International Council for
The Exploration of the Sea

C.M. 1975/L:18
Plankton Committee
Ref. Baltic Cttee

A five-year study of Zooplankton biomass and species composition in the Baltic proper

by

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INTRODUCTION

Since 1963 comprehensive studies of zooplankton have been carried out in the Baltic proper by Swedish scientists. With a modern approach of the plankton methodology, which has been improved ever since then, a new picture of the plankton community has been drawn. The issue for the investigations has changed very much since our first studies. At the beginning our main effort was concentrated on the ecology of the various species of the plankton fauna. Later the species composition and biomass studies became more important. Since 1972 the secondary production of zooplankton in relation to the primary phytoplankton production is in focus. At present the energyflow through the whole pelagic ecosystem is our main interest.

Since the beginning of our work the samples have been very carefully analysed, not only to species but in most cases to developmental stages. It has therefore been possible to follow the cohorts of each species in our studies with dense sampling. The technique with vertical fractionated hauls was shown to be the best one in an area like Baltic with both seasonal and diurnal migration (cf. Ackefors 1969 a, b). In addition to the plankton nets a quantitative plankton sampler has been used (Ackefors 1969 b, 1971 a). Later even horisontal or oblique hauls with a Bongo net have been carried out for zooplanktonbiomass and fish larvae studies (Ackefors et al., 1974, Hernroth & Persson, 1975).

The studies have been carried out both in coastal- and offshore water. In the coastal water of Askö the ecology of the zooplankton in relation to seasonal and vertical distribution has been investigated (Ackefors, 1969 a, b, 1971 a). The offshore studies were first carried out at 70 different plankton stations (Ackefors, 1969 a), but later the studies were concentrated to 7 stations, each representing one subarea of the Baltic proper. The issue for the studies has been to investigate the horisontal and vertical distribution of zooplankton in the Baltic in relation to hydrographical conditions (Ackefors & Hernroth, 1970 a, b, 1971, 1973, 1975). Later biomass and production studies have been carried out both in relation to the primary production and fish production (Ackefors & Hernroth, 1972; Ackefors 1975 a, b).

During the latest phase of our studies (since 1973) even dense sampling in offshore water (c. 18 times $year^{-1}$) has been carried out at two stations in the Baltic proper, one station in the Åland Sea and one in the Gulf of Bothnia (Ackefors & Lindahl, 1975). In order to verify or reject the results of our field studies some laboratory experiments have been made (Ackefors & Rosén, 1970; Ackefors 1971 b).

The present paper is a summary of a five-year study in offshore conditions in the Baltic proper. For each of the separate years a comprehensive report has been prepared (Ackefors & Hernroth, 1970 a, b, 1971, 1973, 1975). The main features of the results are outlined and some conclusions are made.

MATERIAL AND METHODS

The brackish water conditions in the Baltic greatly influence the species composition of zooplankton. The diversity is very low and only about 40 species occur in the Baltic proper from 55°N to 60°N (excluding microzooplankton <0.2 mm). The Baltic is the largest brackish water sea in the world with stable and low salinity conditions. The salinity is about 8‰ at the surface in the southern Baltic proper and 6‰ in the northern part. This is a critical salinity interval for most marine and freshwater species (cf. Remane 1940). 6-8‰ is the lowest salinity in which a lot of euryhaline plankton organisms may occur. In less saline water the number of fresh water species increases. Consequently further to the north in the Baltic (=the Gulf of Bothnia) where the salinity is less than 6‰ the plankton fauna consists of only brackish water and freshwater species except for a sparse occurrence of euryhaline organisms in the deep water with higher salinity and holeuryhaline organisms (cf. Ackefors, 1969 a, 1971 c).

A halocline appears in 40-60 m depth. Below this level the salinity increases to 12-20‰ in the deep basins. Below the halocline the oxygen conditions deteriorate rapidly. The oxygen concentration is less than 1-2 ml O_2/1 in most of the water column. (Fonselius, 1962; Ackefors & Hernroth, 1971).

The temperature conditions fluctuate very much during a year. The surface water in winter is less than 4-5°C in the Baltic proper and fast-ice or drift-ice may occur 1-2 months at the coast and off-shore.

In the end of spring (May) the temperature rises at the surface. The thermocline develops and the water temperature is higher in the surface water than below the thermocline until October-November. In winter the temperature is rather homogeneous from surface to halocline. The temperature is 5-6°C in the bottom water of the deep basins the whole year. (cf. Ackefors 1969 a).

The zooplankton sampling in this study was carried out at 7 offshore stations each representing one subarea of the Baltic proper (fig 1). The subareas are the Arkona Sea (S 12), the Bornholm Sea (S 24) and five subareas of the Gotland Sea (8 A, S 41, F 81, F 78 and F 72). The stations were visited 4-5 times a year, 1968-1972.

All samples in this study were collected with a Nansen net with a mesh-size of 0.16 mm except in 1972 when the mesh-size was 0.09 mm. On most occasions the hauls were fractionated according to the following standards: 25-0 m , 50-25 m, 100-50 m ,200-100 m. Some sampling have been performed according to the hydrographical conditions, i.e. from thermocline to surface, from halocline to thermocline and from bottom to halocline. The samples were preserved in 4% formaldehyde. .

In the laboratory the samples were sub-sampled in the modified whirling apparatus constructed by Kott (1953). The samples were analysed to species and for the copepods also to developmental stages. The two species of Acartia have not been separated except for the adult stage.

For all biomass studies the volume of each species and developmental stage were estimated (Ackefors, 1972). The density was considered to be 1g/cm^3 and the values were converted to wet weight and expressed as gm^{-2} (wwt). A filtration coefficient of 0.7 was applied . Recent studies with WP2-net (UNESCO, 1968) and Nansen net simultaneously have verified, that a coefficient of 0.7 is suitable to apply for all seasons except for the most productive period of the year (Hernroth, unpubl.) During the period in August-September with very high production a coefficient of 0.3-0.5 would have been better. In the future the old results will be recalculated when correction factors are established for each month or season. The biomass figures in this paper are therefore an underestimate for the most productive part of the year.

From 1975 and onward the Nansen net has been replaced by the WP2-net according to an agreement between all countries inside the Baltic Marine Biologists (B M B). A manual for zooplankton-ichtyoplankton investigations in the Baltic (Ackefors et al., 1974) as well as other biological parametres has been prepared by 7 working groups inside B M B. The manual will be presented at the 4th Baltic Symposium on Marine Biology in Gdynia, Poland, in October, 1975.

RESULTS

a. The plankton fauna

About 40 species of zooplankton (excluding microzooplankton <0.2 mm) occurred in the samples. The most abundant species were six copepods, viz. Temora longicornis, Pseudocalanus minutus elongatus, Centropages hamatus, Acartia longiremis, Acartia bifilosa and Eurytemora sp; two cladocerans Bosmina coregoni maritima and Evadne nordmanni; one larvacean Fritillaria borealis (fig. 2). These nine species made together more than 95% of the biomass at all stations except on a few occasions when they made 90% of the biomass. The most important of the nine mentioned species were the copepods T. longicornis and Ps. m. elongatus which together mostly made more than 50% of the biomass in the southern Baltic proper and more than 40% of the biomass in the northern Baltic proper. The cladoceran Podon polyphemoides is very abundant in summer in coastal waters and may sometimes be rather abundant in offshore water (Ackefors, 1969 a). The rotifers Synchaeta spp. (mainly S. baltica and S. monopus) may also be rather abundant but usually only in the coastal waters.

