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Using Antarctic Krill as an Indicator of Environmental Interannual Change

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ABSTRACT. Antarctic krill can increase or decrease in size depending on the food availability. From the observations on a laboratory-shrunk population, it seems that when the krill shrink, the diameter of the compound eye keep remain constant . The mean ratio of the body length to the diameter of the compound eye offers a method for detecting the effect of shrinking in natural populations of krill. Using this method to examine the field samples, it appears that the early field sample had subjected to shrinking in the winter. The sample collected on early summer (Dec. 4) had almost grown to the original size (before shrinkage). While the body length was recovering, the compound eye kept constant until the body length grow to the point beyond to the original size (before shrinkage). This work demonstrates that the influence of the environmental variability to the krill population can be determined by the inspection of the body length and the diameter of the compound eye measurement.

Key Words: Antarctic krill, compound eye, interannual change, shrinkage

Introduction

The Southern Ocean Marine Ecosystem is physically highly variable both seasonally and interannually. The Antarctic marine food web is unique in that it is characterized by dependence on a single key species, Antarctic krill, and by dependence of many of the components of this food web on sea-ice during some or all of their life history. These unique characteristics make this ecosystem especially vulnerable to changes in environmental conditions. Predictions of the Antarctic marine food web responses to environmental variability and climate change first require understanding and documentation of the cycles of natural population variability.

Antarctic krill has often been referred to as the key species in the Antarctic ecosystem because of its great abundance, and its position in the food web; it links the microscopic algae of the water and the larger animals such as fish, squid, seals, birds and whales which depend on it for food. It was recommended that Southern Ocean GLOBEC program includes the study of regional differences in overwintering strategies of Antarctic krill in relation to the physical environment. Laboratory studies show that adult Antarctic krill can survive more than 200 days of starvation and during this period the animals continue to moult - reducing their body size at each moult (Ikeda and Dixon 1982). The ability to survive for long periods of starvation by shrinkage may be a partial answer to the question of what happens to the huge population of these animals during the long and dark Antarctic winter. Euphausiids are not rich in lipids and wax esters, which often stored by crustaceans during long-term food shortages. Shrinking krill may be able to survive during the winter by utilizing their own body protein as fuel. Thus the mean size of individuals in a population at the end of winter could be considerably smaller than it was at the end of summer.

If body shrinkage is the overwintering strategy of

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krill, then it could be hypothesized that there should be a selection order in utilizing organ systems, and the organs which have no function during winter, for example, the reproductive system would be utilized as the first priority. If this hypothesis could be right, this would result in a group indistinguishable in external morphology from the juvenile group. It is important to recognize that the negative growth trajectories of reduction in size need not have the same slopes (but the opposite sign) to the positive growth trajectories followed in spring and summer; nor need all parts of the body follow precisely the same trajectory. Thus there may be subtle morphological differences between the juveniles and the adult group posing as juveniles, and also possibly between the adult age groups.

Sun *et al.* (1995) demonstrated that when a krill shrinks, the number of the crystalline cone in the compound eye keep constant. On the basis of the crystalline cone number count, they suggest that *Euphausia superba* shrink in length during winter and that such shrinkage can be detected by using the ratio of the crystalline core number to the body length.

This paper reports an investigation into the relationships among the ratio of the body length to the diameter of the compound eye, the relationship between the ratio fluctuation and the environment variation, the effects of sexual dimorphism in eye size between males and females, and the eye size change pattern following the body length re-growth.

Materials and Methods

Materials examined in this experiment include two parts: live 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 collected during late spring and early summer: 22 November-19 December, 1982. Sampling stations were located at the area of 65°00.0'-69°00.0' S, 67°00.0'-78°00.0' E, Prydz Bay, Antarctica. 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. Live Antarctic krill were collected from the Prydz Bay Region off Antarctica on 3 occasions: 22 February 1992 (64°59.99' S, 77°39.85' E), 19 March 1992 (63°45.6 S, 105°10.9' E) and 30 March 1993 (64°39.0' S, 77°35.6' E). They were maintained in an aquarium under constant conditions at 0°C. A sample of the population was removed in July 1993 and the animals were preserved in formalin for later analysis.

