DET KGL. NORSKE VIDENSKABERS SELSKAB
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# MISCELLANEA

# 9

Tor Strømgren

## ZOOPLANKTON INVESTIGATIONS IN BORGENFJORDEN, 1967-1969

TRONDHEIM 1973

D K N V S  Miscellanea nr. 9 - 1973

# ZOOPLANKTON INVESTIGATIONS IN BORGENFJORDEN, 1967-1969

by

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ISBN 82-7126-008-1

## ABSTRACT

Strømgren, Tor. Zooplankton investigations in Borgenfjorden, 1967-1969. *K. norske Vidensk. Selsk. Mus. Miscellanea 9:* 1-37.

Frequent sampling of zooplankton, phytoplankton, temperature, salinity, and oxygen has been performed during a 26 month period at three stations in Borgenfjorden, a landlocked and shallow branch of inner Trondheimsfjorden, Western Norway. Borgenfjorden consists of two basins, the outer with very turbulent conditions and rapid exchange of water (approx. 8 days). During the productive seasons the inner basin has a pronounced stratification, and the bottom layers are stagnant, while in the upper 10-15 m the period of exchange is approx. 3 weeks. During summer and autumn both basins show significantly higher temperature than the corresponding layers in the main fjord, and this probably improves the production of several holoplanktonic species, mainly *Temora longicornis*, *Centropages hamatus*, *Acartia longiremis*, *Oithona similis*, *Podon polyphemoides*, and *Evadne nordmanni*. The water exchange causes large and rapid fluctuations of the zooplankton stock, mainly in the outer basin. In the inner basin significantly larger stocks may be established and the periods of maximum abundance are prolonged.

CONTENTS

## INTRODUCTION

In Trondheimsfjorden, extensive zooplankton investigations have been made since 1963 (Strømgren 1973), and during 1967-1969 a corresponding sampling program was carried out in Borgenfjorden, a landlocked and shallow branch of the main fjord (Fig. 1). A similar locality, Nordåsvannet near Bergen, was investigated by Wiborg (1944).

## MATERIAL AND METHODS

Samples were taken from September 1967 to October 1969 at two stations inside Borgenfjorden, St. 4B (Bulungsnesdypet, depth 32 m) and St. 2B (Rolsøydypet, depth 37 m), and one station just outside the entrance, St. 1B (outside Strømmen, depth 18 m) (Fig. 1). As a reference

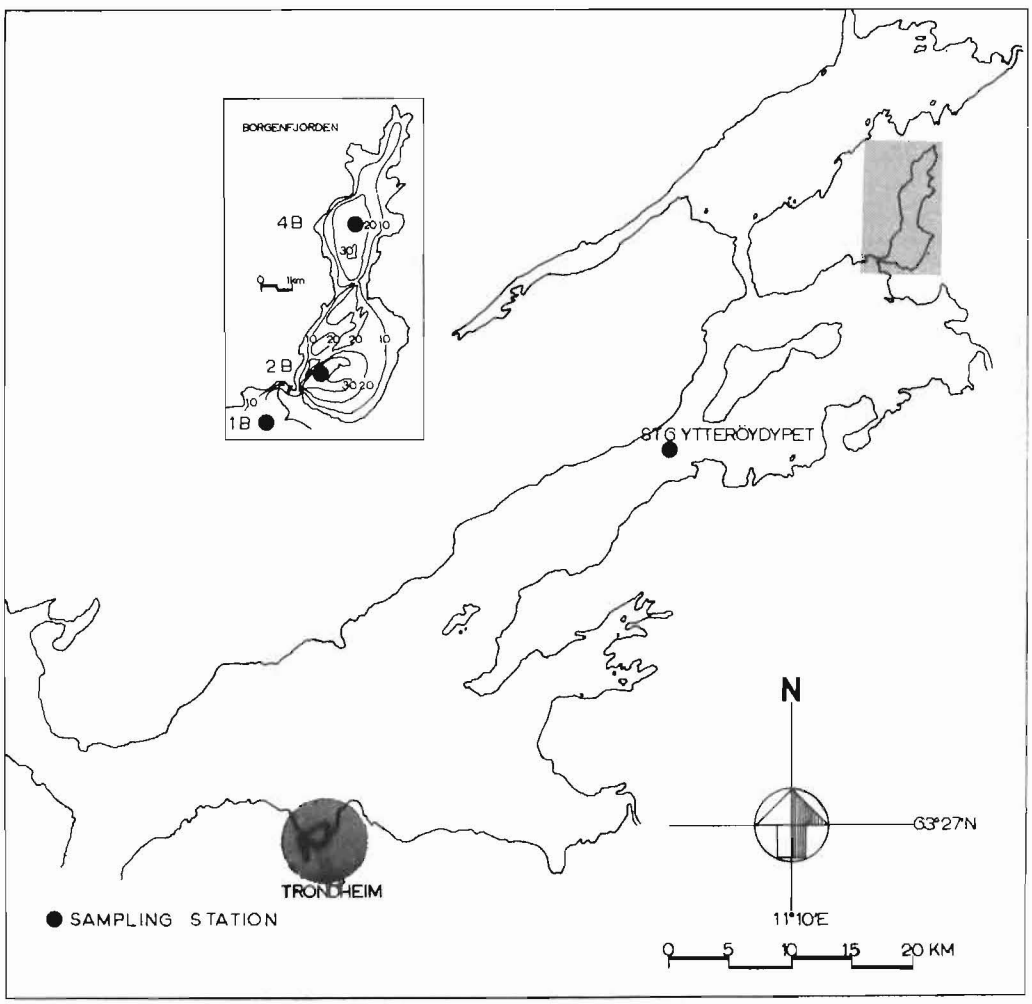


Fig. 1. Trondheimsfjorden and Borgenfjorden, sampling stations indicated.

to the conditions in Trondheimsfjorden proper, one permanent plankton sampling and hydrographic station in the main fjord, St. 6 (Ytterøy, depth 420 m), was included.

All zooplankton hauls were vertical using a 0.1 $m^2$ Juday net with mesh size 190 µ. At the Borgenfjord stations 1B, 2B, and 4B, the hauls were taken from bottom to surface, while from station 6, only hauls from 100-0 m are included in the paper.

Samples were taken every month or at shorter intervals if possible, and the sampling dates are given in Table 1. All samples were taken during daylight hours.

Samples for temperature, salinity, oxygen, and phytoplankton were taken at standard depths: 0, 2, 5, 10, 20, 30, 40, 50, 60, 75, and 100 m. Both zooplankton and hydrographic samples were handled as described in Strømgren (1973) and the limitations of methods and the sources of error are discussed in the same paper.

Table 1. Sampling dates during 1967-69

| 1967 | J | F | M | A | | M | | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4B | | | | | | | | | | | 26 | 25 | | 5 |
| 2B | | | | | | | | | | | 25 | 25 | | 5 |
| 1B | | | | | | | | | | | 24 | 25 | | 4 |
| 6 | | | | | | | | | | | | | | 9 |
| 1968 | | | | | | | | | | | | | | |
| 4B | 10 | 8 | 7 | 2 | 23 | 9 | 27 | 18 | 10 | 9 | 11 | 14 | 6 | 10 |
| 2B | 10 | 8 | 7 | 2 | 23 | 9 | 27 | 19 | 10 | 9 | 11 | 14 | 6 | 10 |
| 1B | 11 | 8 | 8 | 2 | 23 | 8 | 28 | 17 | 10 | 9 | 10 | 15 | 5 | 9 |
| 6 | 9 | 7 | 8 | 4 | 22 | 8 | 31 | 16 | 12 | 16 | 10 | 8 | 4 | 11 |
| 1969 | | | | | | | | | | | | | | |
| 4B | 14 | 11 | 13 | 17 | | 22 | | 19 | | 6 | 2 | 17 | | |
| 2B | 14 | 11 | 13 | 17 | | 22 | | 19 | | 6 | 2 | 17 | | |
| 1B | 13 | 10 | 14 | 15 | | 21 | | 18 | | 5 | 1 | 16 | | |
| 6 | 15 | 10 | 14 | 15 | 25 | 21 | 30 | 18 | 23 | 5 | 1 | 16 | | |

## TOPOGRAPHY

Borgenfjorden proper is separated from the main fjord by a shallow threshold, approx. 6-8 m deep and 200 m wide. Inside this narrow entrance, Borgenfjorden is separated into two basins by a second theshold, of approx 14 m depth. The maximal depth of the outer basin is nearly 40 m, the inner approx. 30 m.

## HYDROGRAPHY

Isopleth diagrams for temperature and salinity at the Borgenfjord stations 1B, 2B, and 4B are given in Figs. 3-4.

At St. 1B, immediately outside the entrance, the stability increases in May, mainly due to low salinity in the surface layer, and a more or less pronounced pycnocline exists throughout the summer. This layering, however, is relatively weak and may easily be broken down. During winter the stability is low.

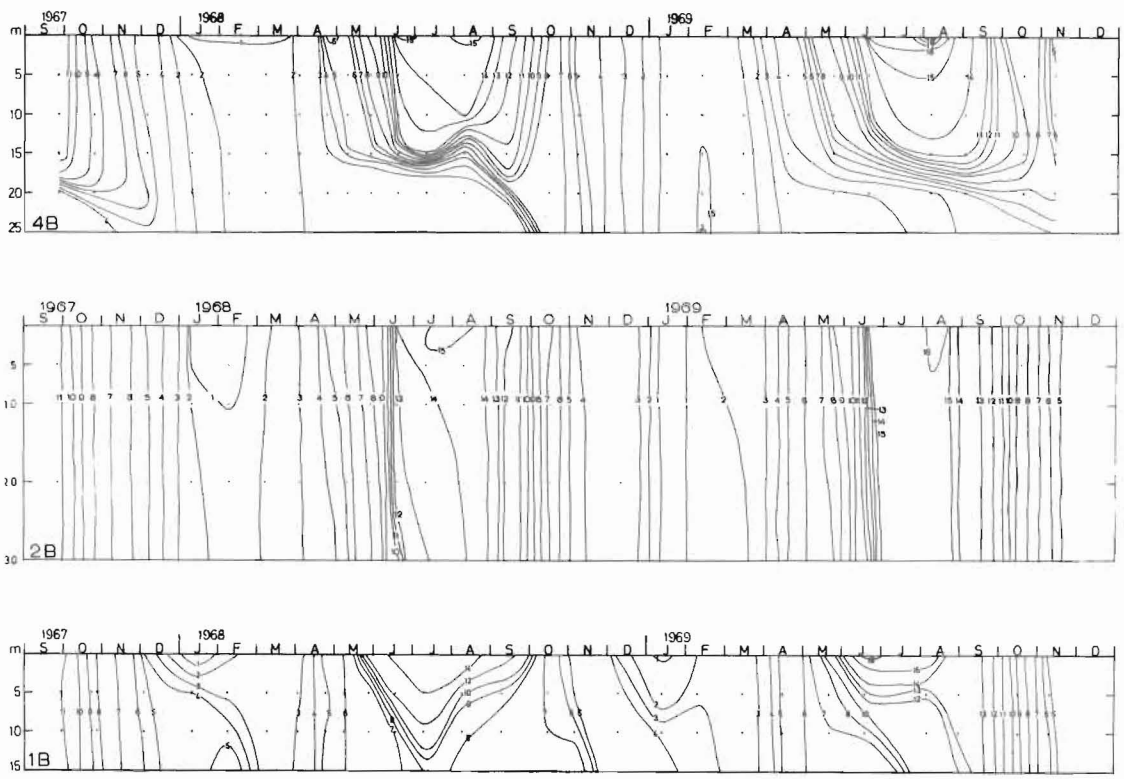


Fig. 2. Temperature isopleths at the Borgenfjord stations 1B, 2B, and 4B during 1967-1969.

