function was fitted to the data:

$$ED = 0.5898e^{0.0282BL}, \quad r = 0.9613$$

Fig. 3 shows the relation between the diameter of the compound eye and the body length of the male krill. The relationship between the eye diameter and the body length of the male krill is also exponential. The following function was fitted to the data of the male krill:

$$ED = 0.544e^{0.0309BL}, \qquad r = 0.9622$$

To compare Fig. 2 and Fig. 3 and the functions for the female and male, we can see that the diameter of the male is apparently bigger than that of the female.

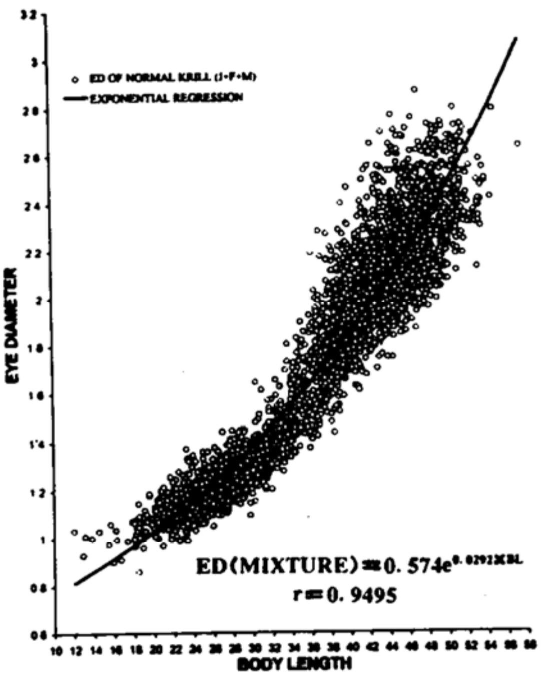

Fig. 1. Relationship between body-length and the diameter of the compound eye of the Antarctic krill for samples collected in late summer.

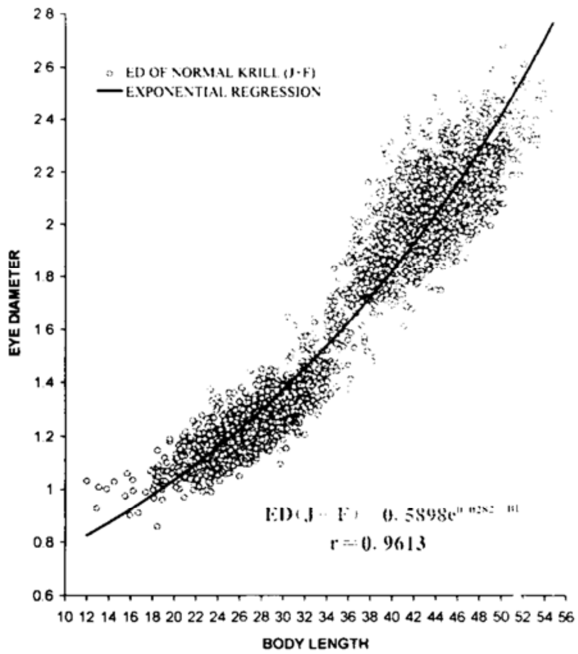

Fig. 2. Relationship between body-length and the diameter of the compound eye of the female krill for samples collected in late summer.

As the compound eye is composed of crystalline cones, so that if the number of the crystalline cone does not decline as animals shrink (Sun and Wang, 1995), the diameter of the compound eye may also not declined as the krill shrink. To test whether this is the case, 70 female and 25 male krill were measured. This sample had been kept in the Australian Antarctic Division's aquarium for 8 months under conditions which lead to shrinkage. There is clear evidence of shrinking in this sample with the mean length declining from 33.13 mm to 25.94 mm. The length distributions at capture and after 8 months in the aquarium are shown in Fig. 4. There is clear evidence of shrinking in this sample with the mean length declining from 32.93 mm to 29.36 mm.