3,506 preserved specimens and 168 aquarium-kept krill were examined. Body length was measured from the tip of the rostrum to the tip of the uropod (standard 1 measurement; Mauchline 1980). The left compound eye was served from the krill, and the diameter of the eye was measured using an image analysis system.

Results

Among the 3,506 high summer collected krill, there are 1,347 female, 1,072 juveniles and 748 male krill. As the juvenile will divided to female and male, so the data of the female and the juvenile were put together when we analyzed the data for the inspection of the relationship between the eye diameter and the body length. Figure 1 shows the relationship between the diameter of the compound eye and the body length of the female. 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:

$$ED=0.5893e^{0.0282BL} \quad (r^2=0.9242)$$

Figure 2 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:

$$ED=0.544e^{0.0309BL} \quad (r^2=0.9258)$$

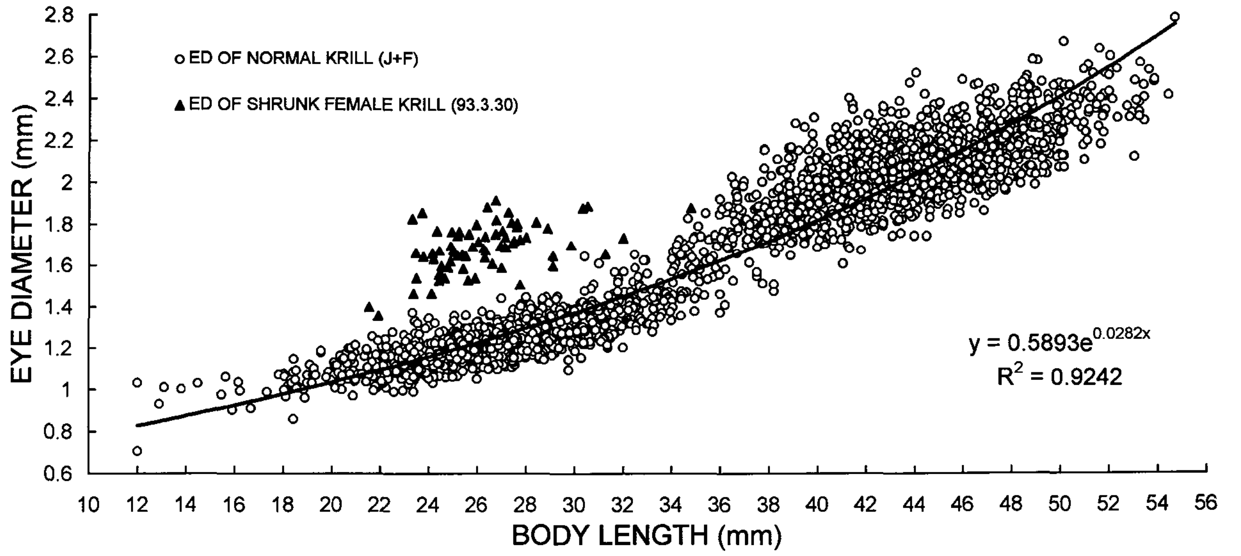

Fig. 1. Relationship between the diameter of the compound eye and the body length of the Antarctic krill for samples collected in high summer and the laboratory shrunk (female).

