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# FIELD AND LABORATORY STUDIES OF HERRING LARVAE (Clupea harengus L.)

by

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ABSTRACT

The present study deals with herring larvae from a local herring stock in Lindåspollene, north of Bergen. Growth and survival experiments of herring larvae in relation to density and type of prey organisms have been carried out in the laboratory. Growth rates of 0.08-0.19 mm/day and 2.3-7.6 µg/day were observed at food densities 1 and 3 plankters/ml.

20% and 10-13% survival of herring larvae were obtained 26 and 39 days after hatching at food densities of 3 plankters/ml. No survival was observed at plankton densities less or equal to 0.1 plankters/ml 22 days after hatching. Larvae younger than 22 days experienced a strong positive selection towards copepod nauplii and bivalve larvae. A digestion rate of ½-3 hours was measured in the larvae to digest copepod nauplii.

Vertical distribution of herring larvae (0-14 days and 30-45 days old) is given in relation to their developmental stage (DOYLE 1977), length, feeding behaviour and time of the day. 0-14 days old larvae were distributed in the whole water column during both day and night, with maximum abundance in intermediate depths (10-30 m) by day, and near the surface by night. 30-45 days old larvae were caught in greatest abundance in 5-15 m depth. Feeding periods of 16-18 hours in early May and 13-20 hours in early June were observed for herring larvae up to 14 days and 30-45 days old respectively, and 19%

and 65% of the larvae were recorded with food in their guts during the feeding period. In the laboratory 67% and 82% of 8 and 22 days old larvae were observed with gut contents after a feeding period of 1 hour.

Laboratory experiments indicate that Bolinopsis infundibulum and Sarsia tubulosa have a considerable predator potential for newly hatched herring larvae.

## INTRODUCTION

During the last century quite a voluminous mass of literature has been published on feeding behaviour of fish larvae (BLAXTER 1965, HUNTER 1979).

For survival and growth of the larvae high concentrations of prey animals are not the only major factor involved. The nutritional value as well as the digestibility and size of the food item, food selection, learning of the larvae and a complexity of other behaviour patterns are also involved. The distribution of the larvae in relation to their prey and predator organisms is also important for assessment of their interrelationship, which finally may cause life or death to the larvae.

HUNTER (1975) stressed the importance of a coordination of field and laboratory studies to assess the effect of predation on larval mortality and that studies of interactions between starvation and predation should be encouraged. Together with field studies, laboratory experiments should be made on the effect of larval size, larval condition, predator search patterns and feeding behaviour on the degree of predation.

For larval abundance estimates it is of great importance to know the spatial distribution of larvae at different ages. WOOD (1971) concluded that it is necessary to carry out investigations on the vertical distribution of herring larvae in all areas under different conditions of illumination.

The investigations described in this paper, which are divided into a laboratory (P.F.) and a field (A.J.) part, are carried out with larvae of the local spring spawning herring stock in Lindåspollene, north of Bergen (see LIE et al 1978).

## MATERIALS AND METHODS

### Laboratory

The experiments were carried out at the Aquarium in Bergen, March - May 1978.

Gonads were dissected intact from ripe herring and transported to Bergen where fertilizing was carried out on ground-glass plates 6-18 hours after capture (BLAXTER 1968). In addition, naturally spawned eggs were collected by scuba divers from the spawning grounds. 8.8 l all glass black aquaria with bottoms of 90 µ plankton net were used. The temperature was $9 \pm 0.5^{\circ}C$. The water was pumped from 100 meters depth and an open culture system was used. The light was adjusted to the natural light regime at this time of the year.

The larvae were offered zooplankton from the near by waters, mostly copepod eggs, copepod nauplii, copepodites, bivalve larvae and polychaet larvae. The zooplankton were collected every day by pumping. The larvae were offered the fraction of plankton organisms between 90 and 500 µ. The density of the plankters in the experimental aquaria was determined every day and adjusted to the original one 0.001-3 plankters/ml. The growth experiments were performed in three parallels which lasted 26-39 days after hatching (see table 1). Samples of five larvae were fixed every second day, except on days 9 and 22 in parallel No. 3, where larger amounts of larvae were fixed for food selection and digestion rate experiments. Standard lengths and dry weights were measured and developmental stage (DOYLE 1977) determined. In digestion rate and food selection experiments, larvae without gut contents were allowed to feed for one hour. Then the larvae were put into clean aquaria. Samples of 7-10 larvae were taken every hour. Selection was determined after BERG (1979).

### Field

The material used in this paper was selected from a study of the diurnal vertical distribution and feeding of young herring larvae (age: 0-14 and 30-45 days) based on two 24-hour stations

carried out on June 2-3 1977 and on May 5-6 1978. The sampling stations were selected from previous experience on larval drift from the spawning area in Lindåspollene (Fig. 1).

Sampling of larvae was carried out with BONGO 60 cm, 505 µm mesh size without any closing device, from R/V KNURR, a 30' boat with hydraulic winch facilities. The towing speed was about 2.5 knots. Volume of water filtered was derived from TSK - flowmeter readings.