The following species were less abundant; the ephyra larvae of Aurelia aurita and Cyanea capillata, the larvae of Sarsia tubulosa the larvae of Pleurobrachia pileus, the rotifers Keratella quadrata quadrata, K. quadrata platei, K. cruciformis, the larvae of the polychaetes Pygospio elegans and Harmothoe sarsi, the cladocerans Podon intermedius and P. leuckarti, the copepods Limnocalanus macrurus, Oithona similis, Cyclops sp, harpacticoid copepods, the larvae of Balanus improvisus, the amphipod Hyperia galba, gastropod larvae, the larvae of Mytilus edulis, Macoma baltica, Cardium lamarcki and Mya arenaria, the chaetognath Sagitta elegans baltica and larvacean Oikopleura dioica.

b. The horisontal distribution of species

In fig. 3 the horisontal distribution of the copepods in four different months (January=winter; May=spring; August=summer and October=autumn) along a transection from south to north is shown (cf. fig. 1). The values are given as percentage of the total biomass. Ps. m. elongatus is abundant from south to north the whole year. The same was true for T. longicornis except in spring. The two species of Acartia (A. bifilosa, A. longiremis) are relatively more abundant in autumn but was important even in other seasons both in the Arkona Sea (S 12) and at the most northern station (F 72). C. hamatus was of less importance. Eurytemora sp. was only abundant in warm water at the most northern station.

Besides the copepods, F. borealis was important in winter and spring (fig. 4). The first winter eggs of the cladocerans do not normally hatch until April-May. From May E. nordmanni and three species of Podon occurred. These species were not very important however. In August when the temperature increased to more than 15°C B. cor. maritima was very important. Some years more than 1 milj.ind.m^{-2} of that species were found in the southern Baltic proper.

The influx of salt bottom water from the Kattegat through the Belt Sea into the Arkona and Bornholm Sea forms the pre-requisites for species, which are less tolerant to low salinity. Due to this fact O. similis is rather abundant in those areas.

c. The vertical distribution of species

The vertical distribution of the copepods and other organisms fluctuated to a certain extent during the different seasons. Fig. 5 shows a typical pattern of vertical distribution. Most of the species were abundant in the samples from 25 m to surface in the moderately warm water above the thermocline (11°C). Below 50 m depth in the cold water very few organisms occurred except for Ps. m. elongatus, which had its maximum distribution somewhat between 100 and 50 m depth. It is conspicuous that a lot of individuals also were found below 100 m depth where the oxygen concentration was less than 2 ml O_2/l.

In very warm surface water (17.5°C) the copepods were distributed in nearly the same way (fig. 6). But it is to be noted that the sample from 25 m to surface also included the cold water just within the thermocline (20-25 m).

That's ~~way~~ why we found Ps. m. elongatus in that sample.

None of these pictures do however reveal exactly where in the water column the organisms occurred. Fig. 7 shows a pattern of vertical distribution from a sampling with a quantitative plankton sampler from August, 1963, about 6 p.m. (Ackefors, unpubl.).Samples were taken every 2.5 m from surface to 25 m depth. The brackish water organisms (Acartia spp. mainly A. bifilosa and Eurytemora sp.) were distributed in the warm surface water down to the lower part of the thermocline. The euryhaline marine copepods (C. hamatus, Ps. m. elongatus, T. longicornis)were distributed within and below the thermocline. (C. hamatus and T. longicornis migrate up into the surface water during the night but Ps. m. elongatus always remains below the thermocline. In winter this copepod is also found in surface water.)

d. The seasonal variation of zooplankton abundance and biomass

The seasonal variation of the zooplankton biomass at two stations S 24 and F 72 is illustrated in figs. 8-9. In the upper part of the figures the percentage of the total biomass for each of the most important species is reproduced. In the lower part of the figures the seasonal variation of the biomass of T. longicornis and Ps. m. elongatus in comparison to other species is reproduced.

In the Bornholm Sea (S24) Ps. m. elongatus and T. longicornis dominated during the first and second quarter of the year. In August-September the same species and B. cor. maritima were dominant. During the last part of the year Acartia spp. and the two copepods T. longicornis and Ps. m. elongatus made about 90% of the biomass. E. nordmanni, F. borealis and C. hamatus were less important. The other species , indicated by the upper thin area in the diagram, made a very little fraction of the biomass during the year.

The mean value of biomass fluctuated from about 3 g m^{-2} in March to about 30 g m^{-2} in August-September. Besides the two copepods, T. longicornis and Ps. m. elongatus, the other species make a very important fraction of the biomass (13-20 g m^{-2}) in August-September.

At station F 72 (northern Baltic proper) five species made the main part of the biomass during the first half of the year, viz.. F. borealis, A. bifilosa + A. longiremis, Ps. m. elongatus and T. longicornis (fig. 9). In the second part of the year the same species dominated except that F. borealis was replaced by Eurytemora sp. during the warm period from July until October-November. C. hamatus made a small part of the biomass during the whole year while B. cor. maritima contributed a little to the biomass in August-September.

The total biomass at station F 72 is, however, less than that at station S 24. During 8 months of the year the biomass was less than 5-6 g m^{-2}. The highest mean value of biomass (27 g m^{-2})was reported for August.

e. The biomass of zooplankton in the different subareas

The biomass of zooplankton in 1972 and the mean value for 1963, 1968-1972, for different plankton stations is displayed in fig. 10. The values are considered to be representative for the seven subareas of the Baltic proper as mentioned above.

The Arkona Sea (S 12) is a transition area between the Baltic proper and the Belt Sea with very unstable hydrographical conditions. The 1972 value for biomass as well as the mean value for the six years are lower than in most other areas. No real maximum appeared.

The Bornholm Sea (S 24) was productive during the whole investigation period. The maximum value of 58 g m^{-2} in August, 1972, was the highest value ever found in the Baltic proper by the authors. At the three stations S 24, 8 A and F 81 the biomass values from May, 1972, and especially from August, 1972, were higher than the previous values during the investigation period 1968-1972. The monthly mean values based on 4 observations for each of the three stations in 1972 were 25.5, 18.2 and 17.2 g m^{-2} (wwt). The corresponding values for stations S 12, S 41, F 78 and F 72 were 8.5, 9.2, 11.5 and 8.0 g m^{-2} (wwt).There were thus great differences between the various subareas in the Baltic proper. The differences were more pronounced in 1972 than the differences between the six-year mean values.

f. The secondary production of zooplankton

No estimate of the secondary production of zooplankton for the whole period has been done so far. A first attempt to estimate the production in offshore water was made in 1972 for the period 1968-1970 (Ackefors & Hernroth, 1972). See discussion below.

DISCUSSION

The salinity of 6-8‰ in the surface water constitutes a habitat which puts the fauna to a severe test with the physiological problems of ion-regulation, osmo-concentration and osmo-regulation (Ackefors, 1971 c). A lot of euryhaline marine organisms live in the lower part of their tolerance range for salinity. However, a few marine organisms succeed in establishing brackish water populations. The capacity of non-genetic adaptation to low salinity is the pre-requisite for the ecological success of certain euryhaline species. (Kinne, 1964). Due to the low number of species there is a lower competitive stress in the Baltic waters which makes it possible for some marine species to establish a higher population density in the Baltic than in other sea areas (Segerstråle, 1969). This might explain the very low diversity of plankton species and why a few species make a large part of the biomass.