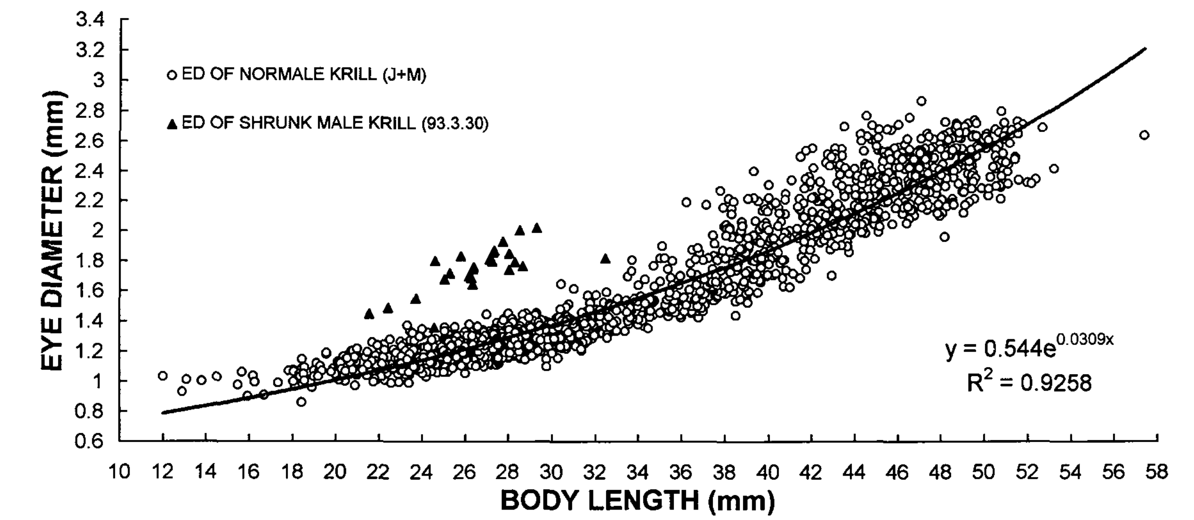

Fig. 2. Relationship between the diameter of the compound eye and the body length of the Antarctic krill for samples collected in high summer and the laboratory shrunk (male).

From the comparison of Figs 1 and 2 for the female and male, we can see that the diameter of the male is apparently bigger than that of the female.

Because the compound eye is composed of crystalline cones, the number of the crystalline cone does not decline as animals shrink (Sun *et al.* 1995), so that the diameter of the compound eye will also not declined as the krill shrink. To test whether this is the case, a sample of laboratory shrunk krill were measured. This sample had been kept in the Australian Antarctic Division's aquarium for 8 months under conditions which lead to shrinkage (Nicol *et al.* 1991). The eye diameter of the compound eye versus body length for the sample of laboratory shrunk krill are shown in Figs 1 and 2 as solid triangles.

The length distributions at capture and after 8 months in the aquarium are shown in Fig. 3. There is clear evidence of shrinking in this sample with the mean length declining from 33.13 to 25.94 mm.

The ANOVA given in Table 1 shows that the body length (BL) of the krill after shrinkage and before shrinkage are statistically significant at the $P = 0.01$ level. The ANOVA given in Tables 2 and 3 show that the ratios (BL/ED) of the high summer krill and the laboratory shrunk krill are statistically signifi-