The gear was hauled horizontally in the depths: 0 m, 5 m, 10 m, 15 m, 25 m and 40 m in 1977 and 0 m, 10 m, 30 m (20) and 40 m in 1978. Lowering and retrieval of the gear to the desired depth was carried out as close to the vertical axis as possible in order to minimize contamination from other strata. The bottom depth was 90 m and 50 m in the deeper parts of the two stations. Sampling depth was determined from the wire length-angle relationship.

All samples were fixed in 4% formaldehyde in seawater and up to 50 individuals in each sample measured to the nearest 0.1 mm standard length (SL). Identification of developmental stages according to DOYLE (1977) was also carried out. For indication of feeding patterns all guts were examined for contents relative to sampling depth, time of the day, temperature and surface illumination (only 1978). All times referred to are in local Norwegian time.

The mean calorific contents used are 2, 13 , 0.6 and 2 cal.$10^{-3}$ per organism for copepod nauplii, calanoid copepods, invertebrate eggs and other animals respectively (ØIESTAD AND MOKSNESS 1978).

## RESULTS

### Laboratory

#### Survival

In parallel No. 1 (see Fig. 2) 80% of the larvae survived until 10 days after hatching. Then it was a drastic reduction in the survival and only 30% of the larvae survived on day 15. The

high mortality continued in the aquaria with food densities between 0 and 1 plankters/ml and no larvae survived on day 23. The larvae offered 3 plankters/ml survived better after day 15 and the survival curve levelled out at 15% surviving larvae 20 days after hatching. At the end of the experimental period (38 days) 10% of the larvae survived at this density.

In parallel No. 2 (see Fig. 3) 80% of the larvae survived until 15 days after hatching. Thereafter the larvae suffered high mortality, especially the larvae being offered the lowest food concentration (0.1 plankters/ml). The bad survival at 0.1 org/ml continued and no larvae survived after day 22 at this density. The survival curve of the larvae offered 1 and 3 org./ml levelled out at 20% and 30% survival 24 days after hatching. At the end of the experimental period (39 days) 10% and 13% of the larvae being offered 1 and 3 plankters/ml survived.

In parallel No. 3 (see Fig. 4) (from naturally spawned eggs) 90% of the larvae survived up to 15 days after hatching. Then a drastic decrease in survival followed, especially where the larvae were offered the three lowest food densities. All larvae being offered the lowest food density died before 22 days after hatching. The survival curve of the larvae being offered 0.5 and 1 food organisms/ml levelled out at 5% and 7% survival at the end of the experimental period 26 days after hatching. The larvae at the highest food density (3/ml) experienced the same low survival after 17 days. However, after 19 days the survival curve entered a less dramatic fall. At the end of the experimental period (26 days), 20% of these larvae survived.

Growth

The daily growth rates in mm/day and µg/day at the three different parallels are indicated in Tables 2 and 3. Growth rates between 0.08-0.19 mm/day and 2.3-7.6 µg/day) were observed at 1 and 3 organisms/ml respectively.

Digestion rate

In 8 and 22 days old larvae 50% of the copepod nauplii were digested in ½ hour. During 1.5 hours 80% and 100% of the copepod nauplii were digested. No undigested copepod nauplii were found

in the guts of the 22 days old larvae after 3.5 hours. One undigested copepod nauplius was found after 4.5, 5.5 and 8.5 hours of digestion in the younger larvae. Most of the bivalve larvae passed undigested through the gut. Where digestion took place it always lasted more than 4 hours. All polychaet larvae were digested in 1.5 hours. The maximum passing time through the gut in 22 days old larvae was 13 hours for copepod nauplii, 24 hours for bivalve larvae and 12 hours for polychaet larvae, see Fig. 6 and 7.

Food selection

Both the 8 and the 22 days old larvae showed a strong positive selection for copepod nauplii and bivalve larvae (see Fig. 8 and 9). 8 days old larvae seem to avoid copepod eggs, copepodites and polychaet larvae, but both copepod eggs and polychaet larvae were recorded in the larval guts. The 8 days old larvae experienced a strong positive selection for diatoms. 67% of the 8 days old larvae were found with food in their guts after 1 hour of feeding.

Table. % occurrence of different kinds of food items in the guts (73 eight-days old larvae).

| | | | | | | |
|---|---|---|---|---|---|---|
| 30 copepod nauplii | 3 copepod eggs | 0 cope-podites | 4 polychaet larvae | 4 diatoms | 28 bivalve larvae | 33 empty |

22 days old larvae seem to avoid copepod eggs and copepodites; only 1% of the larvae had copepod eggs in the gut. Copepodites were not recorded. The larvae showed a weak negative selection for polychaet larvae. 82% of the 22 days old larvae were found with food in their guts after 1 hour of feeding.

Table. % occurrence of different kinds of food items in 22 days old larvae (100 larvae).

| | | | | | | |
|---|---|---|---|---|---|---|
| 42 copepod nauplii | 1 copepod eggs | 0 cope-podites | 30 polychaet larvae | 0 diatoms | 31 bivalve larvae | 18 empty |

Larval condition

The larval population at the food densities 1 and 3 org./ml (parallel No. 3) was split into the following weight categories $\geq$ 120 µg, 90-120 µg and $\leq$ 90 µg (see Fig. 5). On days 16 and 22 no difference was recorded in composition of the larval population at the highest food density level, compared to day 8. At the lower food density (1 org./ml) there was, however, more than 60% runts on day 16. On day 25 there were just a few runts left at the highest density level, but none at the lower one.