The physiological stress of the marine and freshwater organism greatly influences the horisontal as well as vertical distribution of species. Some euryhaline marine organisms live at greater depths (with higher salinity and/or colder water) in the water column than in marine areas. This phenomenon is called the brackish water submergence. O. similis, S. elegans baltica e.g. live in deeper levels with higher salinity. Ps. m. elongatus always avoids warm water. It is obvious for some marine species in the Baltic, appearing in an adverse low salinity, that they prefer cold water. This is a well-known fact for a number of euryhaline species which live under hypo-osmotic or hyperosmotic stress (Kinne, 1963).

The main issue for our studies is now to estimate the production of zooplankton in order to be able to follow the energy flow in the pelagic ecosystem. Ackefors & Hernroth made a first attempt in 1972. Using the mortality coefficients for plankton populations in a coastal area with dense sampling and the biomass values in offshore water (1963, 1968-1970) the secondary production was estimated. The production in the Bornholm Sea was estimated to 7 $gCm^{-2}year^{-1}$ and for a station in the northern Baltic proper the estimated value was 4 $gCm^{-2}year^{-1}$. A mean value for the whole Baltic proper was estimated to 5 $gCm^{-2}year^{-1}$. It is obvious from our present knowledge that this is an underestimate.

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LEGENDS

Fig. 1. Chart of the Baltic proper and the three subareas, the Arkona Sea, the Bornholm Sea and the Gotland Sea according to WATTENBERG (1949). The Gotland Sea is devided into an eastern and western part by WATTENBERG. According to ACKEFORS (1969 a) the Gotland Sea may be devided into five subareas; the southern (SG), the middle eastern and western (MEG and MWG) and the north-eastern and north-western (NEG and NWG). The seven plankton stations are evident from the chart, in some cases with both old and new symbols as well as the depths. The line indicated by ++++ is a transection through the Baltic proper with the plankton stations reported in figs. 3-4.

Fig. 2. The nine most important species in the Baltic proper which make more than 90-95 % of the biomass in the offshore water. The tenth species, *Podon polyphemoides*, is only important in coastal water (from ACKEFORS & HERNROTH, 1972 b).

Fig. 3. The six most important copepods and their percentage of the total biomass along the transection indicated in fig. 1. A mean value 1963, 1968-1972. Ps = *Pseudocalanus minutus elongatus*, Te = *Temora longicornis*, Ac = *Acartia longiremis* + *A. bifilosa*, Ce = *Centropages hamatus*, Eu = *Eurytemora* sp.

Fig. 4. The important species except the copepods in the Baltic proper and their percentage of the total biomass along the transection indicated in fig.1. *Bosmina cor. maritima*, *Podon* spp. (*P. polyphemoides*, *P. intermedius*, *P. leuckarti*), *Evadne nordmanni*, *Fritillaria borealis*, *Harmothoe sarsi*, *Synchaeta* spp.

Fig. 5. The vertical distribution of the six most important copepods of the Baltic proper in the Gotland Deep (F 81) in October, 1970 (from ACKEFORS & HERNROTH, 1971). (For further explanation, see fig. 3.)

Fig. 6. The vertical distribution of the six most important copepods of the Baltic proper in the Gotland Deep (F 81) in September, 1970 (from ACKEFORS & HERNROTH, 1971). (For further explanation, see fig. 3.)

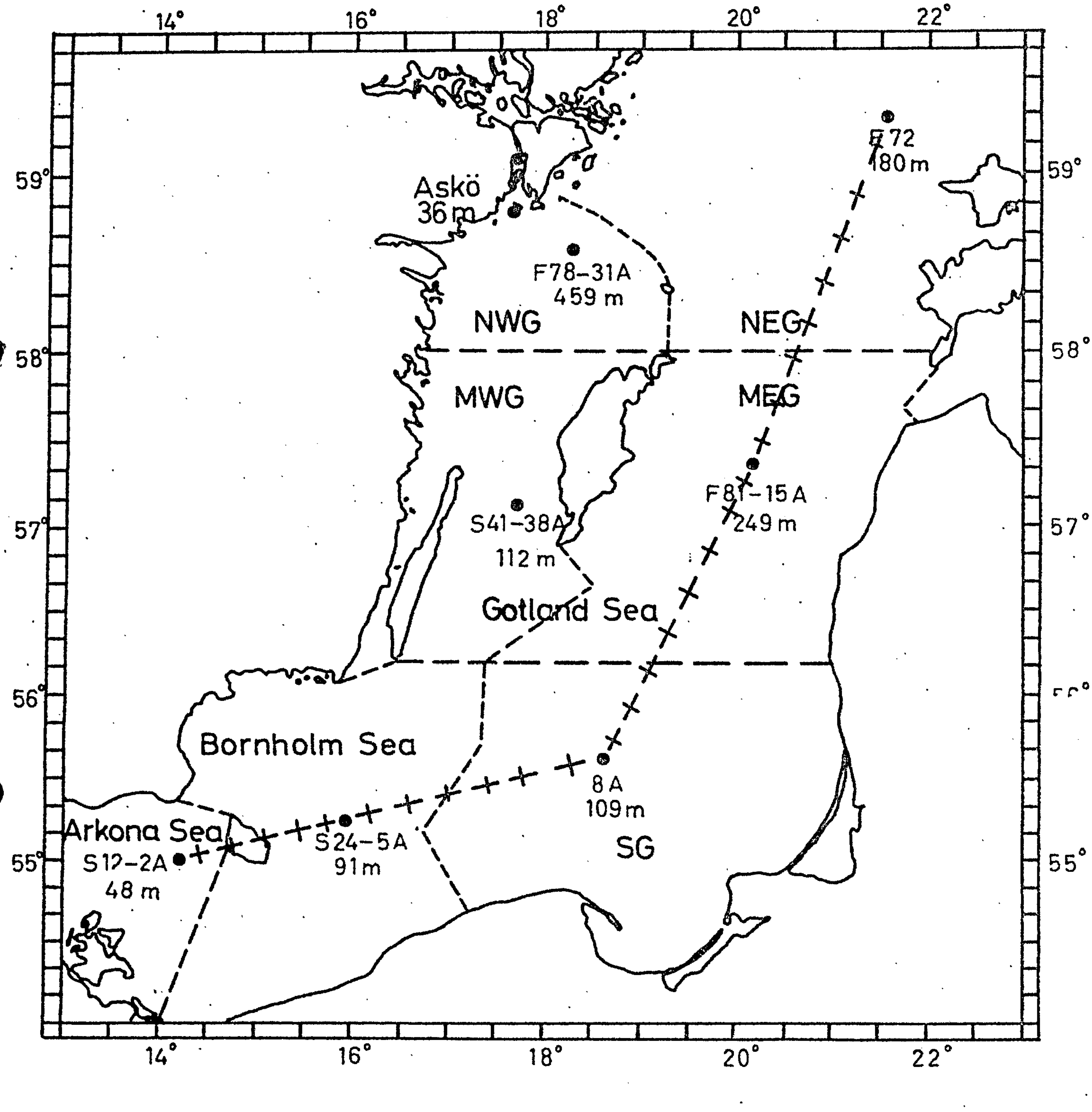
Fig. 7. The vertical distribution of zooplankton from 0 to 25 m depth at station F 72 in August, 1973. Samples taken with a plankton sampler (23 l) every 2.5 m (ACKEFORS, unpubl.).

