Separation of the Sexes of *Calanus finmarchicus* (Gunn.) in the Fifth Copepodite Stage, with Comments on the Sex Ratio and the Duration in this Stage

By

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A considerable body of data has been published on the variations in the size of *Calanus finmarchicus* (Gunn.) in its different developmental stages. In a number of instances measurements of the fourth and fifth copepodite stages have shown a bimodal distribution which has been attributed by authors to the presence of individuals which have developed at different temperatures, or under different feeding conditions, or to the presence of two "races" in the plankton samples. Studying the biometry of *C. finmarchicus*, BARNES and BARNES (1953) found that in the fifth copepodite stage many of the measurements still separated quite clearly into two size groups in a sample which was derived largely from a single generation in the Firth of Clyde. In particular they found that in one group of fifth stage copepodites the head was longer and the metasome narrower than in the other group; they related the first group to adult males and the second group to adult females. Whilst their results suggest that sexual differentiation takes place prior to the adult stage in *C. finmarchicus*, BARNES and BARNES emphasize that the differences are population differences in regard to measurements and cannot be used to separate individuals. WOODHEAD and RILEY (1957) have demonstrated similar population differences in measurements made on *C. helgolandicus* both in the English Channel and in the North Sea, and have used these measurements to confirm a method for separating the sexes of *C. helgolandicus* in Stage V by examination of the urosome. The present paper describes a similar method for the separation of the sexes in Stage V of *C. finmarchicus*, and then applies the method to determine the sex ratio in this stage, and to achieve an estimate of the duration of the fifth copepodite stage in the North Sea.

Method of Separation of the Sexes in Stage V

The material used consisted of fifth stage copepodites of *Calanus finmarchicus* (in the sense of REES, 1949) from the centre of a patch of *Calanus* in the North Sea off the north-eastern English coast in May, 1954. The *Calanus* were taken with a vertically hauled Hensen net and preserved in 5% neutral formalin as soon as possible after collection.

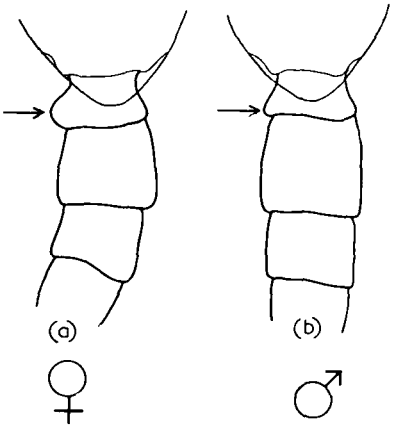

Figure 1. Urosome of Stage V potential female (a), and male (b) types. Arrows indicate ventral bulge on the proximal segments.

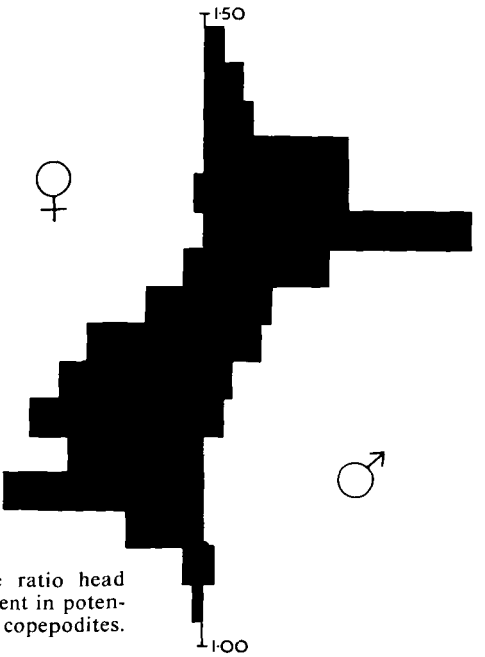

Figure 2. Frequency distribution of the ratio head length/width of first free metasomal segment in potential female and male types of Stage V copepodites.

Figure 2.