Duration of larval developmental stages

From laboratory experiments performed at 9°C, the la-stage (DOYLE 1977) was observed on the day of hatching (day 0) for all herring larvae (Table 4). The lb-stage was observed to last from day 1 to day 3 after hatching, with a peak on day 1. The lc-stage was similarly recorded from day 1, with a peak a few days later.

Table 4. Relative stage composition (%) on each of the days after hatching at 9°C.

| Day | la | lb | lc |
|---|---|---|---|
| 0 | 100 | 0 | 0 |
| 1 | 0 | 67 | 33 |
| 2 | 0 | 36 | 64 |
| 3 | 0 | 28 | 72 |
| 5 | 0 | 0 | 100 |
| 6 | 0 | 0 | 100 |

Field

Vertical distribution

Variations in larval density with depth, developmental stage and length are indicated in Fig. 10. Young herring larvae, 0 - 14 days old (stages la, lb, lc and 2a) were recorded in the whole water column during both day and night on May 5-6

1978. At daytime an apparent maximum abundance occurred in intermediate depths (10-30 m). The older yolk sac larvae (1c including 2a) probably swim deeper than the young ones (1a and 1b). This was clearly indicated around 0900 hrs, with the 1c-maximum in 20 meters depth and 1a/1b-maximum less marked in 10 meters depth. At night-time greatest larval abundance was recorded in surface water. Several times more larvae were caught in the surface haul than in the total number of deeper hauls at night.

Descending migration from surface to intermediate depths probably starts around 0300 hrs, while the ascent starts between 2100-2300 hrs, when surface illumination exceeds or passes below 1 lux respectively.

Vertical distribution of 30-45 days old larvae (fig. 11) is more difficult to investigate, because of their greater avoidance ability relative to the sampling gear. Only vertical distribution of larvae in the upper 40 m of the water column is treated here (bottom depth 90 meters).

All larvae found by midday and early afternoon were taken in 5 m depth. During late evening larvae were caught from 5-25 m depth, with maximum abundance in 10-15 m depth. At night larvae were recorded in the whole water column sampled with a maximum in 5-15 m. The larval maximum persisted in 5-10 m depth during the early part of next day until the end of sampling.

When looking at the larval mean length for 0-14 days old larvae, a small variation was recorded throughout the water column by daytime, with a predominance of smaller larvae in surface water (Fig. 10). At dusk the proportion of bigger larvae increased in surface waters, reaching its maximum mean length (9.17 mm) near midnight.

At dawn the mean length decreased in surface waters and increased in deeper waters, indicating that the bigger larvae moved deeper and thus undergo greater variations in vertical amplitude than smaller larvae. Mean length and range for 1a, 1b and 1c-larvae were 7.90 mm (6.10-9.25 mm), 8.24 mm (6.10-10.15) and 8.79 mm (7.30-10.40 mm).

($\bar{l}$=19.9mm (13-25mm)

The mean lengths of 30-45 days old larvae (stages 3a, 3b and 3c) showed a relatively uniform distribution with depth. The small catches of 30-45 days old larvae give no complete information about the vertical distribution of these larvae, although there is reason to suggest that a considerable part of the larvae stay in the upper intermediate waters, not only by night but also by daytime.

The maximum abundance of 30-45 days old larvae coincides with the thermocline (Fig. 11). The 0-14 days old larvae also tolerated relatively great differences in temperature (3.5°C from 0-30 m).

Food and feeding

1a and 1b-larvae were never found with food in their guts. First feeding 1c-larvae (and 2a) with recently ingested food items in their guts were obtained from between 0300-0500 hrs to 2100 hrs, with peaks at about 0900 and 1700 hrs, making a feeding period of 16-18 hours in early May (Fig. 12).

Feeding incidence of 1c and 2a-larvae was usually below 20%. The highest percentage of larvae with food in their guts (40%) was found in 20-30 meters depth at 0900 hrs, with a mean of 19% during one complete feeding period (Fig. 13a).

30-45 days old larvae (stages 3a-3c) with recently ingested food items were recorded from between 0400-0800 hrs to between 2000-2300 hrs, with peaks at about 1100 and 1700-2000 hrs, giving a feeding period of 13-20 hours in early June. By night only incidentally larvae were observed with food in their guts, and then usually with some heavily digestable food item, i.e. bivalv-larvae.

Feeding incidence of 30-45 days old herring larvae in June was relatively high, with a mean of 65% during the whole feeding period (Fig. 13b).

Frequency distribution of number of food items per larval gut is given in Fig. 13, with data from the whole feeding period pooled. Of 337 herring larvae (1c-2a) examined during the feeding period, 19% had food in their guts. The highest number of particles found in any larva was six. The food items in larvae

with the highest number of particles often turned out to be heavily digestable, i.e. invertebrate eggs and bivalve-larvae.

Of 37 herring larvae (3a-3c), 30-45 days old, 35% were observed with empty guts, 51% with one to eight and 14% with fourteen to nineteen food items in the gut (Fig. 13b). In contrast to many younger larvae (1c-2a) the gut contents of the majority of older larvae mainly consisted of more easily digestable food items, i.e. later developmental stages of the calanoid copepods Pseudocalanus sp., Oithona similis and Acartia sp..