Fig. 8. The seasonal variation of the abundance of zooplankton species and their percentage of the biomass at station S 24. The total amount of biomass in the lower part of the figure. Ev = Evadne nordmanni, Fr = Fritillaria borealis. Ce = Centropages hamatus, Ac = Acartia longiremis + A. bifilosa, Bo = Bosmina cor. maritima, Ps = Pseudocalanus minutus elongatus, Te = Temora longicornis. A mean value for 1963, 1968-1972.

Fig. 9. The seasonal variation of the abundance of zooplankton species and their percentage of the biomass at station F 72. The total amount of biomass in the lower part of the figure. Eu = Eurytemora sp., Fr = Fritillaria borealis, Ce = Centropages hamatus, Ac = Acartia longiremis + A. bifilosa, Bo = Bosmina cor. maritima, Ps = Pseudocalanus minutus elongatus, Te = Temora longicornis. A mean value for 1963, 1968-1972.

Fig. 10. The biomass of zooplankton in g m^{-2} (wwt) at seven different stations in the Baltic proper in 1972 compared with the mean value for 1963, 1968-1972.

Fig.1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459 m
NWG
NEG
MWG
MEG
S41–38A
112 m
F81–15A
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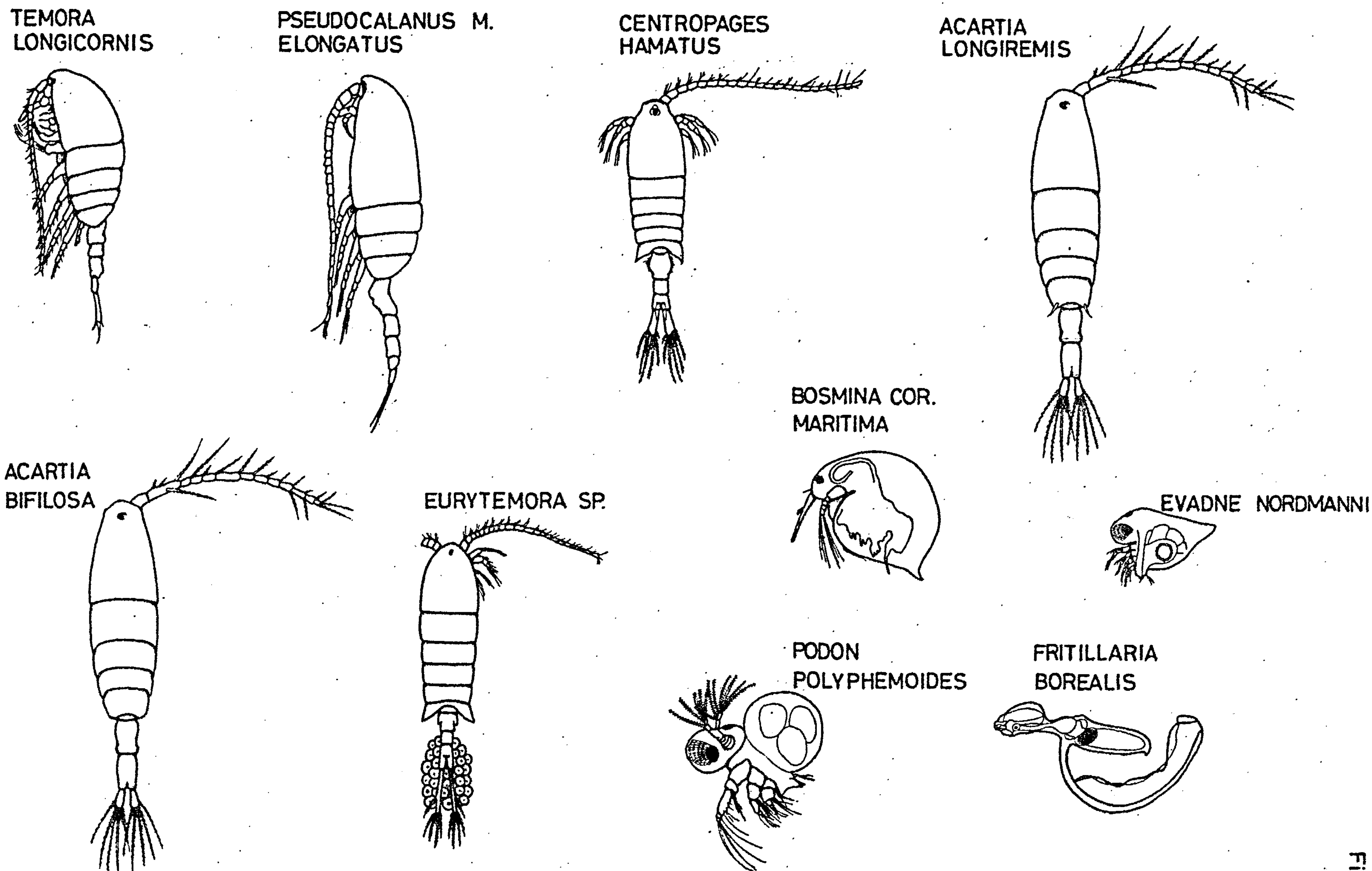
Gotland Sea
Bornholm Sea
8A
109 m
Arkona Sea
S12–2A
48 m
S24–5A
91 m
SG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MARITIMA
ACARTIA
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EVADNE NORDMANNI
PODON
POLYPHEMOIDES
FRITILLARIA
BOREALIS

Fig. 2

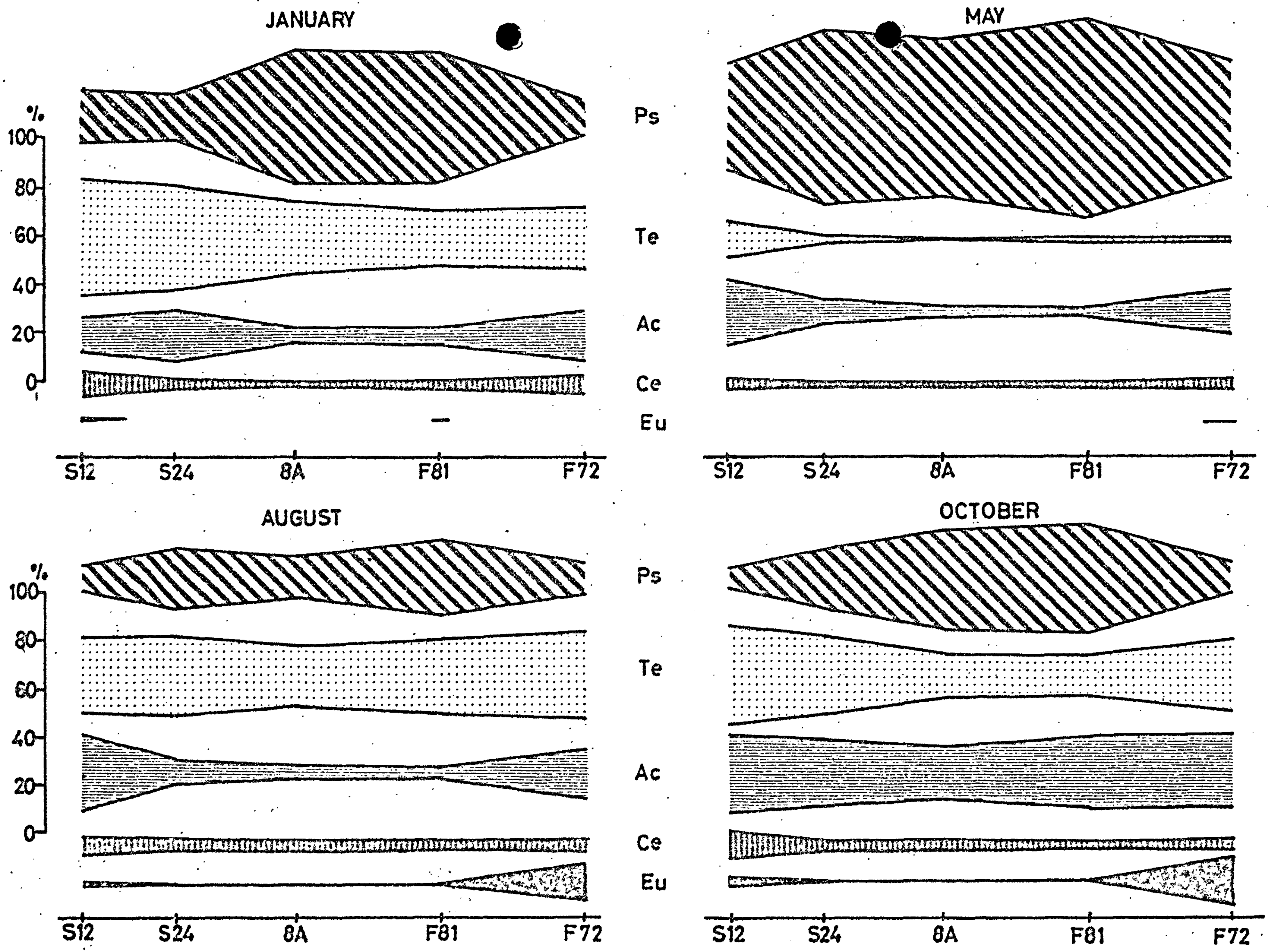
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Fig.3