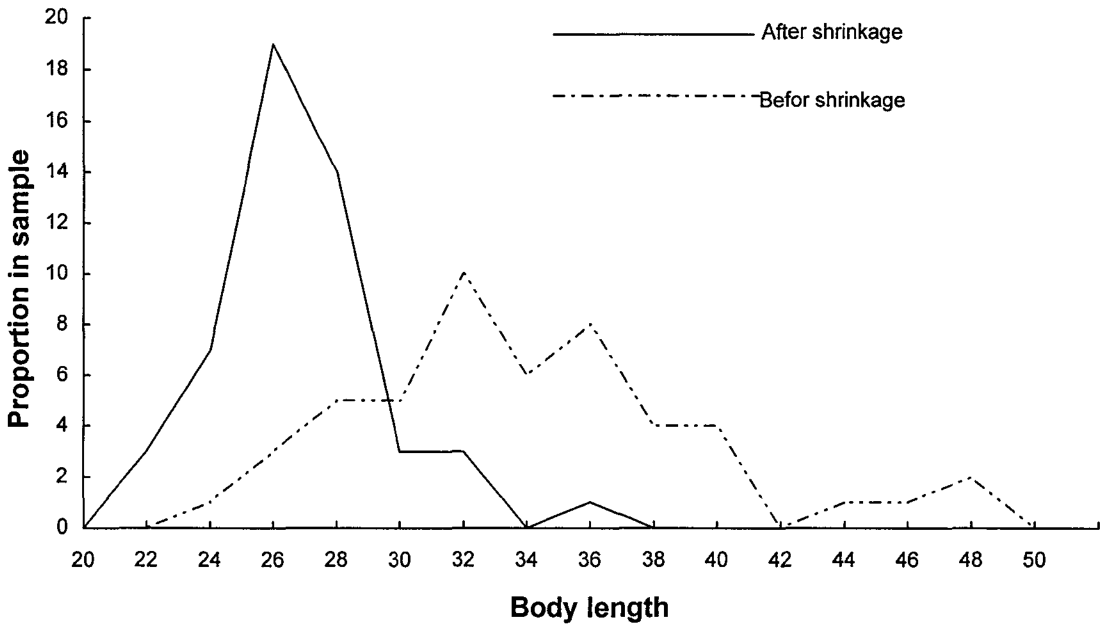

Fig. 3. Length distribution of samples at capture (before shrinkage) and after maintenance in the aquarium (after shrinkage).

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*		
	Before shrinkage	50	1651.25	33.03	28.35		
	After shrinkage	50	1296.84	25.94	7.16		
ANOVA	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	1256.06	1	1256.06	70.74	3.34736E-13	6.90
	Within Groups	1740.12	98	17.76			
	Total	2996.19	99				

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				

cant at the P=0.01 level.

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

According to these results, other three field samples were analyzed: the first one was taken on Nov. 22 (spring), very soon after the retreat of the sea ice. If there was shrinking in natural krill populations, the effects of the shrinking would still be present; the second one was taken on Dec. 4, when the algal bloom was occurred; the third sample was taken on Dec. 19. Figures 4 and 5 show that the eye diameter of the compound eye of the early (Nov. 22) field sample lie above the scatter of high summer field sample. This result implies that the early field sam-

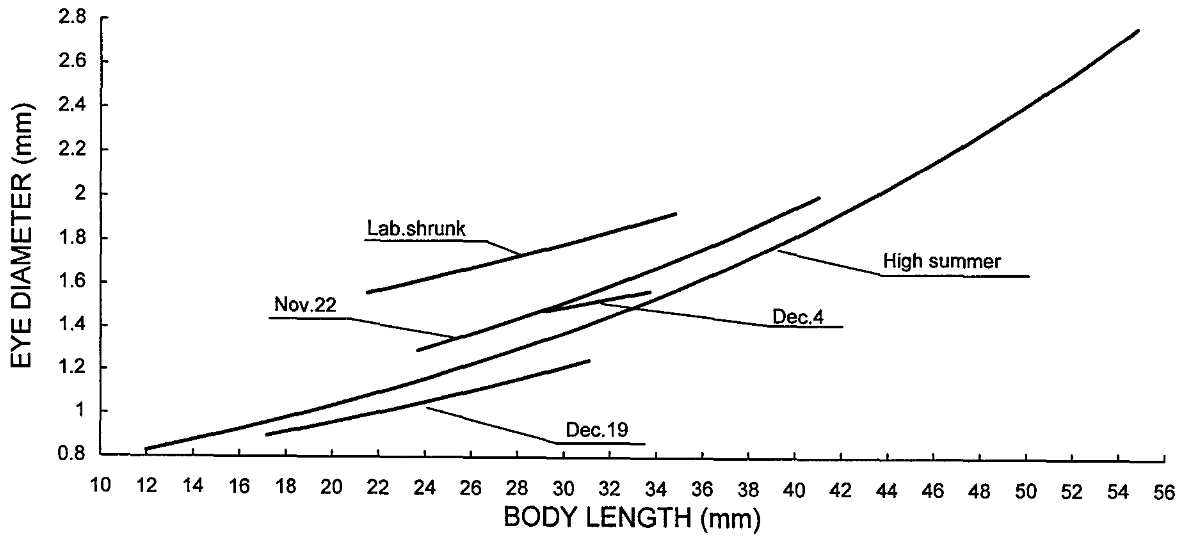

Fig. 4. Relationship between the diameter of the compound eye and the body length of the Antarctic krill collected in high summer, laboratory shrunk, early spring (November 22) and late spring (December 4 and December 19) (female).

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				

ple subjected to shrinkage.

A single factor ANOVA was used to test the BL/ED ratio difference between the early field sample and the high summer field sample. The ANOVA test shows that they are statistically significant at the P=0.01 level ($F_{6.72}$=41.8 for female, $F_{6.72}$=12.07 for male).