The composition of the gut contents of herring larvae (1c-2a and 3a-3c) is indicated in Fig. 14. The relative energetic contribution (cal. $10^{-3}$) from each organism group is also indicated.

Copepod nauplii are the most frequently observed food items of first feeding herring larvae (1c and 2a) in the Lindåspollene. Invertebrate eggs and bivalve-larvae closely follow the occurrence of nauplii in the gut. Calanoid copepods are relatively important as prey organisms, due to their high calorific content, despite their relatively small number.

Among 3a-3c-larvae copepodites of small calanoid copepods play a major role as prey animals, in numbers as well as in energy content. Copepod nauplii and invertebrate eggs were also recorded in the guts, but they seem to give a minor and insignificant contribution respectively to the energy demand of the larvae.

The main calanoid copepod species recorded in the guts were Pseudocalanus sp., Acartia sp., Temora sp., Oithona similis and Centropages sp.

Invertebrate predation on fish larvae

In the laboratory the predation potential of some freshly caught invertebrates to herring larvae were studied in small experimental beakers (160 $cm^3$). Comparative experiments conducted in black plastic bags (1.8 and 7.5 $m^3$) suspended in the natural habitat of the larvae unfortunately were destroyed by some gales.

The laboratory experiments gave, however, some indications on the potential of some presumed predator species, which occurs in great abundance concurrently with the hatching of herring larvae in the Lindåspollen area. Bolinopsis infundibulum and Sarsia tubulosa were observed to have a considerable predator potential towards newly hatched herring larvae. During one hour a newly hatched herring larva was entirely ingested by a Sarsia-specimen. Complete digestion lasted ½ - 2 hours. No larvae were caught in darkness, but on one occasion during daylight two larvae were caught in 2 hours.

While Sarsia was hunting during daylight hours, Bolinopsis appears to be an inactive predator, feeding on newly hatched herring larvae only in darkness. In less than 8 hours during one night, three newly hatched herring larvae were eaten and almost completely digested by one Bolinopsis-specimen.

In a plankton sample a 20 mm gadoid larva was observed to be partly ingested by a Bolinopsis. By fixation (4% formalin), the fish larva was rejected without leaving any obvious signs of having been taken by a predator.

## DISCUSSION

The highest growth rate recorded in the laboratory, 0.19 mm/day, is comparable to the growth rate observed in Lindåspollene in 1978 of 0.15 mm/day during the first 30 days of life, but considerable smaller than observed in 1977 of 0.32 mm/day (unpublished). It is also almost comparable to the growth rates reported by EHRLICH et al. (1976) of 0.22 mm/day and by HAEGELE and OUTRAM (1978) of 0.236 mm/day.

The difference in growth observed between parallel 1 (0.19 mm/day) and parallel 2 and 3 (0.11-0.12 mm/day) at the highest food density level (3 plankters/ml) may be due to several reasons. The composition of food organisms that the larvae in the present experiment were offered, varied to some extent. The larvae in parallel 1 were offered more nauplii than the others and no bivalve larvae at the time of first feeding. The larvae in parallels 2 and 3 were offered less nauplii, and bivalve larvae comprised a great part of their diet. ROSENTHAL (1969) suggests that selection by larvae is a result

of imprint on certain food items at an early age. The difference in diet in the present experiments at the time of first feeding can imprint larvae on different food items and to some extent explain the difference in growth. The imprint on faster moving prey organisms, in addition to too strong mixing of water in parallel 1 will make fewer successful first feeding larvae, and most of the larvae were also observed to die in a short time. In the two other parallels almost all the larvae fed successfully on bivalve larvae. Many of these larvae will probably be runts because of their low ability to digest bivalve larvae. This will also contribute to explain the difference in growth.

In the present experiments it was difficult to observe significant differences in growth of larvae at the different food densities. Larval survival was, however, observed to be in accordance with food density at the different parallels. At the termination of the experiment (parallel 3) 20%, 5%, 3% and 0% survivals were observed at the food densities 3, 1, 0.5 and 0.1 food organisms/ml.

The time used to digest copepod nauplii is ½-3 hours in 22 days old larvae with up to 3 nauplii in the gut. After a digestion time of 1.5 hours 80% and 100% of the copepod nauplii were digested in 8 and 22 days old larvae. The reason for the reported undigested copepod nauplii in the guts after 1.5 hours can be due to interference with undigestable bivalve larvae in the guts. The difference in rate of passage found by ROSENTHAL and HEMPEL (1971), 4-10 hours, LAURENCE (1976), 6 hours and MOKSNESS (1978) 6 hours, compared to our 12-24 hours, can be due to the interruption of feeding in the present experiment with a consequence that empty nauplii shells will not be pressed out of the gut by recently ingested prey organisms. Too many bivalve larvae can be fatal to the herring larvae because most of them pass through the gut undigested.

The high mortality of the larvae between day 15 and 19 (see Figs. 4 and 5) may explain the altering in the weight category composition of the larval population. Most of the runts die and 25 days after hatching almost no runts are left.

Due to lack of an appropriate depth recorder and because of rough bottom, herring larvae were not sampled close to the bottom. In spite of the limitations of the sampling procedure, some general conclusions can be drawn.