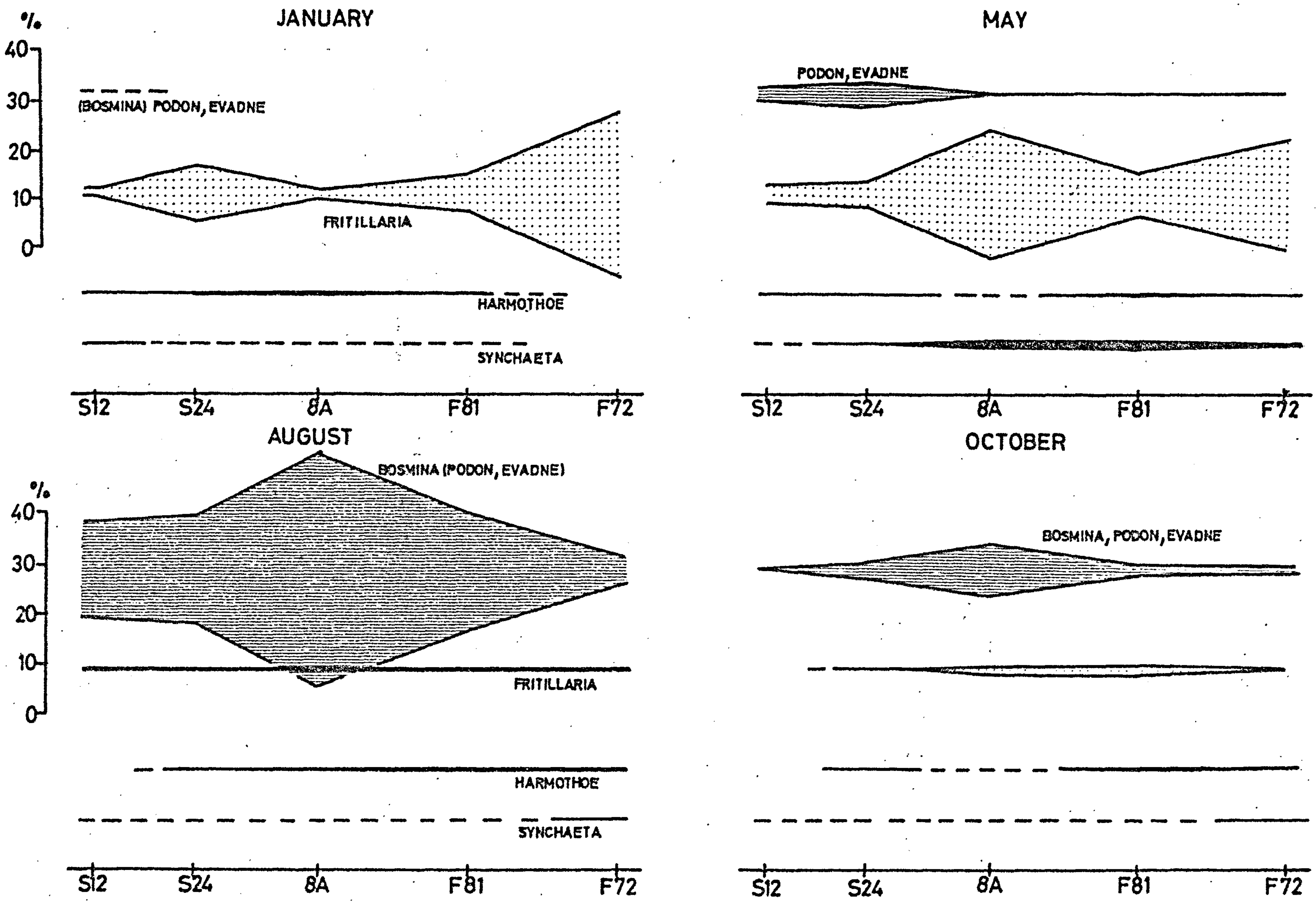
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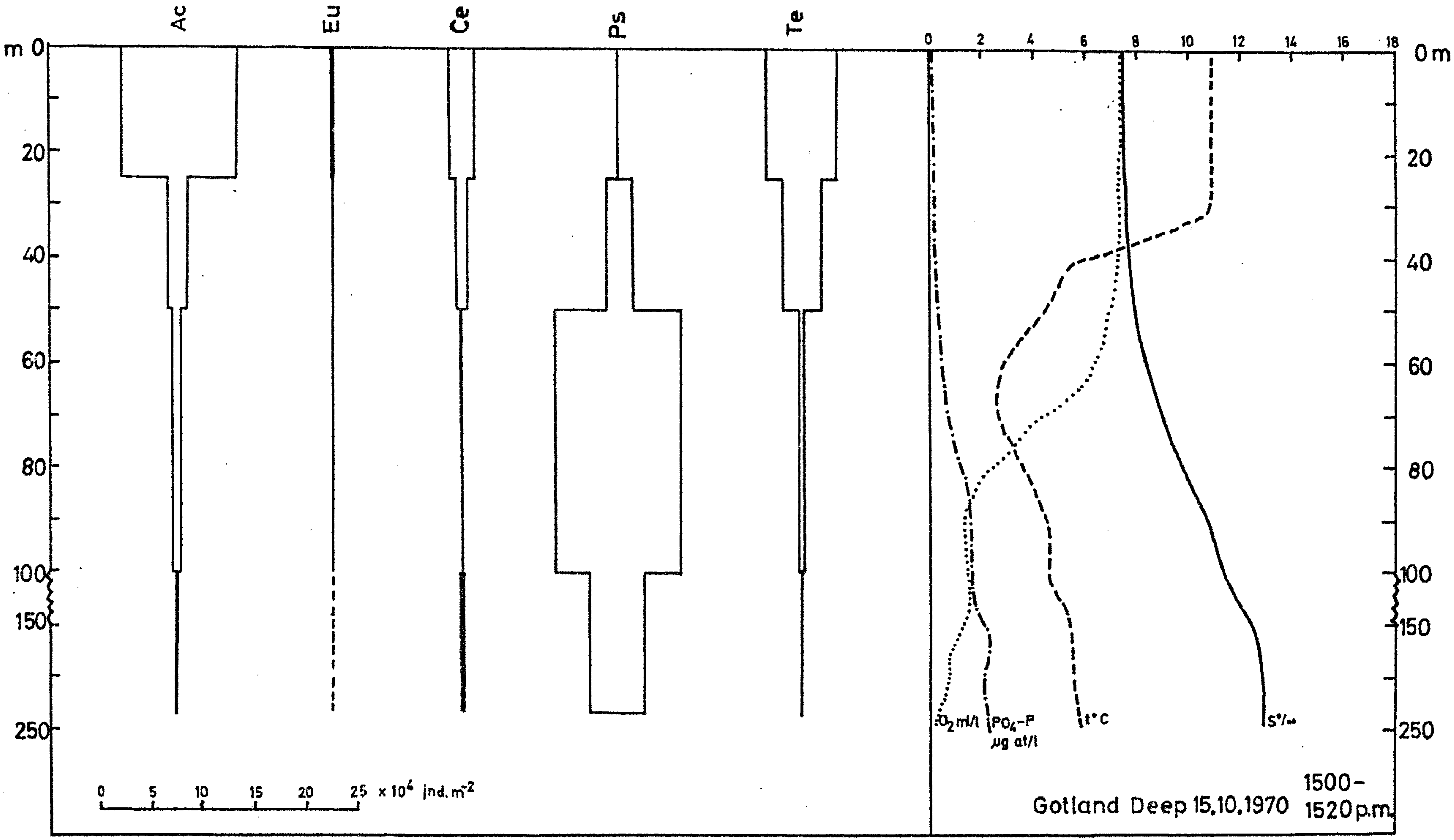