Figures 4 and 5 show that the diameters of the compound eye of the field sample captured on Dec. 4 cannot be separated from those of the high summer field sample. This result means that the krill had grown to the original size (before shrinkage). The ANOVA analysis show that they are not statistically significant at the P=0.05 level ($F_{3.85}$=2.07 for female, $F_{3.85}$=0.37 for male).

Figures 4 and 5 show that the diameters of the compound eye of the field sample captured on Dec. 19 lie under the scatter for high summer field sample. This result implies that when the body length was recovering, the compound eye kept constant until the body length grow to the point beyond to the original size (before shrinkage). The ANOVA analysis shows that it is statistically significant at the P=0.01 level ($F_{6.72}$=85.98).

Discussion

The mean ratio of the body length to the diameter of the compound eye (BL/ED) is lower in a laboratory-shrunk sample of krill than in the samples collected in high summer. The latter would have experienced an extended period of growth, so we regard them as "normal krill". The mean ratio of the BL to the ED is also lower in a sample of krill collected in spring, which is likely to have experienced food limitation over winter, than for the samples collected in high summer. From these results, we can conclude that the early field sample had subjected to shrinking in the winter. The mean ratio of the body length to the

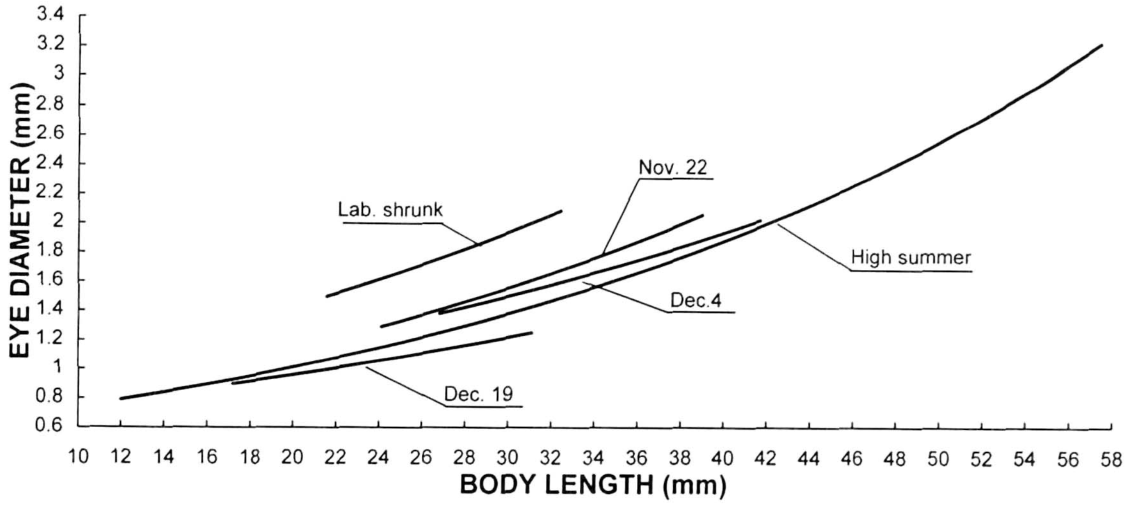

Fig. 5. Relationship between the diameter of the compound eye and the body length of the Antarctic krill collected in high summer, laboratory shrunk, early spring (November 22) and late spring (December 4 and December 19) (male).

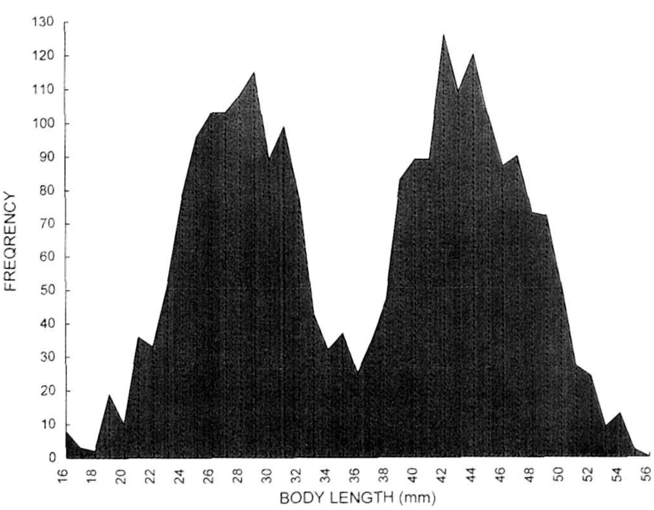

Fig. 6. Body length frequency distribution of juvenile and female krill for all 0-200m oblique haul samples collected in 1991 summer cruise.