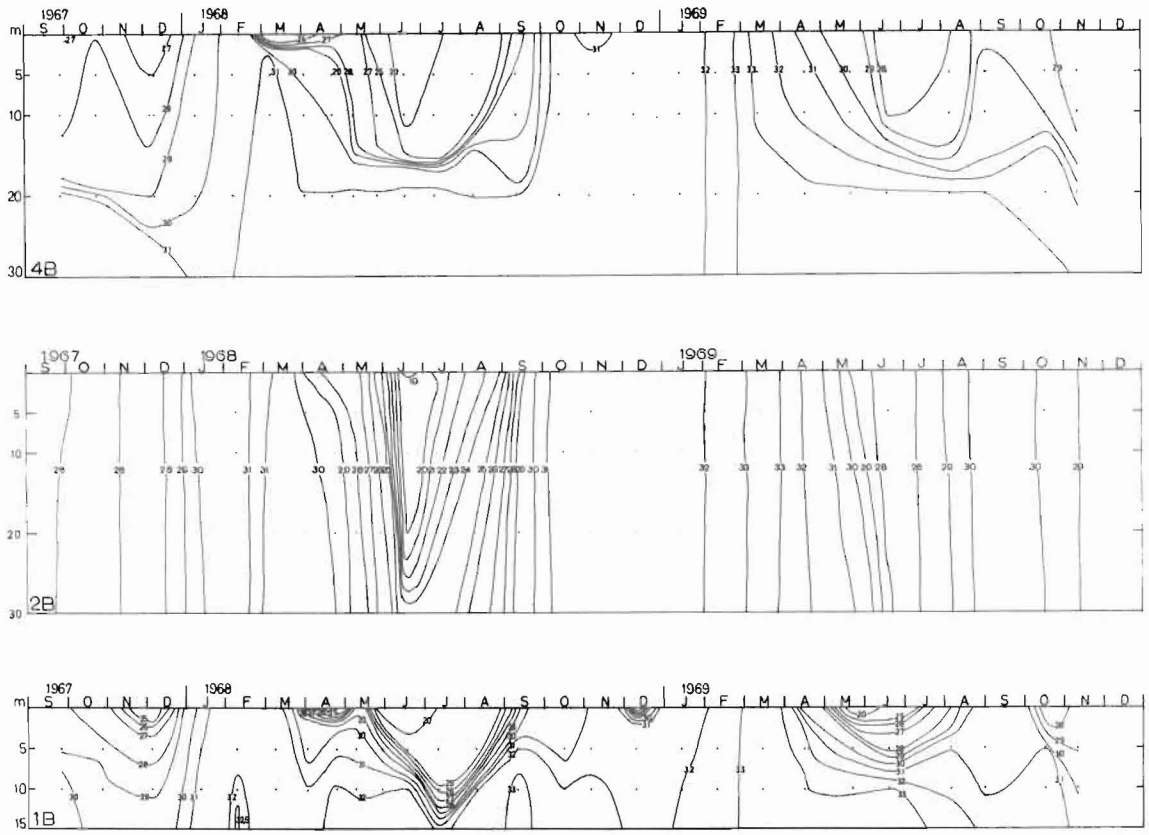


Fig. 3. Salinity isopleths at the Borgenfjord stations 1B, 2B, and 4B during 1967-1969.

The entrance to Borgenfjorden is rather narrow and tidal currents may reach a speed of up to 8 knots. This current causes strong turbulence in the water in the outer basin, represented by St. 2B, where very low stability is found during all seasons. This is demonstrated by the temperature and salinity isopleths (Figs. 2-3). According to McClimans (in prep.), the water masses in the outer basin are renewed in a period of 8 days.

When the tidal current passes the second threshold into the inner basin (St. 4B), its energy is much reduced and influences mainly the layers above threshold level, i.e. the upper 10-15 m. In the inner basin 2-3 weeks are needed to change the water above threshold level (McClimans in prep.).

During spring low salinity and increased temperature form a sharp pycnocline between 16 and 20 m of depth in the inner basin, and the cold and saline winter water is trapped behind the threshold.

The runoff from land is polluted with fertilizers and sewage.

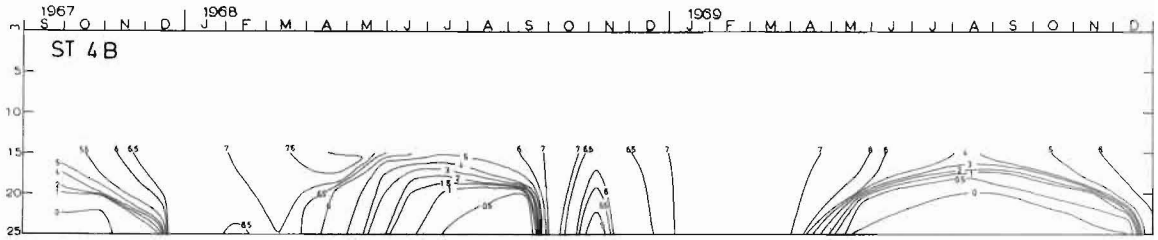


Fig. 4. Oxygen isopleths at the Borgenfjord station 4B during 1967-1969.

The decomposition of organic matter results in oxygen deficiency below the pycnocline and $H_2S$ is formed (Fig. 4).

In late autumn the stability is reduced by diffusion and the stagnant water is renewed. In 1967 the bottom water was changed in December, in 1968 during September-October, and in 1969 in December. No benthic animals are found below 15 m, and even during winter, the bottom deposits smell of $H_2S$.

The river discharge into Borgenfjorden is small. The fresh-water supply to St. 1B observed during May-June 1968 and 1969, had a high silt content and was assumed to originate from Verdalselv, a river 12 km south of St. 1B.

Nordåsvannet (Wiborg 1944), referred to in the introduction, is also contaminated with $H_2S$ in the deeper parts.

According to McClimans (in prep.) the water in Borgenfjorden originates from the surface layers of Trondheimsfjorden, brought in by

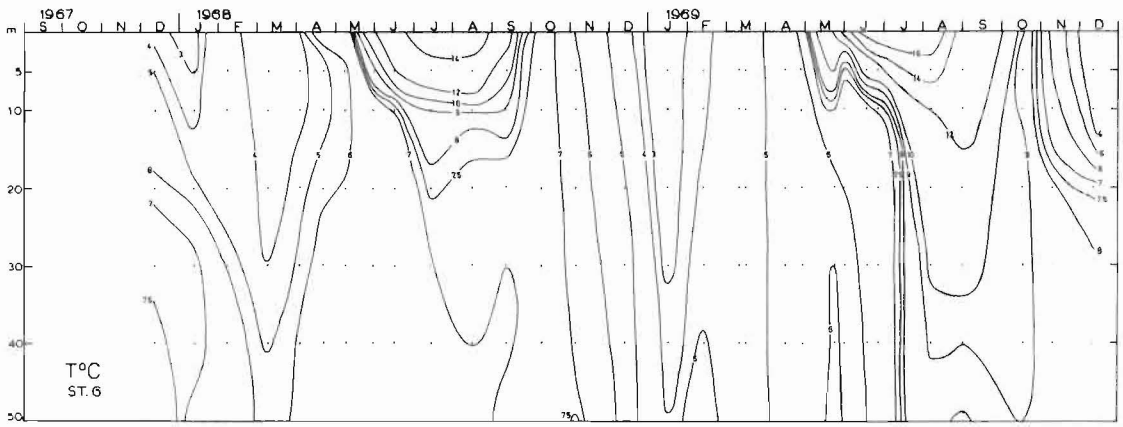


Fig. 5. Temperature isopleths in the upper 100 m at station 6 during 1967-1969.

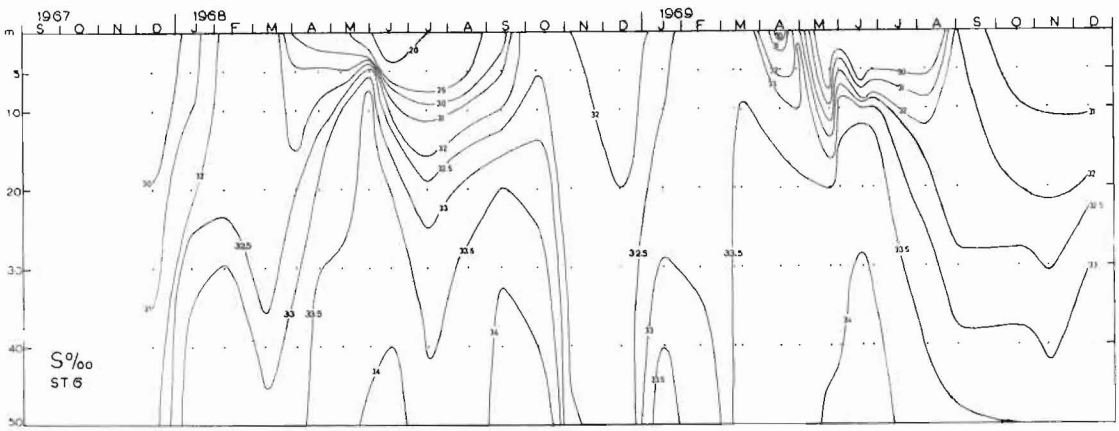


Fig. 6. Salinity isopleths in the upper 100 m at station 6 during 1967-1969.

the tide. St. 6 may give information concerning the main fjord water which is supplied to Borgenfjorden (Figs. 5 and 6). The hydrography of St. 6 during 1967-1969 follows the general trend for this station (Strømgren 1973).