Fig. 4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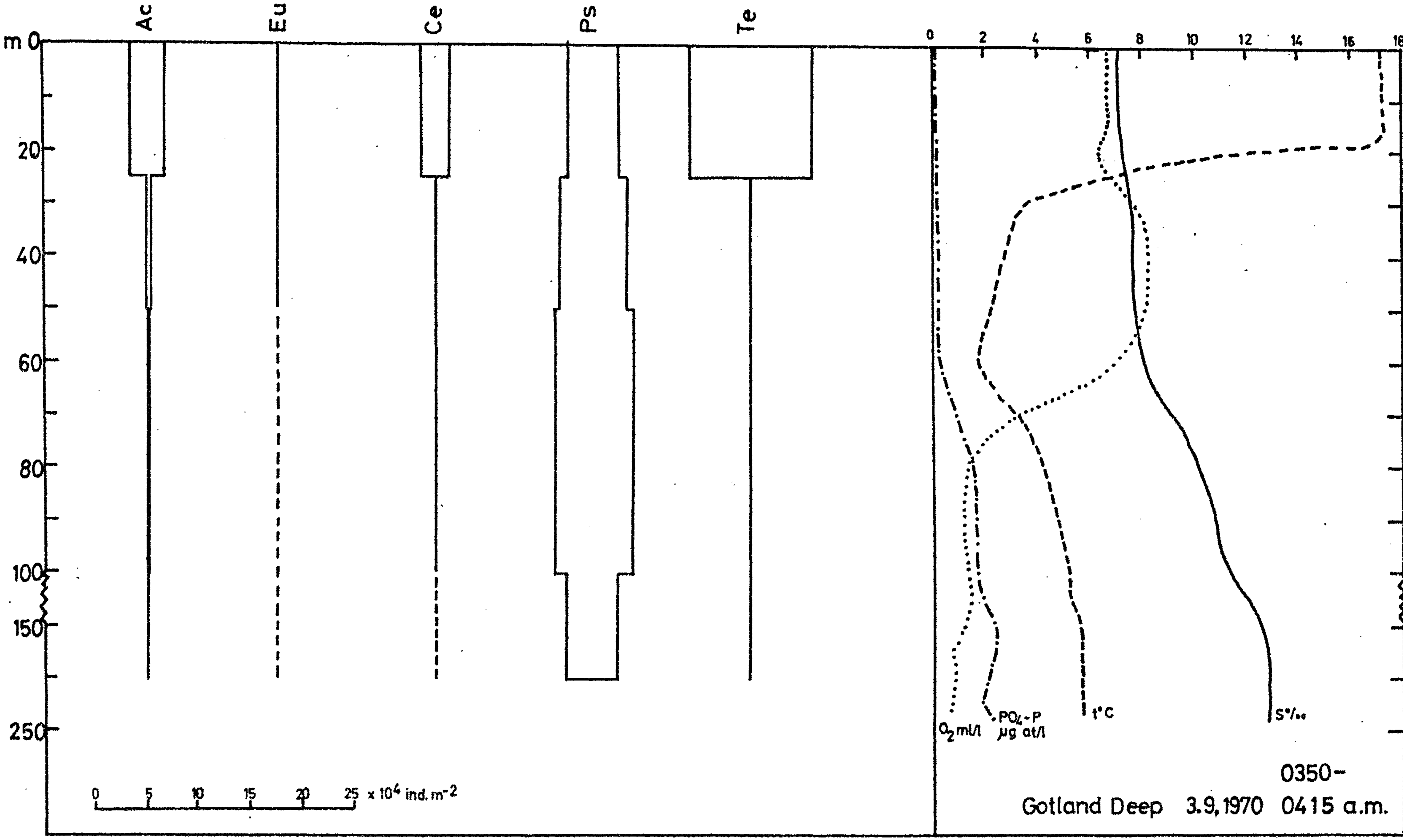
1500–1520 p.m.