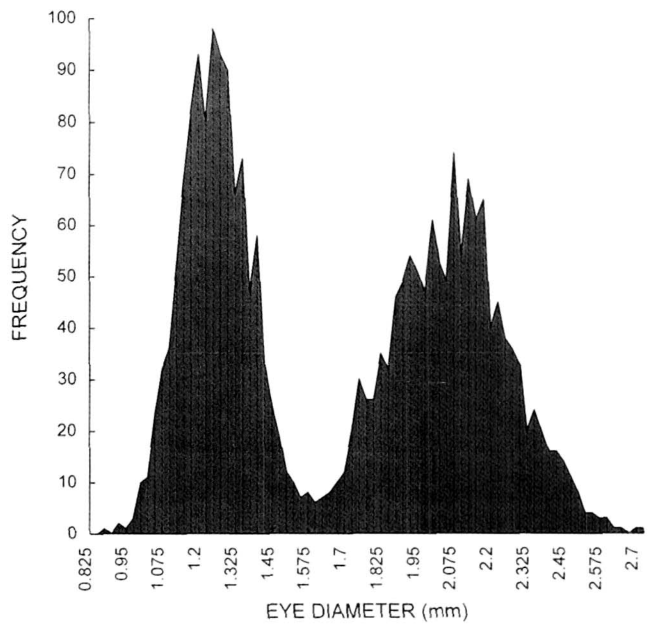

Fig. 7. Eye diameter frequency distribution of juvenile and female krill for all 0-200m oblique haul samples collected in 1991 summer cruise.

diameter of the compound eye of the sample collected on Dec. 4 cannot be separated from that of the high summer field samples. This result implies that the krill had almost grown to the original size (before shrinkage). The diameter of the compound eye of the field sample captured on Dec. 19 lie under the scatter for high summer field sample, and the mean ratio of the body length to the diameter of the compound eye of the sample is higher than that of the samples collected in the higher summer. This result implies that when the body length was recovering, the compound eye kept constant until the body length grow to the point beyond to the original size (before shrinkage).

In 1992's CCAMLR meeting, a procedure was outlined for estimating krill recruitment variability (CCAMLR 1992). The Appendix E suggested that an analysis of length frequency data, possibly using the method of MacDonald & Pitcher (1979), to determine the proportion of recruits in krill samples collected in net surveys. de la Mare (1994) described a method which has been developed along these lines. The aim of the method is to estimate the proportion of recruits in samples from krill populations. The proportion of recruits, known as the gross recruitment or R_1 rate, is the ratio of numbers in one age class, to the numbers in that age class and above, that is :

$$R_1 = \frac{A_0}{\sum_{i=0}^{n} A_i}$$

where A_i is the number of animals in age class i, and n is the age of the oldest animals in the population (de la Mare 1994; Siegel and Loeb 1995).

Now the major problem is how to accurately separate the first fully represented age calss (1+) from the older classes. Figure 6 is the body-length frequency distribution of female and juvenile krill for all 0-200 m oblique haul samples collected in the 1991 summer cruise by the Australian Antarctic Division. Figure 7 is the eye diameter frequency distribution of the same sample. By inspecting these two figures, it is obvious that using the eye diameter data is easier to separate the first year group than using the body length data. That means that the results from the proportion of recruits with the eye diameter data will be more accurate than that with the body length data.

The BL/ED ratio can be used to determine whether the krill has been shrunk and estimate the shrinkage extent. By inspecting the data sets of the body length and the diameter of the compound eye measurement, both time specific and situation specific, we can understand the influence of the physical environment variability to the krill population. Furthermore, because the krill is the key species in the Antarctic food web, the influence effects on the whole ecosystem.

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