Examination of the first (proximal) segment of the urosome of these fifth stage copepodites showed that two types could be separated, as had been previously reported for *C. helgolandicus* (WOODHEAD and RILEY, 1957). In one type the distal ventral edge of the proximal segment formed a simple lip which was slightly curved to overlap the second segment. The second type was characterized by a more pronounced curvature of the ventral surface of the segment, the curve extending further forward and tending to bulge the segment out ventrally (Fig. 1). It was thought that the first type might represent the potential males, and the second, the potential females in this stage. In both sexes the ventral surface of the proximal segment of the urosome was found to be less curved than in the respective sex of *C. helgolandicus*, and the two types were, in fact, rather easier to distinguish in *C. finmarchicus*.

Measurements of the head length, and the width of the first free metasomal segment of the Stage V copepodites showed that two size populations existed within this North Sea sample, similar to those found for the Firth of Clyde (BARNES and BARNES, 1953). These measurements were then used to confirm the sex separation in *C. finmarchicus*, as had previously been done for *C. helgolandicus*. The Stage V's were separated into two groups on the urosome feature and then measured under a dissecting microscope. It was found that the copepodites selected as potential females by the urosome feature tended to have shorter heads and longer bodies than the copepodites in the potential male group. A maximal separation of the two groups was achieved by dividing the head length by the width of the first free metasomal segment, which also eliminated variations due

to differences in the size of the copepodites. When the ratios were derived it was found that an approach to a normal distribution was achieved for each population selected on the urosome feature (Fig. 2).

Both the urosome and biometrical methods select the copepodites on features which approximate to the adult male and female conditions and the close agreement between these methods suggests strongly that the two types in Stage V are the potential males and females respectively. But neither method offers conclusive proof of the sex of a copepodite, however; in a number of the older Stage V females the ovary can be seen through the body wall; this was used to check the separation and it was found that in all cases where a developing ovary could be seen, the Stage V copepodite had a "female" type urosome.

The Sex Ratio in the Fifth Copepodite Stage

Numerous investigations have shown that the proportion of adult male to female *C. finmarchicus* caught at sea is usually low, although the ratio varies with both time and place. Similar scarcities of adult males have been reported for other copepods (e.g., MARSHALL, 1949), but it is generally accepted that this is due to the shorter adult life of the male (RUUD, 1929; REES, 1949; MARSHALL and ORR, 1955). For *C. finmarchicus* this is supported by the work of RAYMONT and GROSS (1942) who found that whereas adult males died in one or two weeks when kept in laboratory cultures, adult females lived for three to nine weeks under the same conditions. Similar results have been reported by MARSHALL and ORR (1955).

Since it has not previously been possible to distinguish the sexes in *C. finmarchicus* before they were adult, little is known of their relative numbers in the copepodite stages. However, MARSHALL and ORR infer that the sexes may be about equal since MARSHALL (1949) found them to be approximately equal in the fourth and fifth copepodite stages of other species in which the males were generally scarce as adults. Also BARNES and BARNES (1953) found that the two size populations, which they suggested represented potential males and females in fifth stage *C. finmarchicus*, each formed about fifty per cent. of the sample.

Occasionally collections of adult *Calanus* have been made in which males considerably outnumber the females. These collections have nearly always been taken when a number of adults are beginning to moult from Stage V (FARRAN, 1929, S. Ireland; NICHOLLS, 1933, Clyde; ØSTVEDT, 1953, Norwegian Sea; USSING, 1938, Greenland), and when a series of collections have been made over a sufficiently short period it is apparent that the males tend to appear before the females, indicating a shorter development time for the males, in addition to their shorter adult life.