Fig. 5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Gotland Deep 3.9.1970 0415 a.m.

Fig. 6

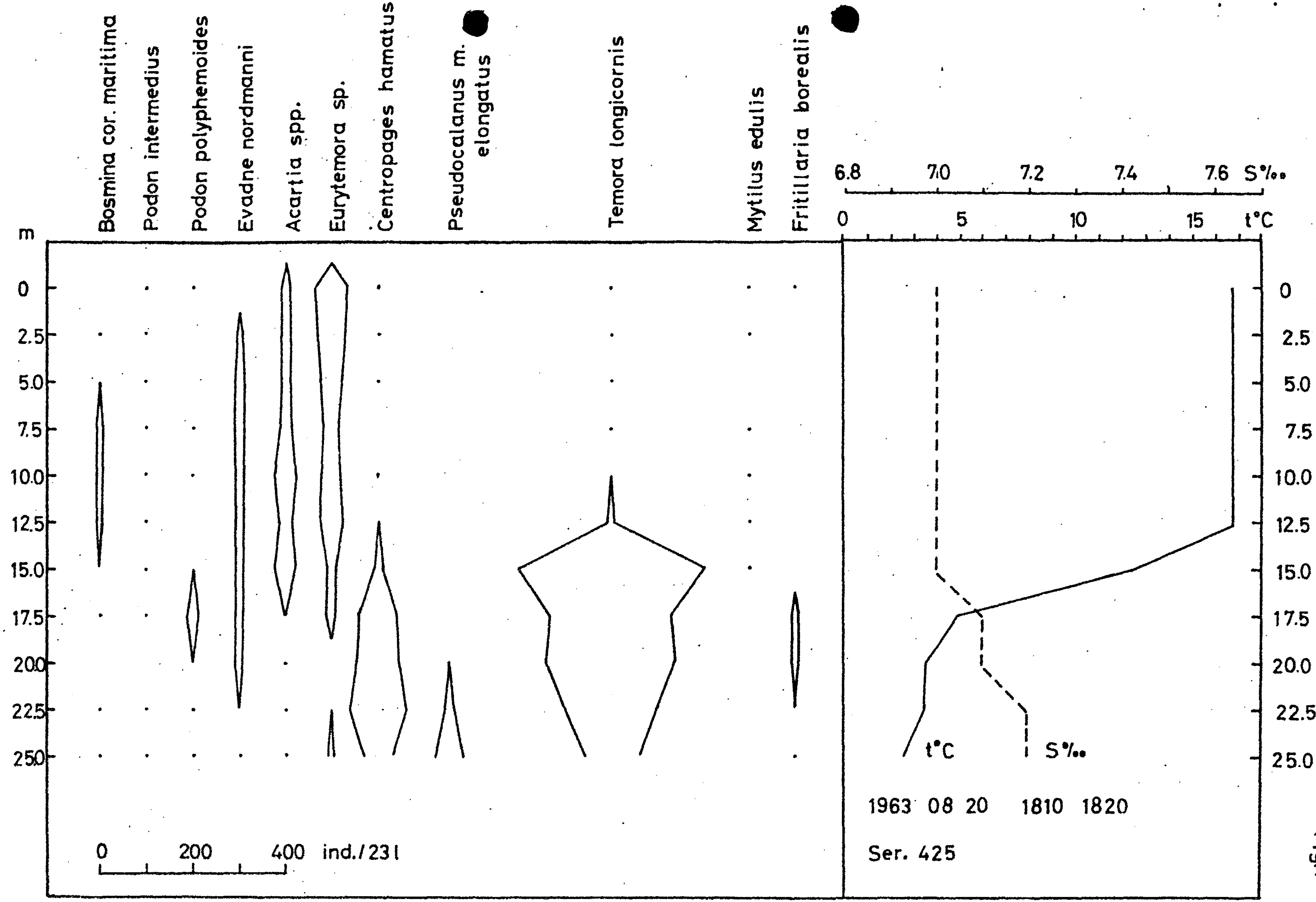
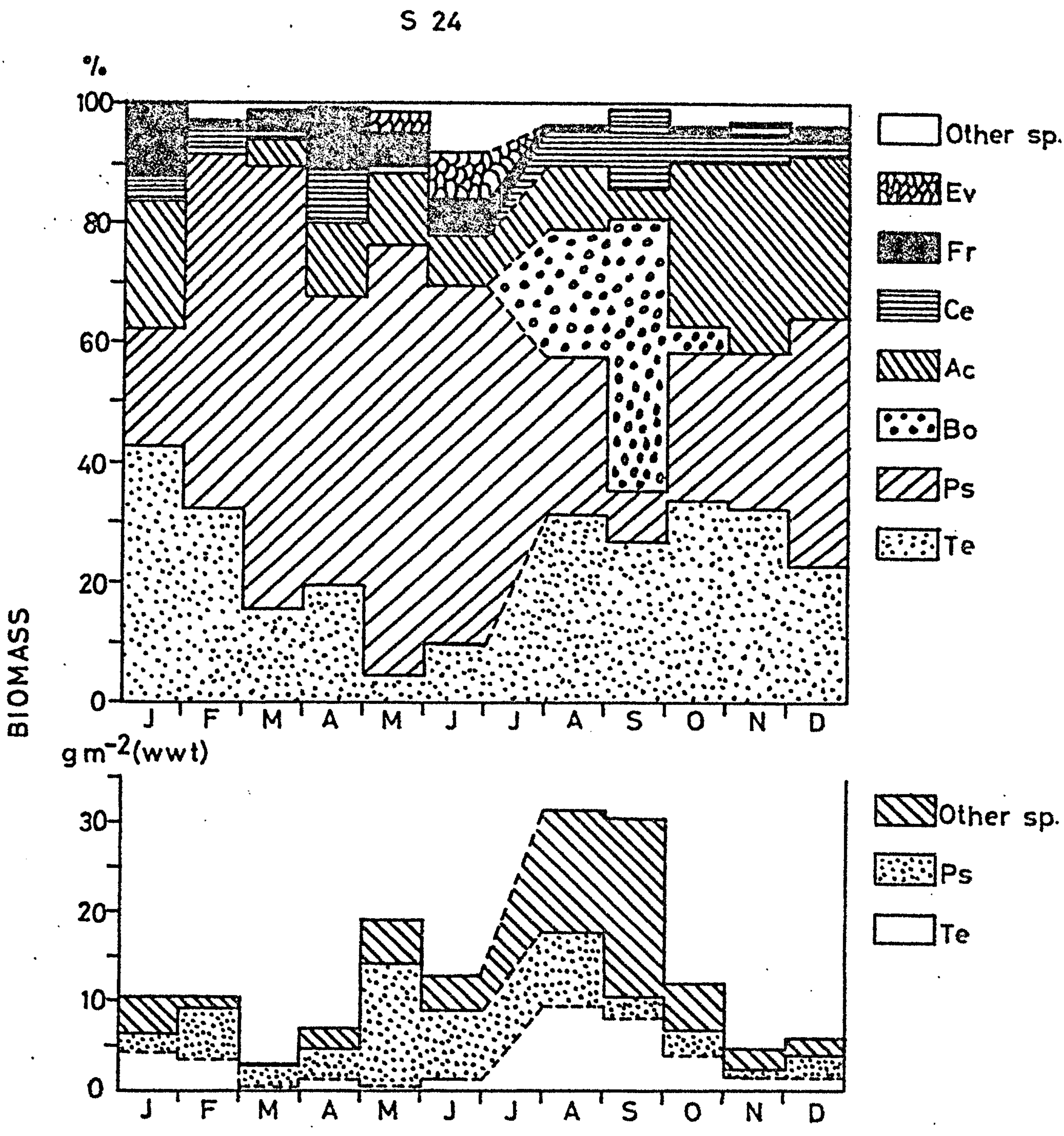

Bosmina cor. maritima
Podon intermedius
Podon polyphemoides
Evadne nordmanni
Acartia spp.
Eurytemora sp.
Centropages hamatus
Pseudocalanus m. elongatus
Temora longicornis
Mytilus edulis
Fritillaria borealis
6.8 7.0 7.2 7.4 7.6 S‰
0 5 10 15 t°C
m
0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
t°C
S‰
1963 08 20 1810 1820
Ser. 425
0 200 400 ind./23 l