## RESULTS AND DISCUSSION

### COMPOSITION OF THE ZOOPLANKTON

The general composition of the zooplankton at St. 2B, calculated in per cent of number, shows that the copepods are dominant most of the year (Fig. 7). During spring they are numerically replaced by larvae of

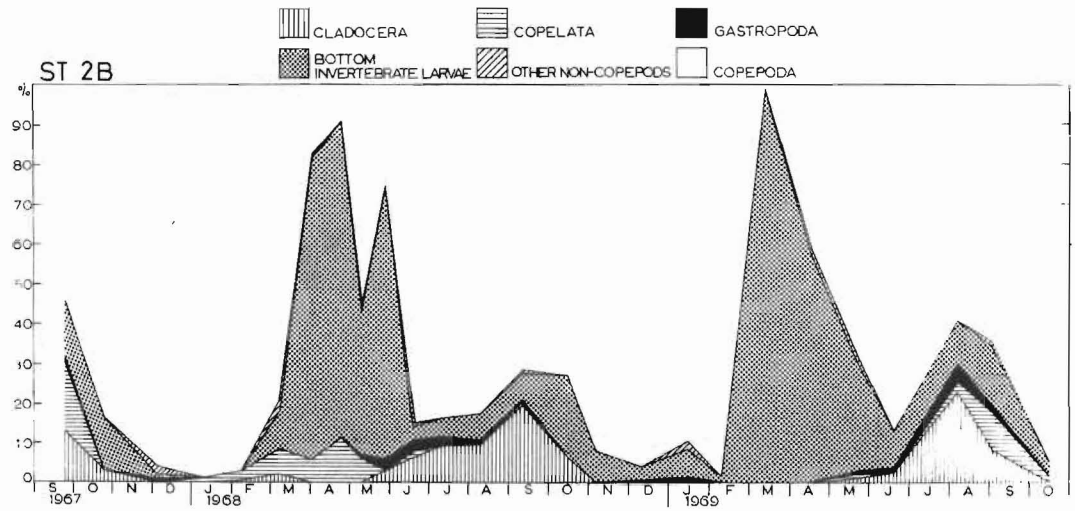


Fig. 7. Percentage composition of the zooplankton at the Borgenfjord station 2B during 1967-1969.

bottom invertebrates. These larvae, however, have a small biomass. Small percentages of Copelata occur in spring, and Cladocera are of some importance during summer and autumn. All Borgenfjord stations, 1B, 2B, and 4B, showed the same general trend of zooplankton composition.

In the main fjord, deeper living organisms might seasonally occur in the 100-0 m samples (Strømgren 1973), but in Borgenfjorden only common inhabitants of the uppermost layers were found.

When the composition at the Borgenfjord stations is compared to Nordåsvannet (Wiborg 1944), a similar trend is found with the Copepoda, Cladocera, and Copelata as the most important groups. However, the bottom invertebrate larvae, are of greater numerical importance in Borgenfjorden.

## COMPOSITION OF THE COPEPODA

The composition of the Copepoda at St. 2B, calculated in per cent of number, is shown in Fig. 8.

A few species, *Oithona similis*, *Acartia longiremis*, and *Pseudocalanus elongatus*, were of significant importance during all seasons at all stations. *O. similis* was of greatest importance in autumn and winter,

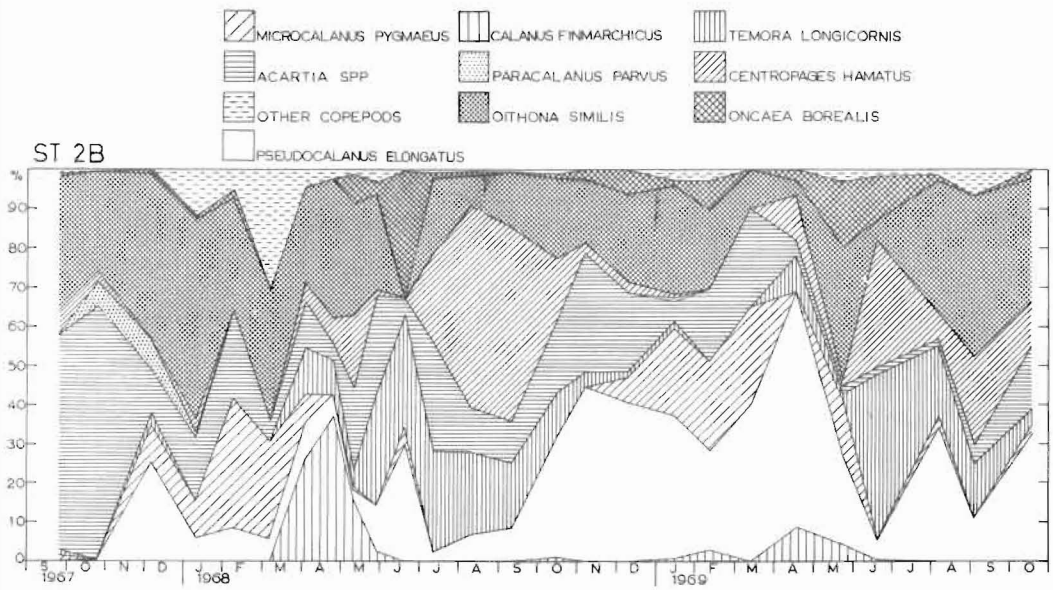


Fig. 8. Percentage composition of the Copepoda at station 2B during 1967-1969.

while in summer *Temora longicornis* and *Centropages hamatus* tended to dominate. *P. elongatus* showed the greatest percentages in winter, while *A. longiremis* peaked in summer and autumn. During winter *Microcalanus pusillus* occurred regularly at all stations. The influence of *Calanus finmarchicus* was quite small, although in spring their nauplii might contribute more than 40% of the total number of copepods. In late spring and early summer *Oncaea borealis* showed a maximum percentage.

The same species occur both in Borgenfjorden and in the 100-0 m layer in the main fjord, but the relative composition shows significant differences. Species which are not confined to the uppermost layers (*C. finmarchicus, M. pusillus, Scolecithricella minor*) show greater percentages in the main fjord, while a number of summer species are quite dominant in Borgenfjorden (*T. longicornis, Acartia* spp., *C. hamatus*).

When Borgenfjorden is compared to Nordåsvannet, the same copepods occur, but their relative importance differs. *A. longiremis* and *C. hamatus* were of greater importance in Borgenfjorden, while *Paracalanus parvus*, which in Nordåsvannet composed more than 30% of the stock in autumn, was rather insignificant in Borgenfjorden. In both localities *O. similis* was important during all seasons. The winter peaks of *P. elongatus* observed in Borgenfjorden showed no parallel to Nordåsvannet.

## VOLUME VARIATIONS

The variations in zooplankton volume during 1967-1969 in the Borgenfjord stations 1B, 2B, and 4B in 100-0 m at St. 6 in the main fjord, are shown in Fig. 9. The wet weights in grams of samples taken below 1 $m^2$ of surface are given for a short period in the same diagram. In autumn 1967 the total volumes were rather small at St. 1B, 2B, and 4B. In 1968 small peaks during April-May were found at all stations, with the maximum occurring in summer. The summer maximum appeared to be delayed in time progressing inward in the fjord. At St. 6 in the main fjord, an autumn maximum was found during September-October. In 1969, April-May maxima again occurred at all stations followed by summer maxima during June-July. At St. 6 a very rapid increase took place at the end of June. At the innermost station in Borgenfjorden, St. 4B, a

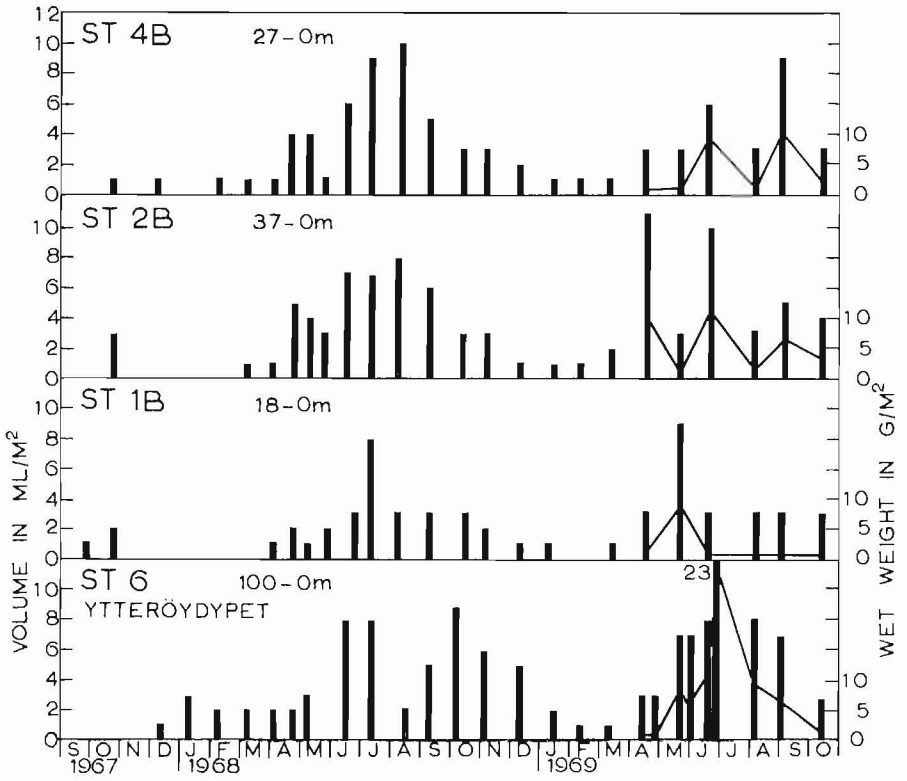


Fig. 9. Zooplankton volume in ml/$m^2$ (left scale) and wet weight in g/$m^2$ (solid line, right scale) at St. 1B, 2B, 4B, and 6 during 1967-1969.

significant volume peak was found during August-September.

In the outer part of the main fjord, we normally find two or three maxima annually, while in the inner parts the number of peaks is reduced (Strømgren 1973). The Borgenfjord stations do not show autumn maxima except at St. 4B in 1969.

The wet weights recorded from April to October 1969 correspond well with the volume measurements.

## COPEPODA

### Calanus finmarchicus (Gunnerus)

In Trondheimsfjorden 1963-1966, *C. finmarchicus* was the dominant species in the zooplankton during nearly all seasons, although very significant annual fluctutations occurred, particularly in the inner part of the fjord (Strømgren 1973). In Borgenfjorden *C. finmarchicus* was numerous only in spring.

## Variation in numbers

Significant maxima occurred at St. 6 and the Borgenfjord stations during April-May 1968 (Fig. 10). The maxima were composed mainly by nauplii and copepodite stages III-I. At the innermost station 4B, copepodite stage III dominated. The maximum total number was gradually delayed in time from stations 6 and 1B to St. 2B, and further to St. 4B.

In April 1969 a spring maximum of nauplii and young copepodite stages again occurred at all stations. The maximum at St. 6 was earlier than at the Borgenfjord stations this year also.

In the main fjord, the years 1963-1966 were classified according to the number of *C. finmarchicus* during spring maxima (Strømgren 1973), and compared to that, 1968 and 1969 at St. 6 must be regarded as poor years.