Since males precede the females from Stage V it would be expected that the percentage composition of the sexes in the fifth stage would not be constant at 50:50 but would vary, the proportion of females increasing as the males become adult. Plankton collected by Dr. D. H. CUSHING (work in preparation for publication) on a series of Hensen net surveys off the north-eastern English coast in 1954 provided material to investigate whether the predicted change in sex ratio really occurred. On these surveys a repeated grid of plankton hauls had been carried out following the movement of plankton patches and sampling

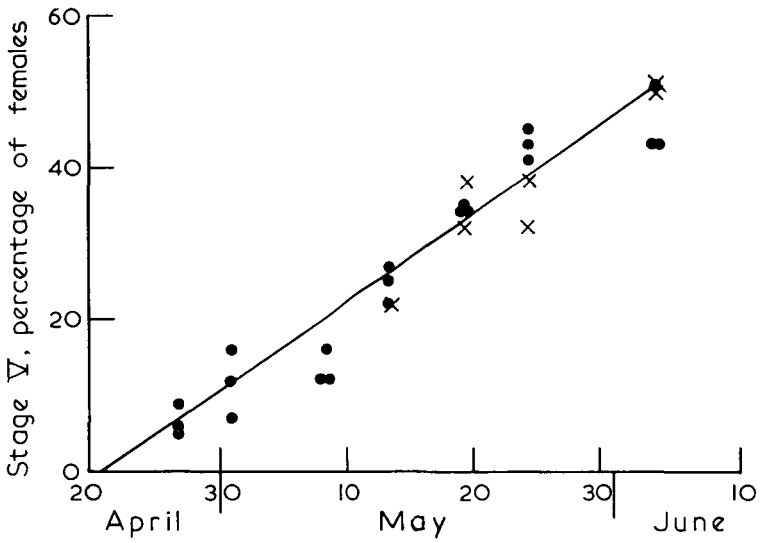

Figure 3. Change in the ratio ♀ : ♂ with time in the patch of Stage V copepodites.
● = *Calanus finmarchicus*
× = *Calanus helgolandicus*

the patches at fairly short time intervals. From this material a patch of fifth stage copepodites was chosen which had been sampled several times in succession after its first appearance from Stage IV. Three samples were chosen from stations near the centre of the patch on each occasion that it had been sampled; from each sample one hundred fifth stage copepodites were examined and the percentage of each sex present, as selected by the urosome feature, was recorded. The results are presented graphically in Figure 3.

It can be seen that at any one time there was fairly close similarity in the proportion of the sexes found at the three stations. The results show an increasing percentage of females with time, as was expected; however, the change in the proportion of the sexes did not begin at 50% but with more than 90% potential males.

These results suggest that the males develop more rapidly than the females in the fourth stage as well as the fifth stage. Therefore, the males appear first in Stage V; the percentage of females subsequently rises as they enter this stage from Stage IV, and also because the males are passing out of Stage V to become adult before the females. As the proportion of the two sexes is constantly changing it has not been possible to determine the absolute sex ratio in Stage V.

Throughout the investigation the copepods were checked by examination of the fifth pair of thoracic legs to ensure that no *C. helgolandicus* were included (REES, 1949). In this way it was found that the plankton samples included a small percentage of *C. helgolandicus* and for comparison the sex ratio in Stage V of this form was determined at a few stations (Fig. 3). It is interesting that although REES (1949) described *C. finmarchicus* and *C. helgolandicus* as having separate life cycles in the North Sea, on this occasion the sex ratios in *C. helgolandicus* Stage V's appeared to be changing in the same way and at the same time as that of *C. finmarchicus* in the seven samples examined.