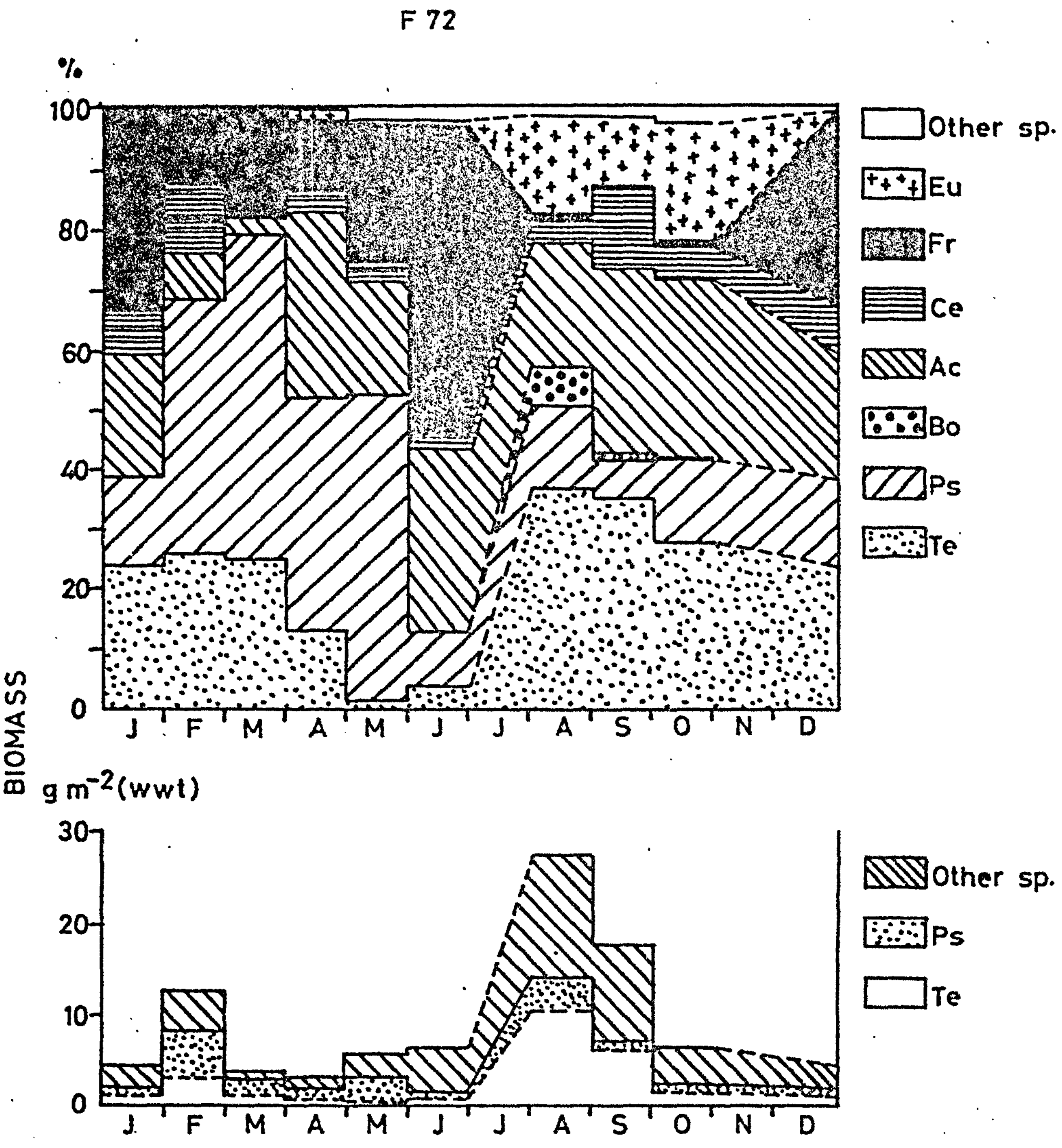
Fig.7

Fig.8



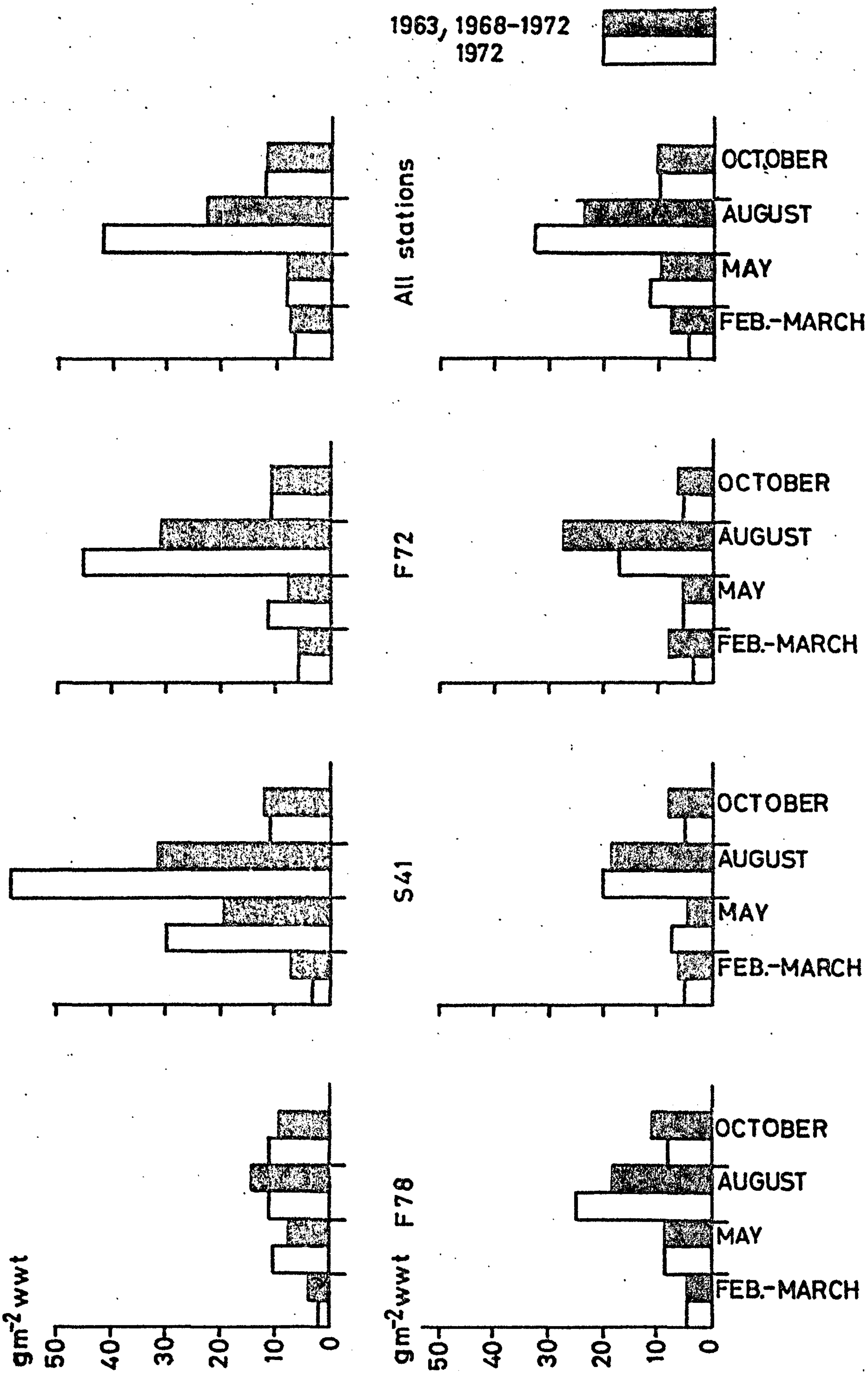
1963, 1968 - 1972

Fig. 9



1963, 1968–1972

Fig. 10



1963, 1968-1972
1972
F 81
8A
S24
S12
All stations
F72
S41
F78
OCTOBER
AUGUST
MAY
FEB.-MARCH
gm⁻² wwt
0
10
20
30
40
50