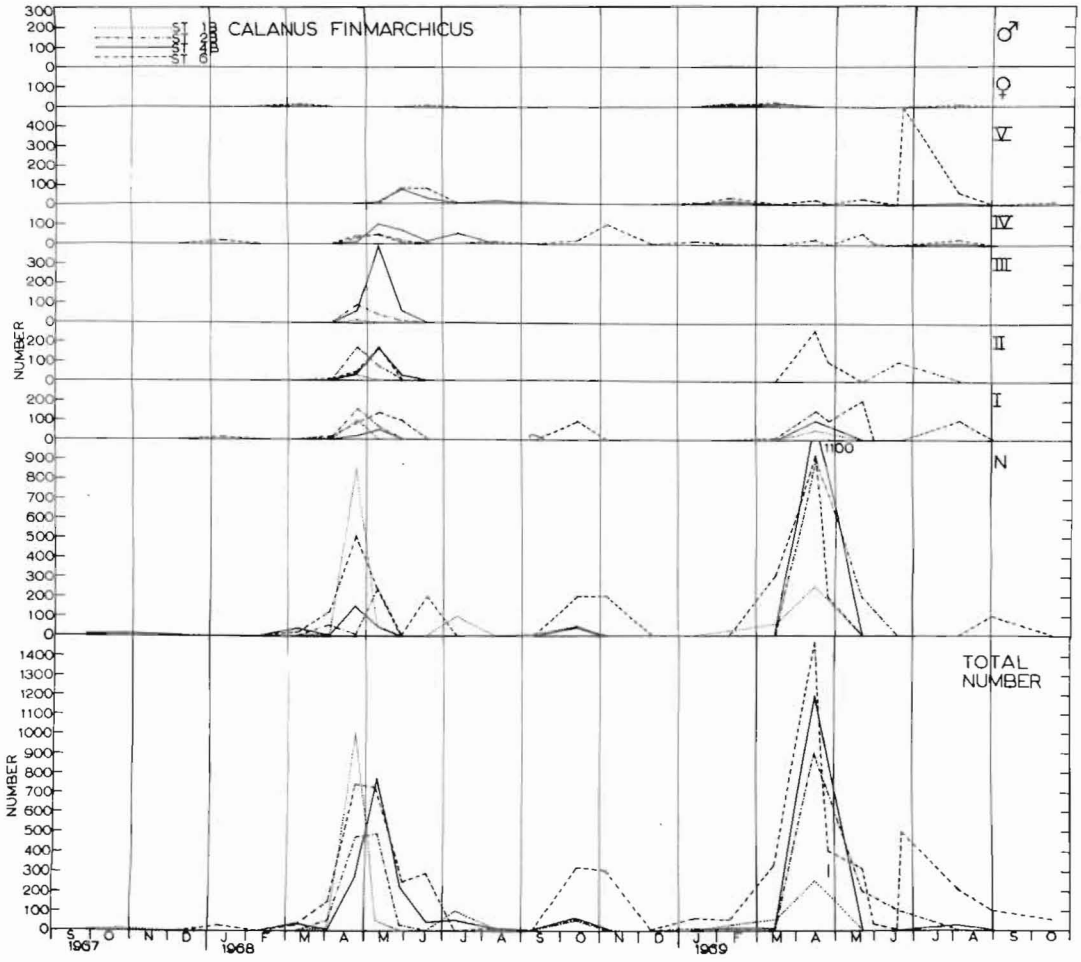


Fig. 10. *Calanus finmarchicus*, stage distribution and total numbers during 1967-1969, at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface.

In autumn only a few individuals of *C. finmarchicus* occurred at the shallow Borgenfjord stations, while at St. 6, small peaks were observed. This trend is similar to that found during 1963-1966 with small stocks in the inner fjord in autumn. During winter, *C. finmarchicus* is practically absent from Borgenfjorden.

## Propagation

In Borgenfjorden only single adults were encountered. This indicates that spawning is confined to waters above greater depths and the larvae found at St. 1B, 2B, and 4B were probably transported in from the main fjord. In 1968 and 1969 a few adults occurred in 100-0 m at St. 6 (Fig. 10), and nauplii were present from March to May both years, with the maximum in April. None of these spawnings gave a significant spring generation of older copepodite stages. The gradual delay inwards for the spring maxima from St. 6 to St. 4B, also points to immigration. In the innermost basin low water exchange and abundant food may improve growth, and older copepodite stages may thus be accumulated, as indicated at St. 4B in May 1968. In autumn spawning also takes place in the main fjord, but the number of larvae is small and the distribution is probably deeper, and this may prevent a significant transport over shallow thresholds.

In Nordåsvannet Wiborg (1944) found quite small numbers of old stages of *C. finmarchicus*, and he suggested that a winter population was not established.

## Paracalanus parvus (Claus)

*P. parvus* belongs to the allochthonous zooplankton, and during 1963-1966 permanent stocks were not established in Trondheimsfjorden (Strømgren 1973).

*P. parvus* was found at the Borgenfjord stations from October to December in 1967 and in October 1969, but it was not recorded at St. 6 (Table 2).

Table 2. *Paracalanus parvus*, numerical variation of adults and copepodite stages V-IV during 1967-1969, at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface

| | 1967 | | | 1968 | 1969 |
|---|---|---|---|---|---|
| | O | N | D | O | O |
| St. 4B | 0 | 0 | 10 | 0 | 0 |
| St. 2B | 240 | 80 | 1 | 0 | 750 |
| St. 1B | 10 | 0 | 0 | 0 | 50 |
| St. 6 | - | - | 0 | 0 | 0 |

Wiborg (1954) suggested that local stocks of *P. parvus* might survive and propagate during favourable conditions in fjords even in northern Norway. In Nordåsvannet, Wiborg (1944) found spawning in April and in Oslofjorden he suggested there was more or less continuous spawnning (Wiborg 1940). It is difficult to separate young *P. parvus* from *Pseudocalanus elongatus*, and possibly young stages of *P. parvus* may easily be overlooked. Propagation may occur in Borgenfjorden when adults are present, but it seems improbable that a young brood would have any success. Obviously local stocks of *P. parvus* are not established even in the landlocked Borgenfjord.

## Pseudocalanus elongatus Boeck

Probably all *Pseudocalanus* in Borgenfjorden and in the 100-0 m hauls at St. 6 are *P. elongatus* (Strømgren 1973). During 1963-1966 two maximum periods were found annually, with small peaks in spring and the large maxima in summer and in autumn.

### Variation in numbers

At the Borgenfjord stations two maximum periods were observed although there was a more irregular distribution in relation to time than

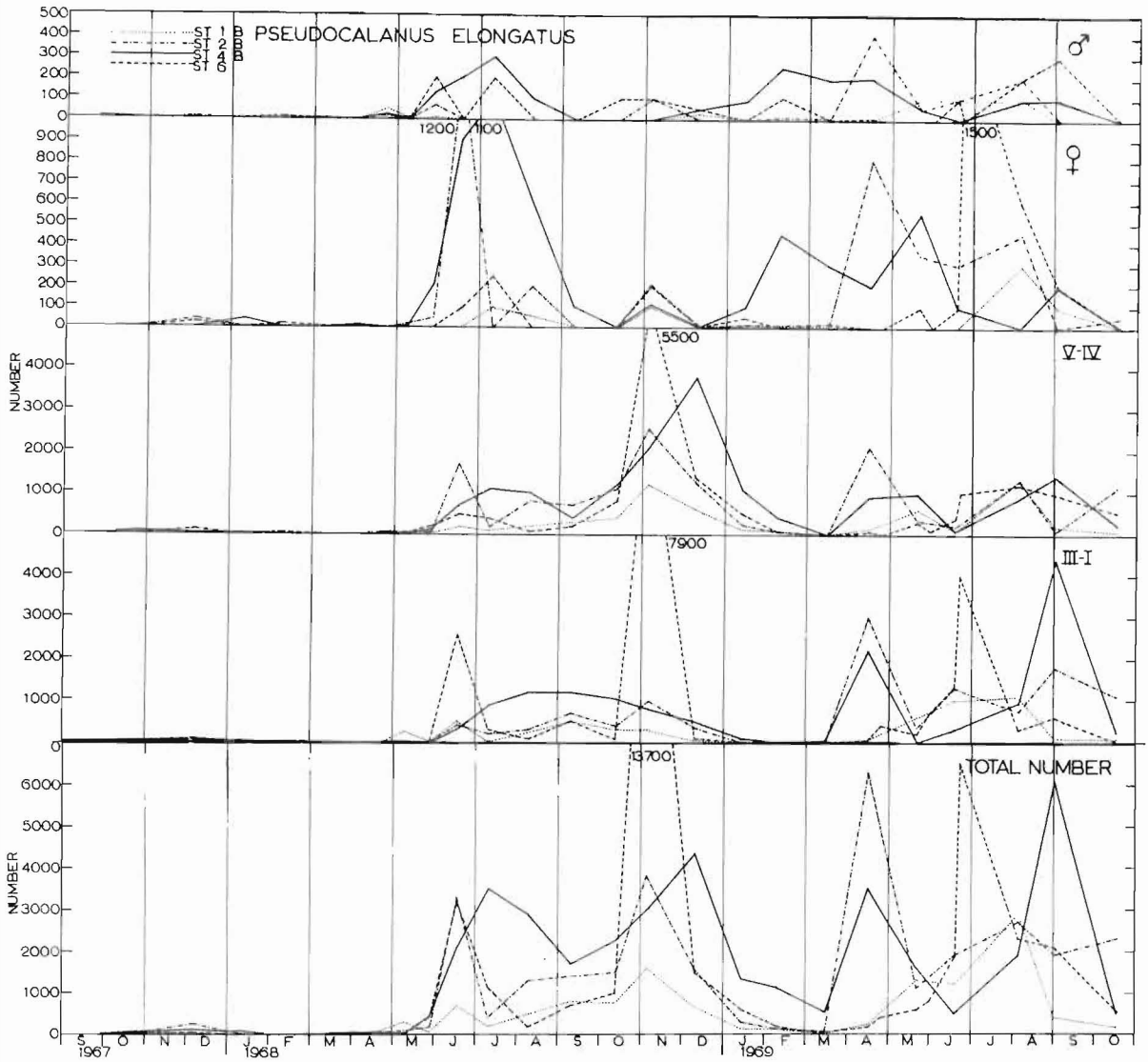


Fig. 11 *Pseudocalanus elongatus*, stage distribution and total numbers during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface.

in the main fjord (Fig. 11). In 1967 few individuals occurred in the period September to December, while a significant stock was found in the same period in 1968 and 1969. In 1969 a pronounced maximum was observed in Borgenfjorden proper in April, while in 1968 the first maximum of the year occurred during June-July.

There seems to be a tendency for the maxima at St. 4B to occur later than at the other stations, but when a stock is established, high numbers tend to persist. The delayed, prolonged, and relatively large stocks at St. 4B may be due to immigrants followed by an accumulation in the inner basin, combined with abundant food supply. At the other Borgenfjord stations, and particularly at St. 6, the stock is quite variable, probably due to more rapid water movements.

## Propagation

Both males and females were present during all seasons, particularly at the stations in Borgenfjorden proper (Fig. 11). From September 1967 to April 1968, however, very few adults were found. Propagation obviously took place in Borgenfjorden more or less continuously, but due to the water exchange with the main fjord, different populations were mixed and generations were thus difficult to separate. In the main fjord, spawning probably started during March-April and went on more or less continuously throughout summer and autumn (Strømgren 1973). A similar propagation period must be expected also in Borgenfjorden. In spring 1968 the water temperature was significantly lower than in 1969, and low temperature may have retarded the development. In 1966 a similar trend was observed in the main fjord (Strømgren 1973).

## *Microcalanus pusillus* G.O. Sars

Of the genus *Microcalanus*, only *M. pusillus* was observed in the shallow Borgenfjord.