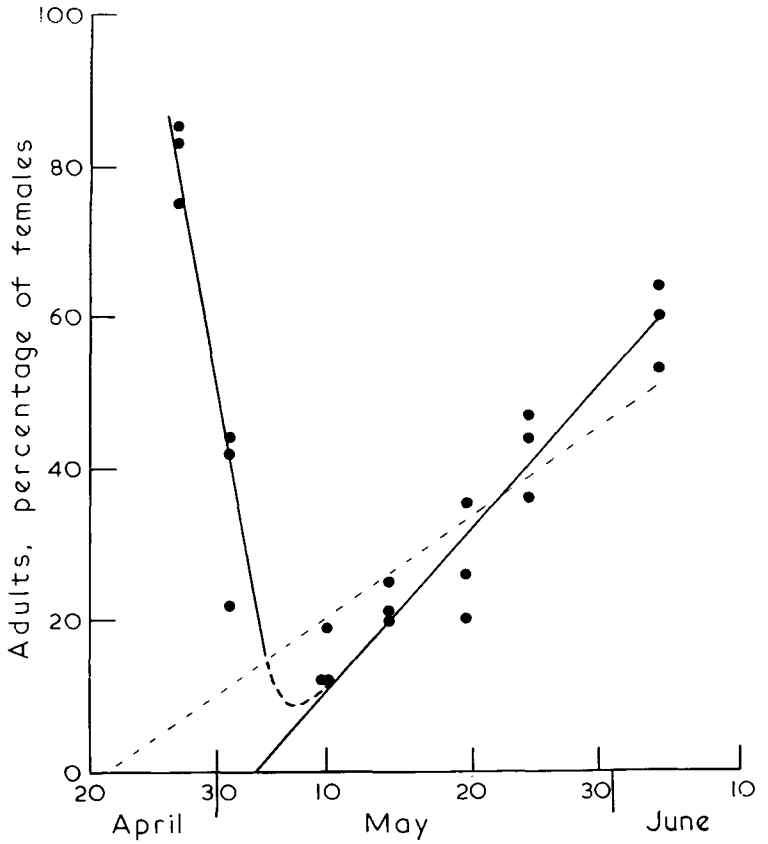

Figure 4. Change in the ratio ♀ : ♂ with time in the adult copepods at stations for the Stage V's shown in Figure 3.
—— = line for the change in ratio of the adults,
------ = line for the change in ratio of the Stage V's.

Separation of the Sexes in Stage IV

Since the males tended to moult from Stage IV before the females it was possible that some degree of sexual differentiation might be discernible in this stage. An attempt was therefore made to separate the potential sexes in the fourth stage copepodite of *C. finmarchicus*. This was done by measuring these copepodites and then deriving the ratio of the head length to the width of first free metasomal segment; in all, some 700 copepodites from several stations were measured. However, the frequency distribution of the ratios generally showed only one population of measurements and no significant trend could be seen.

Duration of the Fifth Copepodite Stage

The determination of the sex ratio of adult *Calanus* on the same stations that had been used for the Stage V's showed that initially nearly all the adults were

female, but these females only occurred in small numbers, being the last survivors of the previous generation. The first adult copepods of the new generation to appear were the males which rapidly outnumbered the last of the older females, so that the percentage of females fell to a low figure. This percentage later increased as the females of the new generation moulted from Stage V to become adult (Fig. 4). Although there is rather more variation in the sex ratio of the adults than was the case for the Stage V's, the change in the sex ratio with time appears to be best expressed by a straight line. Comparing this line with that for the Stage V's, it is clear that the slope for the adult line is much steeper, indicating a more rapid accumulation of females, probably due to the shorter life of the adult male (RAYMONT and GROSS, 1942).

Extrapolation of the lines expressing the temporal change in sex ratio of the adults and the Stage V's, gives an approximate estimate of the dates of first appearance of the females in these stages, and if it is accepted that the first females to appear in Stage V would also be the first to become adult, the difference between these dates of 12 days gives an approximate estimate of the duration of the females in Stage V. Since the males develop more rapidly than the females, the duration of the potential males in Stage V would be less than 12 days.

Acknowledgement

We wish to record our gratitude to Dr. D. H. CUSHING for allowing us to use his plankton collection, and for access to his unpublished data on the distribution of *Calanus* off the NE coast in 1954.

Summary

1. A method has been described for the separation of the sexes in the fifth stage copepodite of *C. finmarchicus* by examination of the urosome. The method was supported by evidence derived from the biometry of this stage.

2. The proportion of the sexes in a patch of Stage V copepodites in the North Sea was followed over six weeks. Initially almost all the Stage V's were males, suggesting that the males developed more rapidly than the females in Stage IV. The percentage of males in the patch decreased with time. Similar changes occurred in Stage V *C. helgolandicus* in this patch.

3. It was not possible to separate the sexes in the fourth stage copepodites of *C. finmarchicus*.

4. The duration of the potential females in Stage V was estimated as about 12 days in this generation in the North Sea; the duration of the potential males in Stage V is probably rather shorter.

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