Newly hatched larvae (1a and 1b) showed little variation in their diurnal vertical distribution, but the amplitude increased with age. At daytime maximum abundance of younger larvae (0-14 days) occurred in intermediate depths (10-30 m), while at night-time in surface waters. Similar observations were done by LISIVNENKO (1961) who reported that newly hatched herring larvae (0 - 4 days) remain in surface layer by night and descend to midwater layers by day. SELIVERSTOV (1974) investigated the vertical distribution of Atlanto-Scandian herring larvae from deep spawning grounds and claimed that regular diurnal migration starts at the age of 6-9 days with the commencement of external feeding. SCHNACK (1972) observed the vertical migration of herring larvae to increase with increasing larval size and recorded no obvious difference in the vertical distribution between day and night in small larvae ($\leq$ 10 mm). Bigger larvae (> 10 mm) were, however, observed to stay higher in the water column by night than by day. He also supposed a larval concentration to be found between 10-30 meters. GRAINGER (1978) similarly reported that the depth of maximum larval abundance (l = 7-12 mm) usually was found between 5-15 m, and assumed that a decline in abundance with depth was the generalised distribution of the larvae during daylight.

30-45 days old larvae were recorded in greatest abundance in upper intermediate waters (5-15 m) during the 24-hours sampling. Sampling of larvae in deeper waters was not carried out. BRIDGER (1958) observed that under cloudy conditions by day many more larvae were caught close to the surface and in midwater than close to the seabed. At night the vertical distribution was more uniform in all depths. On bright days with high light intensity, few larvae were caught near the surface, while considerably more larvae were caught in midwater than close to the bottom. Similar findings were also made by WOOD (1971).

Avoidance-reactions of larvae to the sampling gear will most probably be involved in sampling of older larvae. BRIDGER (1956) showed that the night catches of larvae were much greater than by

day, and that the daytime catches of larvae decreased by increasing larval size as a consequence of avoidance.

A feeding period of 16-18 hours was recorded in first feeding herring larvae (age $\leq$ 14 days) in early May 1978, and 13-20 hours for 30-45 days old larvae in early June 1977. BLAXTER (1966) suggests 18 hours available for feeding in early May at 60°N, which is in close agreement with the present observations. In June, however, 22-24 hours available for feeding (BLAXTER 1966) differs from the present observations, but this may be due to cloud-cover.
Young larvae ($\leq$ 14 days) seem to prefer copepod nauplii, while 30-45 days old larvae frequently were observed with later developmental stages of calanoid copepods in their guts. BLAXTER (1965) in his review work on food selection by herring larvae concluded that smaller larvae caught at sea most frequently contain copepod nauplii and eggs, mollusc-larvae and some green food. BAINBRIDGE and FORSYTH (1971) studied feeding of herring larvae in the Clyde, and they found that the spring spawning herring larvae fed almost exclusively on the nauplii and copepodite stages of copepods, despite the presence of a large number of barnacle nauplii. BJØRKE (1978) observed 91.7% of the gut contents of young herring larvae (6-12 mm) to be composed of Calanus finmarchicus-eggs, while copepod nauplii comprised only 4.6%. The high contribution of copepod eggs seems to be a particular case for Atlanto-Scandian herring.

Bolinopsis was observed by scuba divers to occur in great abundance over the spawning area, but no records of herring larvae in their guts were made. In the laboratory, however, Bolinopsis infundibulum and Sarsia tubulosa seemed to possess a considerable predator potential for newly hatched herring larva. LEBOUR (1925) reported Bolinopsis infundibulum and Sarsia tubulosa not to be predators on fish larvae. GAMBLE (1977), however, reported a 4.5 mm haddock larva to be taken by a Bolinopsis (12 mm gut length), while a 11.5 mm herring larva avoided Bolinopsis up to 35 mm in gut length.

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Table 1. Start and duration of the parallels.

| Parallel no. | Start | Duration | Density of food organisms / ml |
|---|---|---|---|
| 1 | 4 April | 38 days | 0, 0.001, 0.01, 0.1, 1, 3 |
| 2 | 14 April | 39 days | 0.1, 1, 3 |
| 3 | 30 April | 26 days | 0.1, 0.5, 1, 3 |

Table 2. Daily growth rate of the larvae in mm/day at different densities of food organisms.

| Parallel no. | Food density plankters/ml | Daily growth rate mm/day |
|---|---|---|
| 1 | 3 | 0.19 |
| 2 | 1 | 0.08 |
| 2 | 3 | 0.11 |
| 3 | 0.5 | 0.10 |
| 3 | 1 | 0.11 |
| 3 | 3 | 0.12 |

Table 3. Daily growth rate of the larvae in µg/day at different densities of food organisms.

| Parallel no. | Food density plankters/ml | Daily growth rate µg/day+ |
|---|---|---|
| 1 | 3 | 7.6 |
| 2 | 1 | 2.3 |
| 2 | 3 | 4.1 |
| 3 | 0.5 | 2.6 |
| 3 | 1 | 4.2 |
| 3 | 3 | 3.9 |

+From EYS, 8 days after hatching to end of experiment.