In the main fjord *M. pusillus* had its center of distribution below 100 m, in Borgenfjorden *M. pusillus* was normally scarce. In Nordåsvannet, which has a similar shallow threshold at the entrance, *M. pusillus* was also scarce (Wiborg 1944). A large maximum was found at St. 1B outside the entrance, where very large numbers ($>$ 100.000 ind./$m^2$) occurred in May 1969 (Fig. 12). This maximum is related to a simultaneous maximum at St. 6. The maximum at St. 1B coincided with the very low salinity in the surface layer ($<$ 15 o/oo).

At St. 4B, small peaks of *M. pusillus* were also found in winter, perhaps related to the renewal of bottom water in the inner basin. At St. 2B, which is characterized by rapid water exchange and no stratification, *M. pusillus* was very limited. Adults were scarce at St. 2B and 4B, and a local propagation in Borgenfjorden proper is evidently of minor importance. It seems probable that although old stages are found at St. 1B, the main spawning takes place over greater depths.

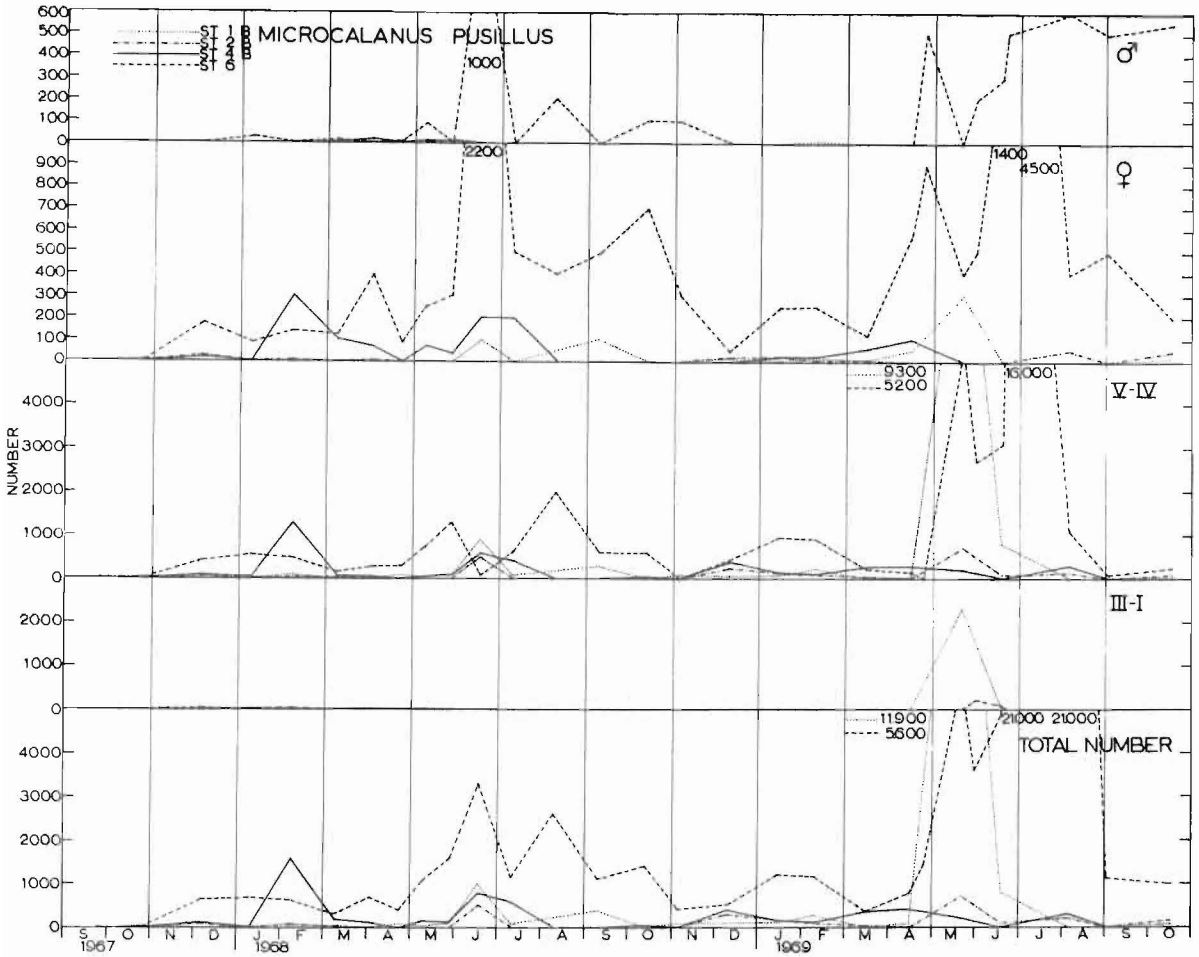


Fig. 12. *Microcalanus pusillus*, stage distribution and total numbers during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface.

## Temora longicornis Müller

The neritic *T. longicornis* is an important percentage of the summer plankton in Trondheimsfjorden, except in the innermost part, where it was rather insignificant (Strømgren 1973).

### Variation in number

In Borgenfjorden very large numbers of *T. longicornis* may occur (Fig. 13). Small spring maxima are indicated both in 1968 and in 1969. Large stocks occurred in June of both years, particularly in 1969 when then number at St. 2B exceeded 150.000 ind./$m^2$, and more than

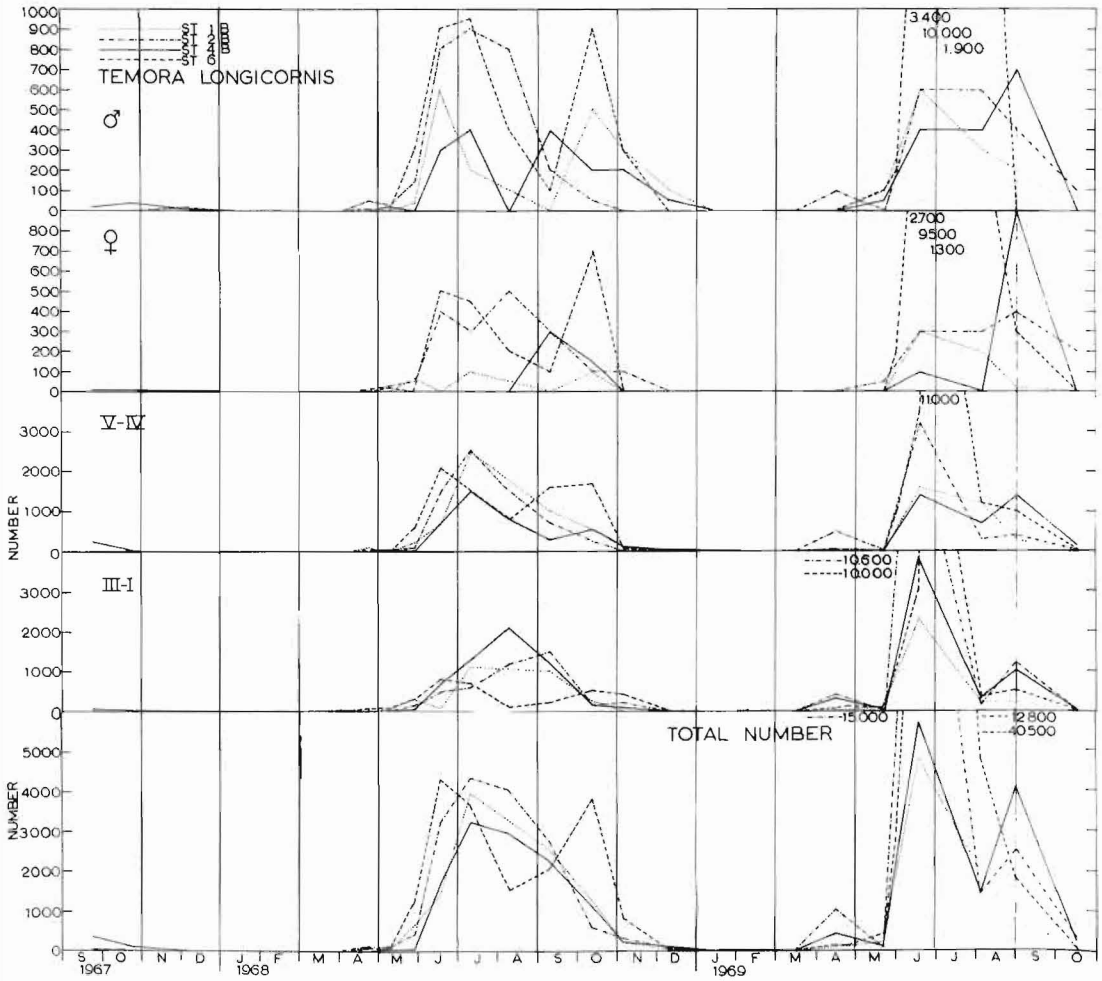


Fig. 13. *Temora longicornis*, stage distribution and total numbers during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface.

400.000 ind./$m^2$ was recorded at St. 6. At St. 6 the stock increased by 380.000 ind./$m^2$ within a week. *T. longicornis* was abundant throughout summer at all localities, and the stock did not decline until October-November. Wiborg (1944) reported moderately large stocks from Nordåsvannet.

## Propagation

During maximum periods all stages occurred (Fig. 13), and propagation obviously took place when the temperature was favourable, from March-April until September-October. A similar propagation period was also found in the main fjord (Strømgren 1973).

The larvae produced in cold water before May had no success, and production in great scale did not start until June. During winter adults were absent in the samples, while single specimens of young stages occurred occasionally. As discussed in Strømgren (1973), very small stocks of adults may exist, although they are not caught in the net, but the possibility of resting eggs may also be considered (A. Berner pers. comm., Conover 1964).

Apart from extreme values, the stock in the shallow Borgenfjord in 1968 and 1969 seems to be of the same magnitude as at St. 18, 15 and 6 in the main fjord. During 1963-1966, the trend of the maxima in the main fjord indicated a supply of *T. longicornis*, and the very rapid increase at St. 6 in June 1969 is obviously not due to local production. Probably shallow areas in the fjord, like Borgenfjorden, do not provide the main fjord with significant stocks, and the supply most likely must originate outside the main fjord.

## Centropages hamatus Lilljeborg

**The neritic** *C. hamatus* has a typical seasonal occurrence in the main fjord (Strømgren 1973). In Borgenfjorden small April-May maxima occurred in 1968 and 1969, followed by large summer-autumn stocks (Fig. 14). Borgenfjorden thus shows a **trend similar** to the main fjord, but generally with significantly larger stocks.

In June 1969 very large numbers were taken at St. 6 (260.000 ind./$m^2$) and St. 2B (116.000 ind./$m^2$). These maxima of *C. hamatus* show a parallel to *T. longicornis*, and as for *T. longicornis* the increase at St. 6 is probably not of local origin.

Except from June 1969, the largest numbers were found at St. 2B and St. 4B in Borgenfjorden, while at St. 1B and St. 6, the values were significantly lower. This difference generally included all stages. This trend indicates that *C. hamatus* finds favourable conditions in Borgenfjorden. Farran (1911) and Colebrook et al. (1961) stated that *C. hamatus* attains the largest stocks in basins and landlocked waters.

In the main fjord the distribution of *C. hamatus* in time and space indicated that immigrants were of importance (Strømgren 1973).