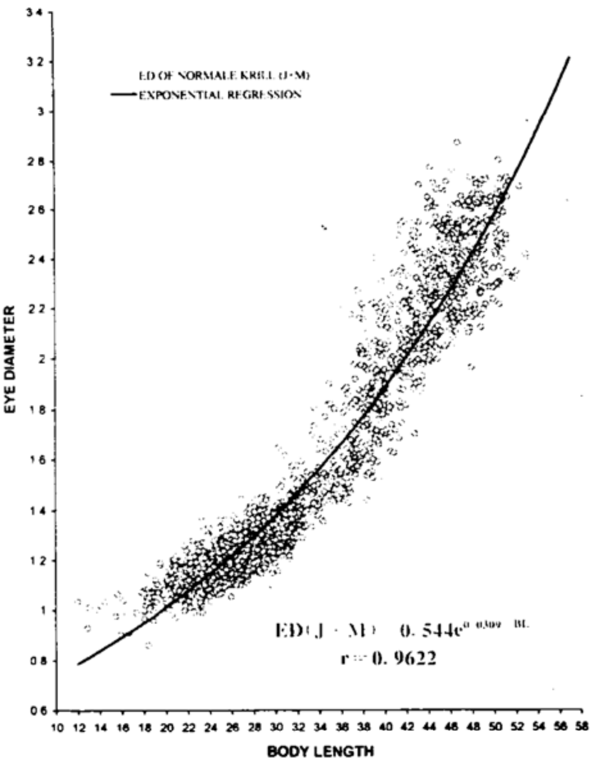

Fig. 3. Relationship between body-length and the diameter of the compound eye of the male krill for samples collected in late summer.

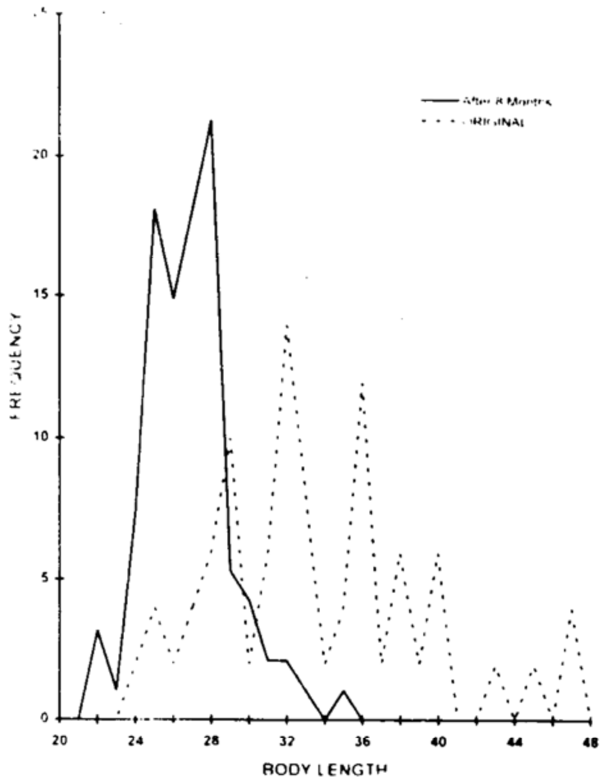

Fig. 4. Length distributions of samples at capture (before shrinkage) and after maintenance in the aquarium for 8 months (after shrinkage).

Table 1. ANOVA for BL differences between samples at capture (before shrinkage) and after maintenance in the aquarium (after shrinkage)

Summary				
Groups	Count	Sum	Average	Variance
After 8 months	50	1468.16	29.36	6.68
Oringinal	50	1646.3	32.93	28.87

Anova						
Source of variation	SS	df	MS	F	P-value	F crit
Between groups	317.34	1	317.34	17.85	5.3586E−05	3.94
Within groups	1742.15	98	17.78			
Total	2059.49	99				

The ANOVA given in Table 1 shows that the body length (BL) of the krill after shrinkage and before shrinkage is statistically significant at the P = 0.01 level.

The diameter of the compound eye versus body length for the laboratory shrunk krill (1993) are shown in Fig. 5 and Fig. 6 as solid triangles.

The ANOVA given in Table 2 and Table 3 show that the ratios (BL/ED) of the high summer krill and the laboratory shrunk krill are statistically significant at the P = 0.01 level.