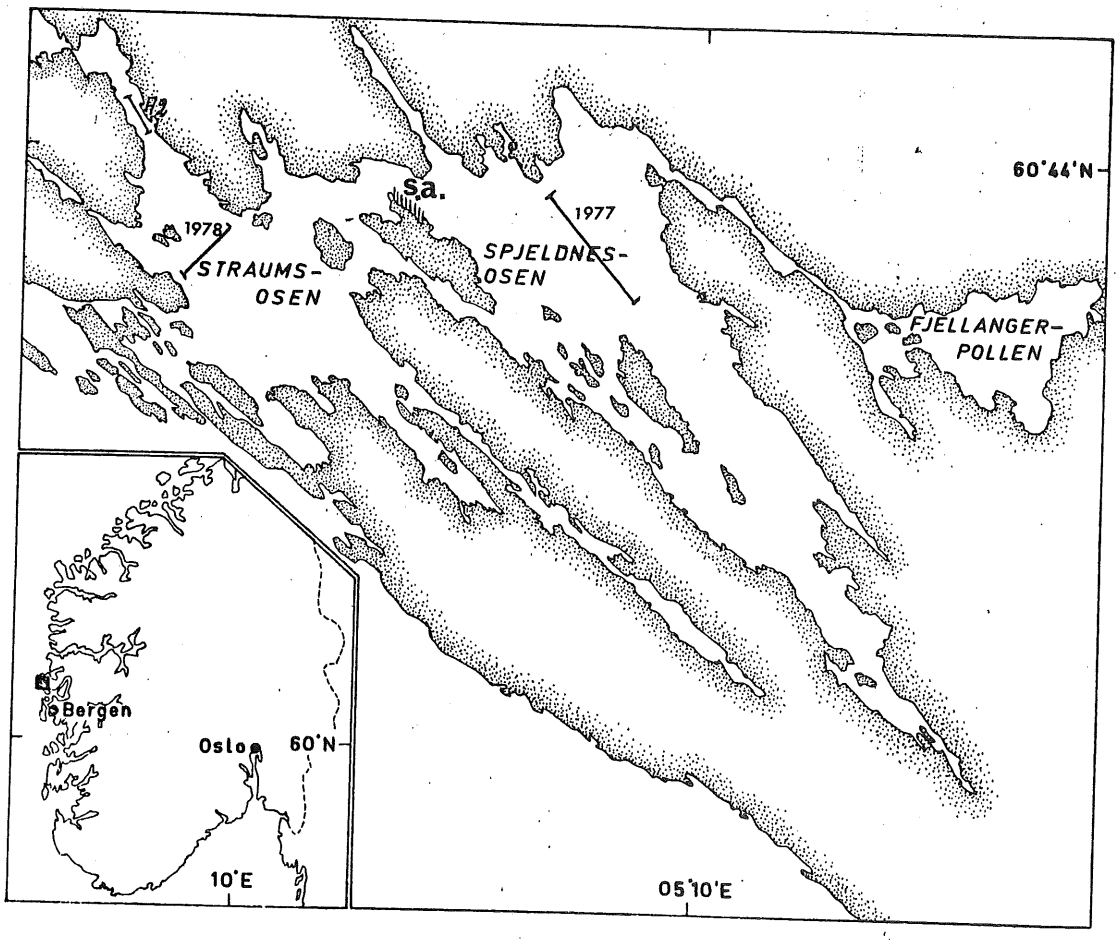


Fig. 1. Area of location of Lindåspollene with the spawning area (**s.a.**), and the two diurnal sampling stations indicated (1977 and 1978).