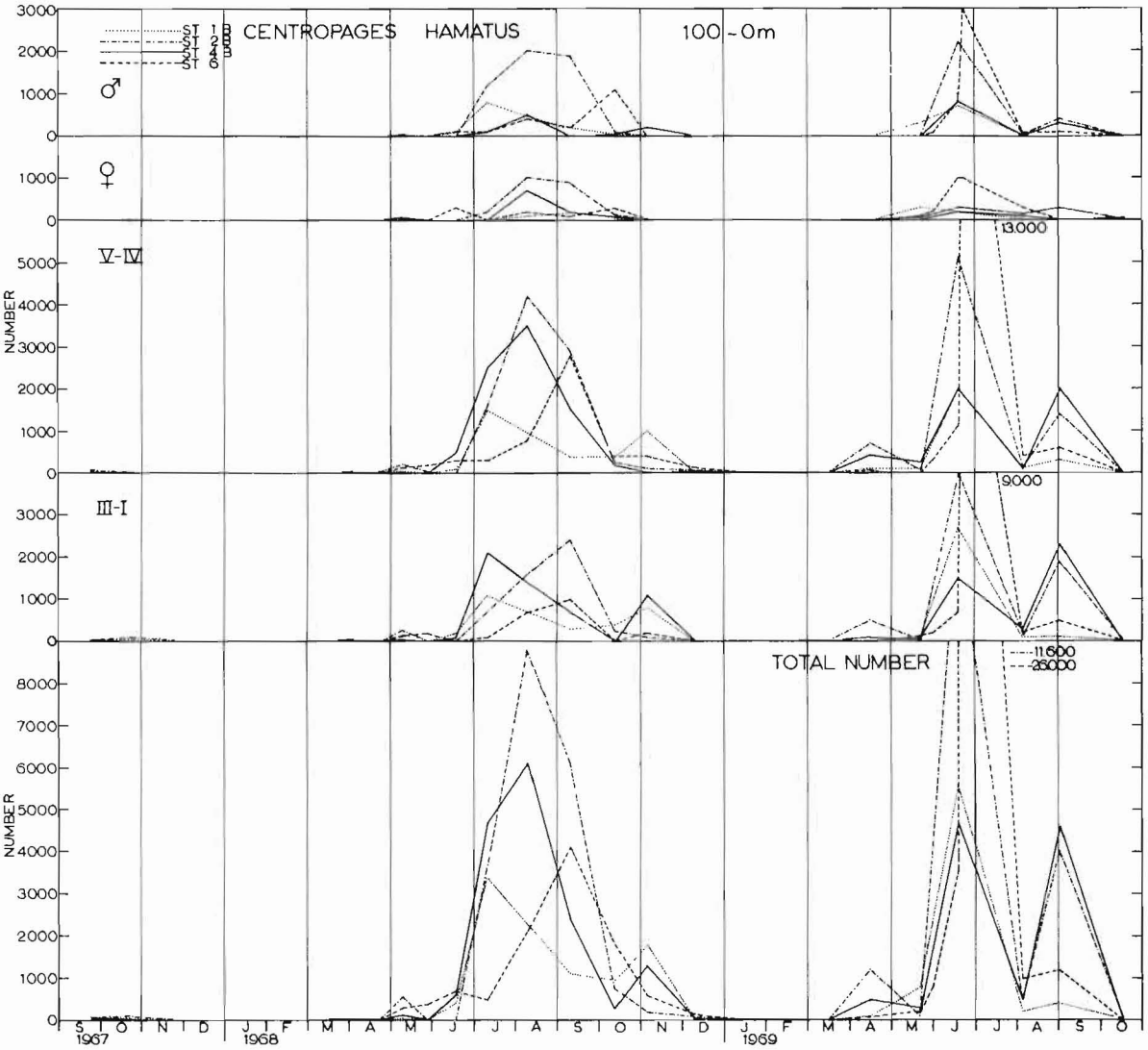


Fig. 14. *Centropages hamatus*, stage distribution and total numbers during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B and 4B from bottom to surface.

Probably the production of *C. hamatus* in shallow areas of the fjord may add to the stocks at the stations in the main fjord.

Adults were caught from May to November, while during winter and early spring they were practically absent. A small spring generation was produced in April-May, but had no success. The next generation was probably spawned in June and obviously breeding continued until September-October. The rate of productivity seems related to temperature. In 1969 no adults were observed before the small spring maximum of young copepodite stages. The adults may have escaped attention, due to low concentration, but as suggested for *T. longicornis*, winter eggs or resting stages may occur (Marshall 1949, Strømgren 1973).

## Acartia longiremis Lilljeborg

Two species of *Acartia*, *A. longiremis* and *A. clausi* occur in Trondheimsfjorden (Strømgren 1973). During 1967-1969, mature stages of *A. longiremis* were numerous, while only one male and 10 females of *A. clause* were recorded. Thus, practically all copepodite stages III-I of *Acartia* probably belong to *A. longiremis*. At Hitra (an island) outside Trondheimsfjorden proper, *A. discaudata* Giesbrecht was abundant in a tide pool, but in Trondheimsfjorden and in Borgenfjorden it was never found.

*A. longiremis* has its main distribution in Borgenfjorden in the period from June to October-November, but even in winter small numbers of

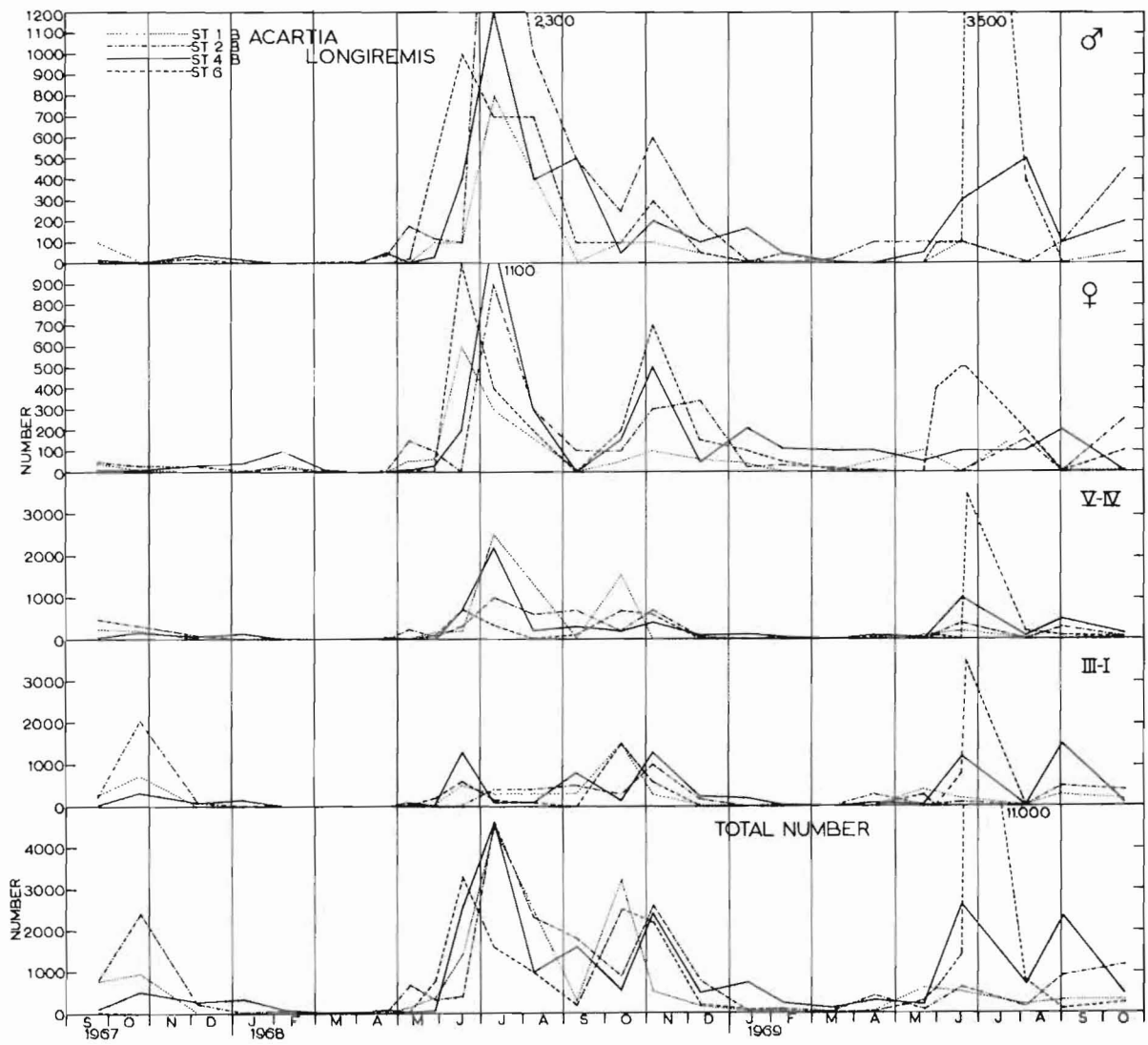


Fig. 15. *Acartia longiremis*, stage distribution and total numbers during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface.

adults as well as of copepodite stages III-I were present (Fig. 15). A small spring peak is indicated during April-May, followed by a large maximum during June-July and a peak of intermediate size during September-October. At St. 6 a very prominent maximum was found in June 1969, showing a parallel to *T. longicornis* and *C. hamatus*, and the bulk of this stock must have been transported in from other areas. *A. longiremis* is a typical neritic species, and sheltered coastal waters generally seem to be favourable. Except for extreme values, *A. longiremis* is more abundant in Borgenfjorden proper than in the main fjord (Strømgren 1973). During 1963-1966 the abundance of *A. longiremis* seemed inversely related to the number of *C. finmarchicus*. Possible explanations for this relation are different responses to freshwater supply of the two species (Légaré 1957, Strømgren 1973), or predation of *C. finmarhcicus* on young *A. longiremis* (Conover 1964, Strømgren 1973).

Both adults and copepodite stages III-I were present during all seasons. The maximal breeding period is from June to late autumn, perhaps with peaks in June and in autumn, but spawning may occur in winter and early spring.

## Oithona similis Claus.

Different stages of *Oithona similis* are not separated, but since nauplii and the smallest copepodite stages pass through the net, the number refers mainly to older stages.

In Trondheimsfjorden *Oithona similis* was very abundant with main maxima in summer-autumn (Strømgren 1973). In Borgenfjorden *Oithona similis* was found during all seasons and might be abundant even in mid-winter (Fig. 16), indicating a pronounced tolerance of low water temperature. A general increase in numbers started at all stations in June. The largest maxima occurred during August-October.

In May 1969 a separate maximum at St. 1B coincided with sudden reduction of surface salinity (< 15 o/oo), and thus shows a parallel to *M. pusillus*.