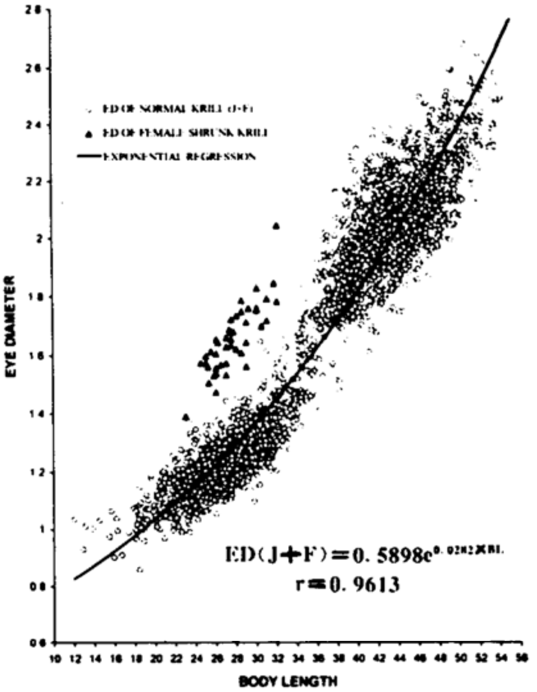

Fig. 5. Comparison of the difference of the diameter of the compound eye between the laboratory shrunk female krill and the normal (high summer) female krill.

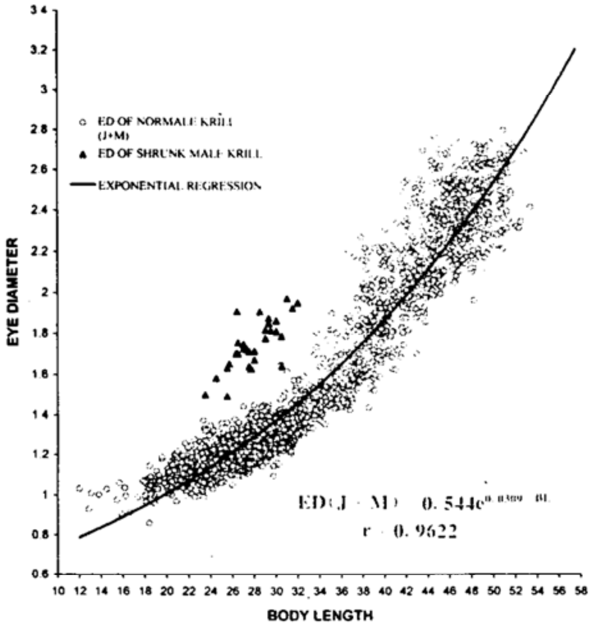

Fig. 6. Comparison of the difference of the diameter of the compound eye between the laboratory shrunk male krill and the normal (high summer) male krill.

Table 2. ANOVA for BL/ED ratio differences between high summer and laboratory shrunk samples (female)

Summary						
Groups	Count		Sum	Average		Variance
NM-F	1347		28718.29	21.32		2.34
SHRUNK-F	70		1092.19	15.60		1.49
Anova						
Source of variation	SS	df	MS	F	P-value	F crit
Between groups	2175.26	1	2175.26	947.24	1.1428E−159	6.72
Within groups	3249.44	1415	2.30			
Total	5424.70	1416				

It is clear that the diameter of the compound eye of the laboratory shrunk sample is significantly greater than that of the high summer field samples at the same body length. This result supports the hypothesis that the diameter of the compound eye does not decrease as animals shrink.

Table 3. ANOVA for BL/ED ratio differences between high summer and laboratory shrunk samples (male)

Summary					
Groups	Count		Sum	Average	Variance
NM-M	748		15469.50	20.68	4.17
SHRUNK-M	25		381.35	15.25	1.05

Anova						
Source of variation	SS	df	MS	F	P-value	F crit
Between groups	712.51	1	712.51	174.99	3.77893E−36	6.72
Within groups	3139.28	771	4.07			
Total	3851.79	772				

4 Discussion

If body length of the krill is considered to be a proximate measure for age, then the high correlation between body length and the diameter of the compound eye means that the latter can also be considered a proximate measure for age. The apparent exponential relationship between the diameter of the compound eye and body length implies that the diameter of the compound eye will be a better parameter for the age determination than the body length.

The prospect that the diameter of the compound eye appears to be relatively unaffected by shrinking indicates that it is a more reliable indicator of age than that obtained from length data. At a minimum, the ratio of body-length to the diameter of the compound eye offers a method for detecting the effect of shrinking in natural populations of krill.

It was demonstrated that the number of the crystalline cones of the compound eye was not affected by krill body shrinkage (Sun *et al.*, 1995; Sun and Wang, 1995). But the procedures of counting the crystalline cones of the compound eye is complex and it is hard for us to measure the samples on a large scale. To measure the diameter of the compound eye is easier than to count the number of the crystalline cone, it is just as easy as to measure the body length, and it is suitable for measuring krill on a large number.

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