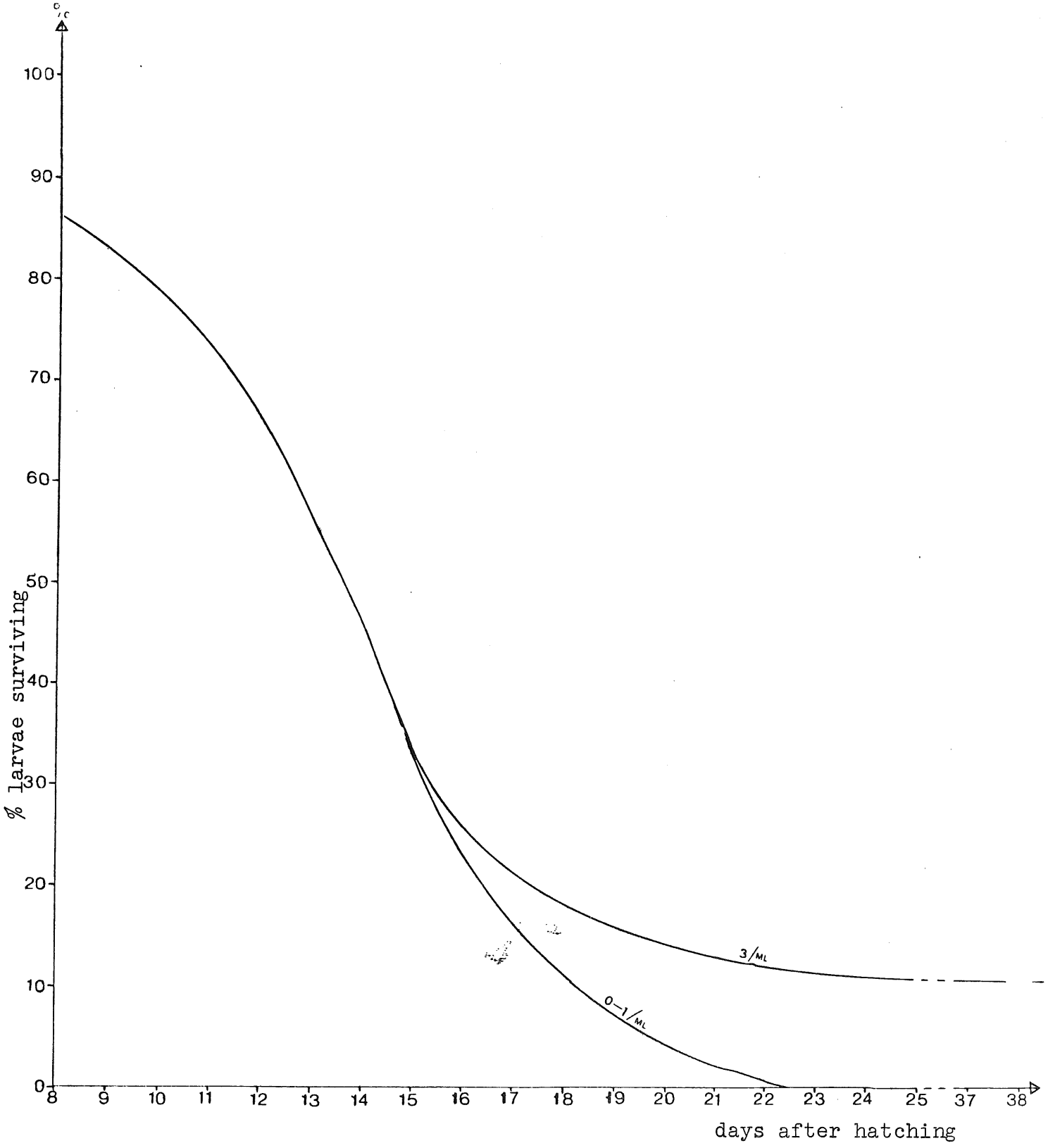


Fig. 2 Survival of larvae offered prey organisms at density levels 0-3/ml (parallel no. 1). Larval number at the commencement of the experiments n=200.