At the Borgenfjord stations the largest numbers occurred at St. 4B during all periods of abundance, and the maxima at St. 4B seemed also

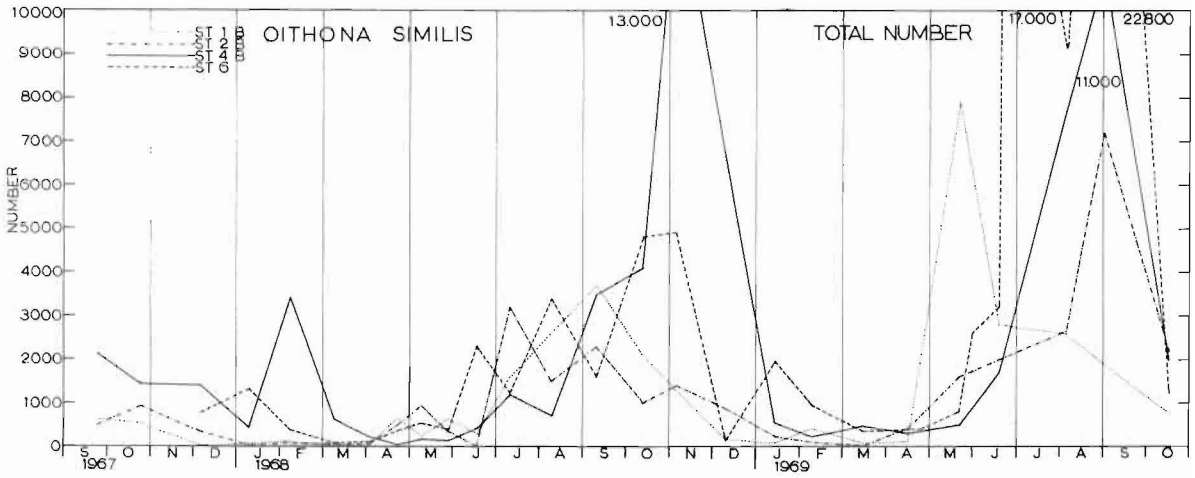


Fig. 16. *Oithona similis*, total numbers during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface.

to be prolonged. The maxima at St. 2B were smaller and declined more rapidly. During periods when great differences were found between St. 2B and 4B, February 1968, November 1968, and probably August/September 1969, salinity and temperature conditions were equal at both stations, and the differences in abundance may be due to accumulation of *Oithona similis* in the inner basin.

The very large maxima at St. 6 in 1969, with an increase from approx. 30.000 ind./$m^2$ to 170.000 ind./$m^2$ within five days, show a parallel to several other species, and transport into the area is the probable explanation. After a decline in August an even larger maximum was obtained during the first days of September. During 1963-1966, there were indications of an immigration into the fjord during summer-autumn, but probably local shallow areas in the fjord contribute considerably.

As smaller stages were not found in the samples, breeding periods were not recorded. It is possible that *Oithona similis* spawns vigorously in summer-autumn, probably due to high temperatures, but spawning on a small scale may also take place in winter.

## Oncaea borealis G.O. Sars

Small stages of *O. borealis* escaped through the net, and the catch consisted mainly of adult females and males, the females dominating. During 1963-1966, *O. borealis* showed a pronounced preference for the main

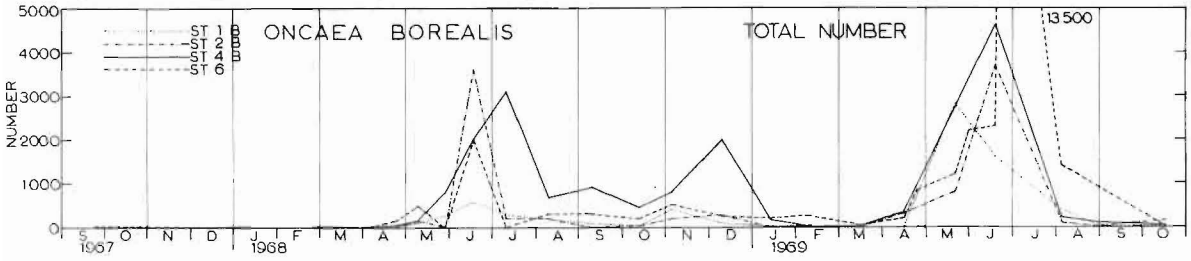


Fig. 17. *Oncaea borealis*, total numbers during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface.

fjord (Strømgren 1973).

At the Borgenfjord stations maxima occurred at St. 1B and 2B in June 1968, at St. 4B in July and December the same year (Fig. 17). In 1969 a peak at St. 1B in May was followed by maxima at St. 2B and 4B in June. At St. 6 maxima occurred in June 1968 and 1969. In late June 1969 an extremely rapid increase in numbers at St. 6 also occurred.

Compared to St. 6 during 1964-1966 (Strømgren 1973), *O. borealis* was quite abundant at St. 2B, and particularly at St. 4B. St. 4B showed on the average the greatest numbers and the maxima were prolonged. This trend indicates an accumulation in the inner basin.

As for *Oithona similis* and *M. pusillus*, the maximum at St. 1B in May 1969 coincided with low surface salinity.

The lack of younger stages in the samples prevents a direct determination of breeding activity. Females dominated during all seasons, while males and females in copulation were found mainly in June 1968 and during May-June 1969 (Table 3). The period of copulation indicated during May-June is obviously followed by spawning. Pairs in copulation were observed also in autumn.

Table 3. *Oncaea borealis*, total numbers of males during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface

| | 1968 | | 1969 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Febr. | June | May | May | June | June | July | Aug. | Sept. |
| 4B | 0 | 200 | 0 | - | 400 | - | - | - | 100 |
| 2B | 1 | 0 | 50 | - | 0 | - | - | 50 | 0 |
| 1B | 0 | 0 | 1200 | - | 200 | - | - | 0 | 0 |
| 6 | 0 | 0 | 100 | 800 | 0 | 2500 | - | 0 | 0 |

## Oncaea similis G.O. Sars

In the main fjord *Oncaea similis* was recorded only twice between 1963-1966, in May 1965 at St. 15 and St. 6 (Strømgren 1973). In 1968 and 1969 a few more records were made, and the numbers per haul are given in Table 4. At all stations maxima occurred during May-June, but St. 4B gave the smallest numbers. The relatively large maximum in May 1969 at St. 1B, coincided with a similar peak of *O. borealis*, *Oithona similis* and *M. pusillus*.

Table 4. *Oncaea similis*, variation in numbers during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface

| | 1968 | | | 1969 | | | |
|---|---|---|---|---|---|---|---|
| | April | May | June | May | June | July | Aug. |
| 4B | 0 | 40 | 0 | 0 | 0 | - | 0 |
| 2B | 0 | 15 | 0 | 400 | 500 | - | 0 |
| 1B | 0 | 240 | 0 | 1800 | 400 | - | 100 |
| 6 | 40 | 110 | 800 | 350 | 900 | - | 0 |

## Pareuchaeta norvegica (Boeck)

This deep-living copepod was recorded only once in Borgenfjorden.

## Metridia longa (Lubbock)

A few copepodite stages V and IV were recorded in Borgenfjorden in spring and autumn. Copepodite stages III-I and nauplii occurred more frequently, but were taken only in the period March to May.

### Acartia clausi Giesbrecht

One male was found at St. 1B in September 1968.

### Oithona spinirostris Claus

Young stages of *O. spinirostris* might have been recorded as *O. similis* and thus escaped attention. Females of *O. spinirostris* were found three times at St. 1B, February 1968, February 1969, and May 1969.

### Harpacticoida

Harpacticoids, mostly *Microcetella norvegica* Boeck, occurred frequently in small numbers. At St. 2B harpacticoids were found in almost every haul during all seasons.

## COELENTERATA

Coelenterates were normally not identified, but large *Beröe cucumis* Fabricius were observed frequently. Gelatinous material from the large medusae *Aurelia aurita* L. was often found in the samples.

## PTEROPODA

### Limacina retroversa (Phipps)

In Trondheimsfjorden, *L. retroversa* has a restricted occurrence in time and space, and very few numbers were recorded in the inner fjord (Strømgren 1973)

In 1968 the maxima occurred in June at St. 6 and the Borgenfjord

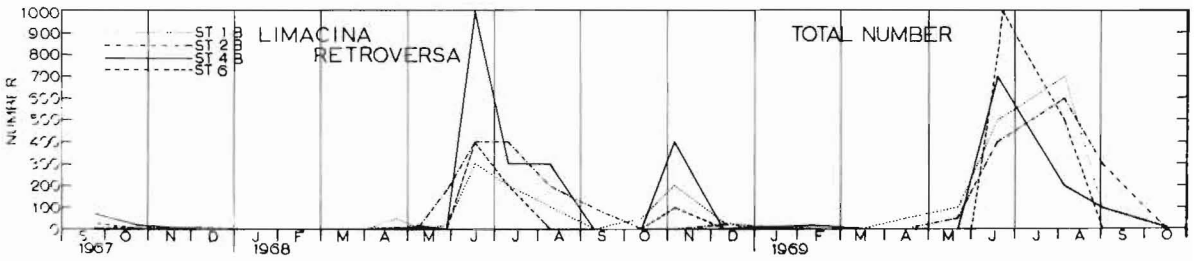


Fig. 18. *Limacina retroversa*, total numbers during 1967-1969 at St. 6 in 100-0 m at St. 1B, 2B, and 4B from bottom to surface.

stations 1B, 2B, and 4B (Fig. 18). The largest numbers were found at St. 4B. At St. 4B and at St. 2B, the peak was prolonged until August. In November an autumn maximum occurred. In 1969 maxima were found during June-July with peaks in June at St. 6 and 4B, and during July-August at St. 1B and 2B. Compared to 1963-1966, significantly larger maxima were found at St. 6 in 1968 and especially in 1969. Small spring maxima were indicated both in 1968 and 1969.

## CHAETOGNATA

Small specimens of *Sagitta elegans* Verrill were recorded twice in Borgenfjorden. *Eukrohnia hamata* (Möbius) was taken once at St. 1B.

## CLADOCERA

### Podon polyphemoides (Leuckart)

During 1963-1966, *P. polyphemoides* was quite variable in Trondheimsfjorden, with large fluctuations from year to year.

In June 1968 a large maximum occurred at St. 4B, a moderate one at St. 1B and a small one at St. 2B (Fig. 19). In June 1969 moderate numbers were found at all the Borgenfjord stations. During August-September of both years, the largest values were obtained at St. 2B, but significant numbers occurred also at St. 1B and 4B. The difference in abundance between the Borgenfjord stations 2B and 4B in autumn, may indicate that the turbulent conditions at St. 2B, with high temperature

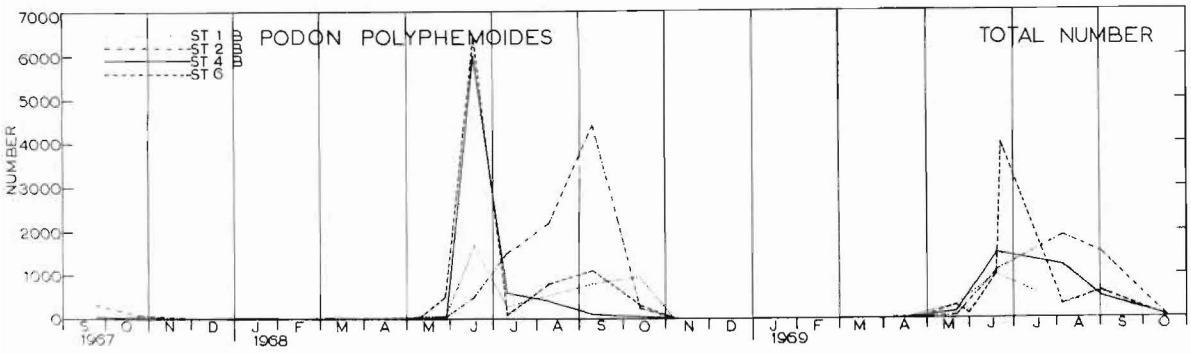


Fig. 19. *Podon polyphemoides*, total numbers during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface.

from bottom to surface, increases the volume of water which is favourable to *P. polyphemoides*, compared to the stratified water found at St. 4B.

## Evadne normanni Lovén

Of the genus *Evadne*, only *E. nordmanni* was found by examining a relatively large number of specimens from Trondheimsfjorden. In Borgenfjorden a number of specimens was also examined, but only *E. nordmanni* was found.

In 1968 a maximum occurred at St. 6 at the end of May, followed by a peak at St. 4B in June (Fig. 20). In 1969 small numbers were observed during April-May, and a significant peak was observed at St. 6 at the end of May. A very rapid increase of the stock took place at St. 6 in late June with a maximum of 130.000 ind./$m^2$, but it declined throughout July. Small peaks occurred in August at St. 1B and 2B, and during August-September at St. 4B. During winter only single specimens occurred.

The variation in Borgenfjorden corresponds to that found in the

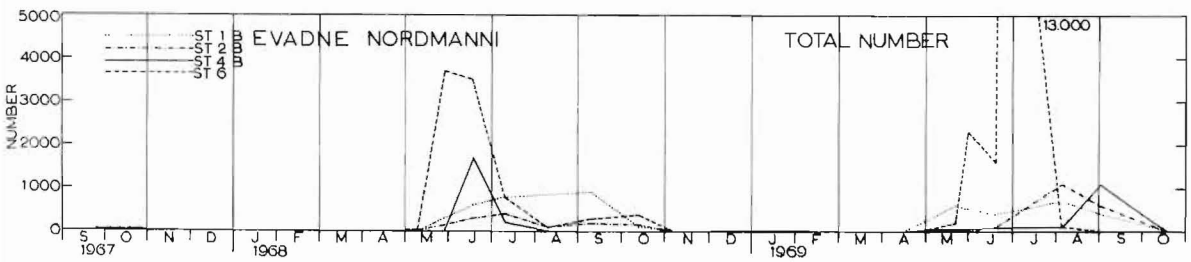


Fig. 20. *Evadne nordmanni*, total numbers during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface.

main fjord, and as in Trondheimsfjorden, the annual variations were large. Generally *E. nordmanni* was much more abundant at St. 6 than at the Borgenfjord stations during June-July, while in autumn the opposite trend is indicated.

## OSTRACODA

Only a few *Conchoecia* spp. were found at the Borgenfjord stations.

## AMPHIPODA

A few *Temisto abyssorum* (Boeck) were taken in Borgenfjorden.

## MYSIDACEA

In Borgenfjorden only single specimens were taken in ordinary vertical hauls. Hauls with Beyers bottom sledge, however, gave large numbers in autumn.

## EUPHAUSIACEA

In Borgenfjorden only larvae of Euphausiacea were found twice.

## DECAPODA

Decapod larvae occurred singularly but were not determined as to species.

## COPELATA

### Fritillaria borealis acuta Lohmann

*F. borealis acuta* had its main occurrence during April-May at all stations, while smaller stocks were found in autumn (Fig. 21). The fluctuation in numbers indicates that *F. borealis acuta* is quite variable both in Borgenfjorden and at St. 6.

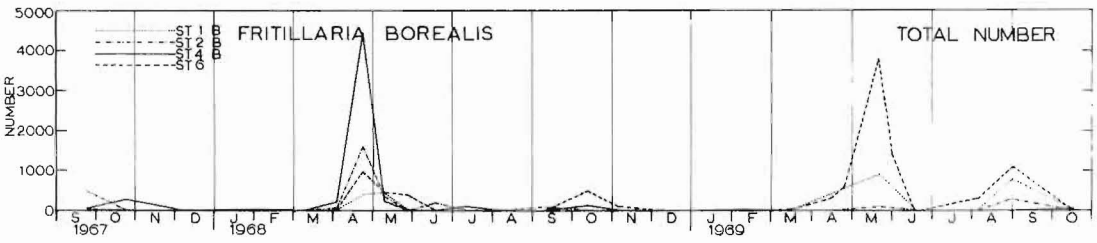


Fig. 21. *Fritillaria borealis acuta*, total numbers during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface.

### Oikopleura spp.

The three species of *Oikopleura*, which are recorded in Trondheimsfjorden (Strømgren 1973) were not separated. *Oikopleura* spp. had a very restricted occurrence at St. 6 and in Borgenfjorden.

In autumn 1967 no specimens were found, in 1968 a few, while in 1969 *Oikopleura* spp. were abundant at St. 2B and 4B. At St. 6 no specimens were found. Wiborg (1954) suggested that *O. dioica* Fol and *O. parva* Lohmann were supplied to the northern coast from southern localities.

## LARVAE OF BOTTOM INVERTEBRATES

### Cirriped larvae

Very large numbers occurred at the shallow Borgenfjord stations, with prominent maxima in April-May, particularly in 1969 at St. 2B. They were not determined as to species, but the bulk probably belonged to the

genus *Balanus*. St. 2B is situated at a locality which is characterized by a large stock of *Balanus balanus* (L.).

## Polychaet larvae

During 1967-1969 large numbers of polychaet larvae, mainly spionids, were taken at the Borgenfjord stations. The number of spionid larvae is shown in Fig. 22. During April-May 1968 and 1969, small maxima occurred, mainly at St. 2B, and from June to September very large numbers were found at St. 4B. The bottoms below 18-20 m of the basin, represented by St. 4B, are contaminated with $H_2S$.

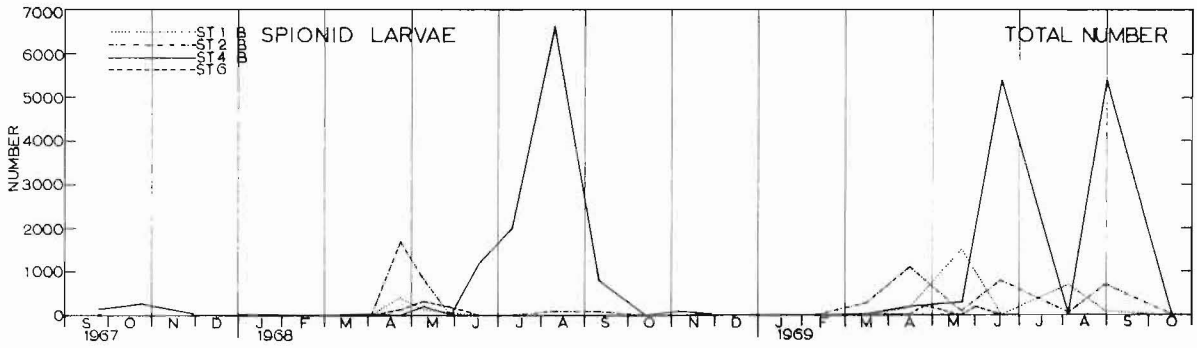


Fig. 22. Spionid larvae, total numbers during 1967-1969 at St. 6 in 100-0 m, at St. 1B, 2B, and 4B from bottom to surface.

## Cyphonautes larvae

Cyphonautes larvae had two peaks of abundance, during May-June and August-October. On the average the largest numbers were found at the shallow Borgenfjord stations.

## Bivalvia larvae

As in the main fjord, the bivalvia larvae in Borgenfjorden seemed to have two maxima annually, with peaks during May-June and August-September. The larvae were not identified as to species.

## Echinoderm larvae

In Borgenfjorden proper, quite a few numbers of echinoderm larvae were observed. Small peaks occurred during April-May and the period June to September-October. Many species are probably represented. The smallest numbers occurred at St. 4B, probably because large bottom areas are unhabitable for adult echinoderms.

## Ascidiaceae larvae and eggs

During 1967-1969 larvae and eggs of ascidians occurred in the plankton exclusively at the Borgenfjord stations. Ascidians are abundant in this locality, and the larvae found resembles those of *Ciona intestinalis* (L.) which is the dominant species in Borgenfjorden. Both larvae and eggs ready to hatch, were found. Eggs were observed during January-February 1968, with a maximum abundance of 1.800 ind./$m^2$, while larvae were found both years during January-February, May-June and September, with an average of less than 1.000 ind./$m^2$. According to Gulliksen (1972) *C. intestinalis* does not spawn in Borgenfjorden during winter, and the eggs and larvae observed in the cold season probably originate from deep water in the main fjord.

## Other invertebrate larvae and eggs

A few phoronid larvae were found in August and September in 1969 at St. 1B.

# CONCLUSIONS

The water in Borgenfjorden originates from the surface layers in Trondheimsfjorden transported in by the tide. The zooplankton in Borgenfjorden is accordingly very dependent on the zooplankton in the upper layers of the main fjord.

In the outer basin of Borgenfjorden the water is changed within approx. eight days, and during this short period, a local stock of holoplankton can hardly be established. Rapid fluctuations are thus the general trend. Another characteristic of the outer basin is strong turbulence, and when warm surface water is introduced in summer, the whole basin rapidly warms to a high temperature from bottom to surface. This situation may represent an improvement for species which have high reproductive rates and high temperature optima. Such species find optimal conditions in the whole water column and large numbers may be produced in the outer basin in spite of rapid exchange.

In the inner basin, the water above threshold level needs 2-3 weeks to be renewed, summer temperature is relatively high, and food is very abundant. Temperate or warm water species introduced from the outer basin (*Temora longicornis, Centropages hamatus, Acartia longiremis*) may reproduce and give rise to large numbers under such optimal conditions. As the interchange with the main fjord is slow, large and relatively permanent stocks may be established.

Because the zooplankton in Borgenfjorden is greatly dependent on the zooplankton in the main fjord, the prehistory of the main fjord water is decisive for the development in Borgenfjorden. Species which are variable in the main fjord must be expected to fluctuate more significantly in Borgenfjorden proper, both seasonally and annually.

During the cold season the rate of productivity is slow, and the zooplankton in both basins in Borgenfjorden is quite similar to that in the surface layer of the main fjord.

During winter and spring, species (*Calanus finmarchicus, Microcalanus pusillus*) which normally live in deep water, may come to the surface, and both adults and larvae are brought into Borgenfjorden. These species normally show a rapid decline in numbers after the introduction, and permanent stocks are not established.

Occasionally, as in May 1969, several species which normally live in deeper water, showed a maximum at St. 1B, outside Borgenfjorden proper. Simultaneously, quite low surface salinity was observed and this indicated that a fresh water current in the surface might have brought the deep living species near to the surface either due to upwelling or to entrainment. These species may be transported into Borgenfjorden proper.

## ACKNOWLEDGEMENTS

The investigation was supported by The Norwegian Research Council for Science and the Humanities, and the preparation of this paper was supported by the Royal Norwegian Society of Sciences and Letter, The Museum.

I am greatly indebted to Mr. E. Lande for sampling assistance. Valueable technical assistance was given by Mrs. I. Harder.

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