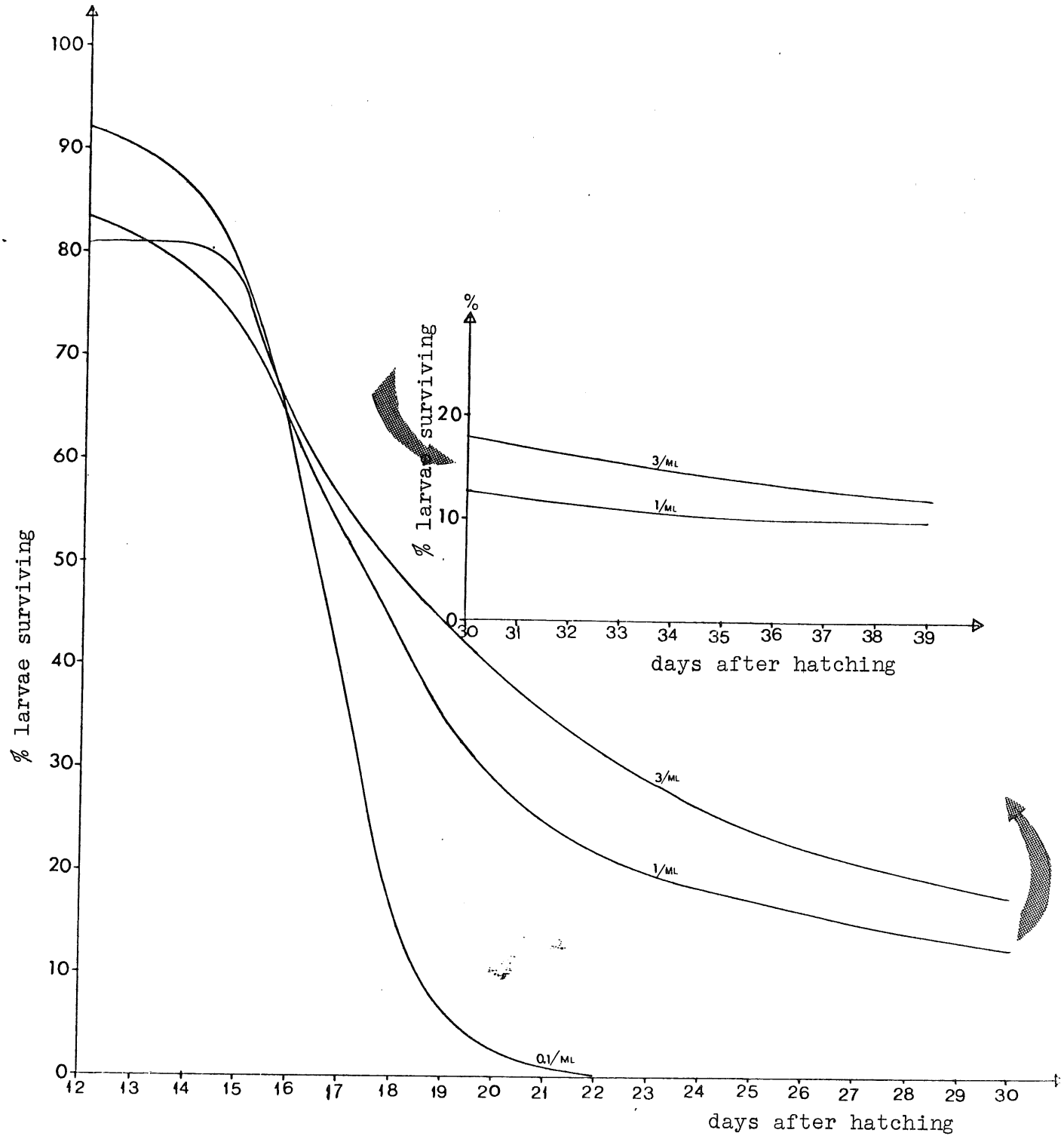


Fig. 3 Survival of larvae offered prey organisms at density levels 0.1-3/ml (parallel no. 2). Larval number at the commencement of the experiment n(3/ml)=200, n(1/ml)=240 n(0.1/ml)=180

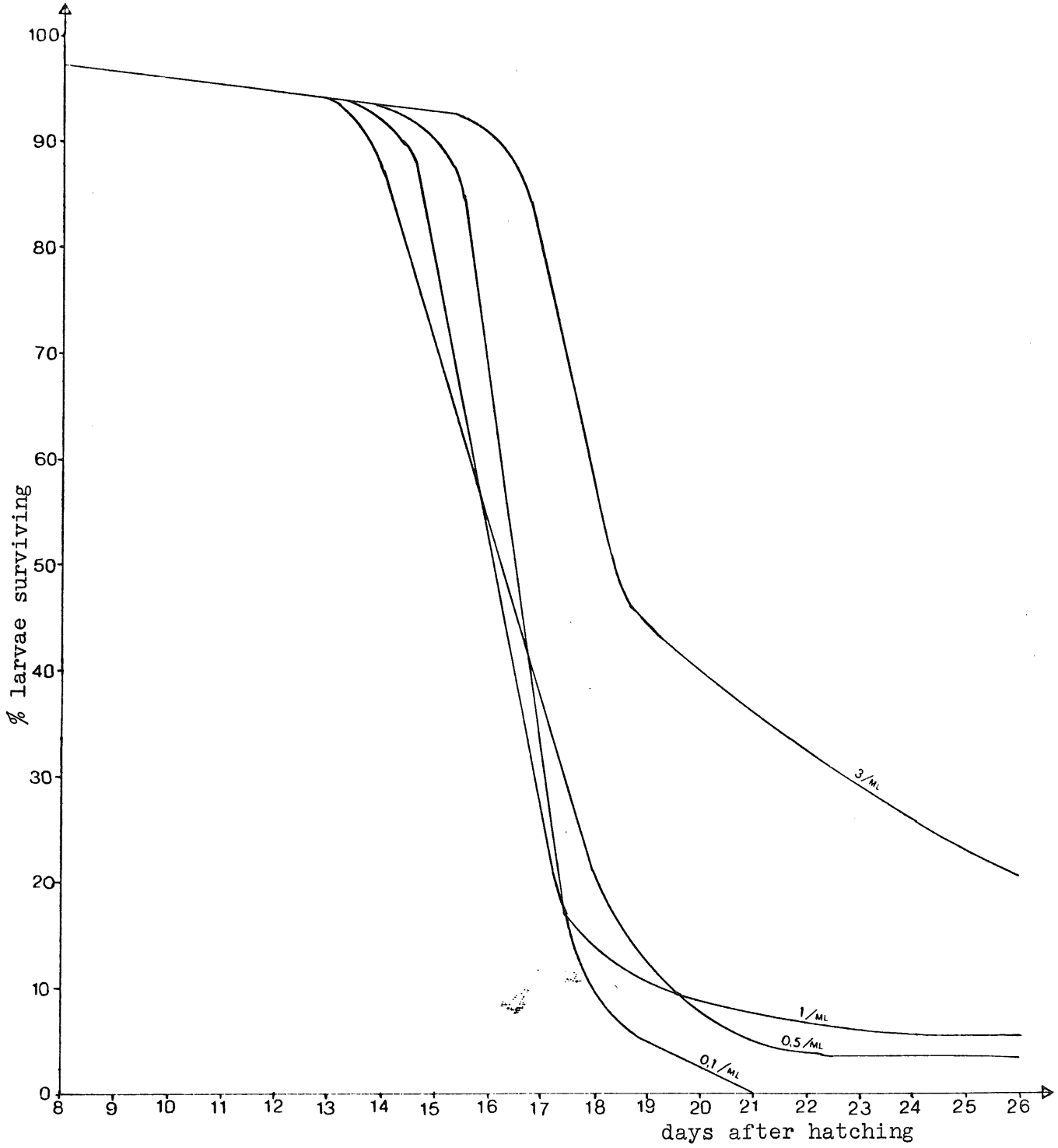


Fig. 4 Survival of larvae offered prey organisms at density levels 0.1-3/ml (parallel no. 3). Larval number at the commencement of the experiment n(3/ml)=807, n(1/ml)=833, n(0.5/ml)=450, n(0.1/ml)=365

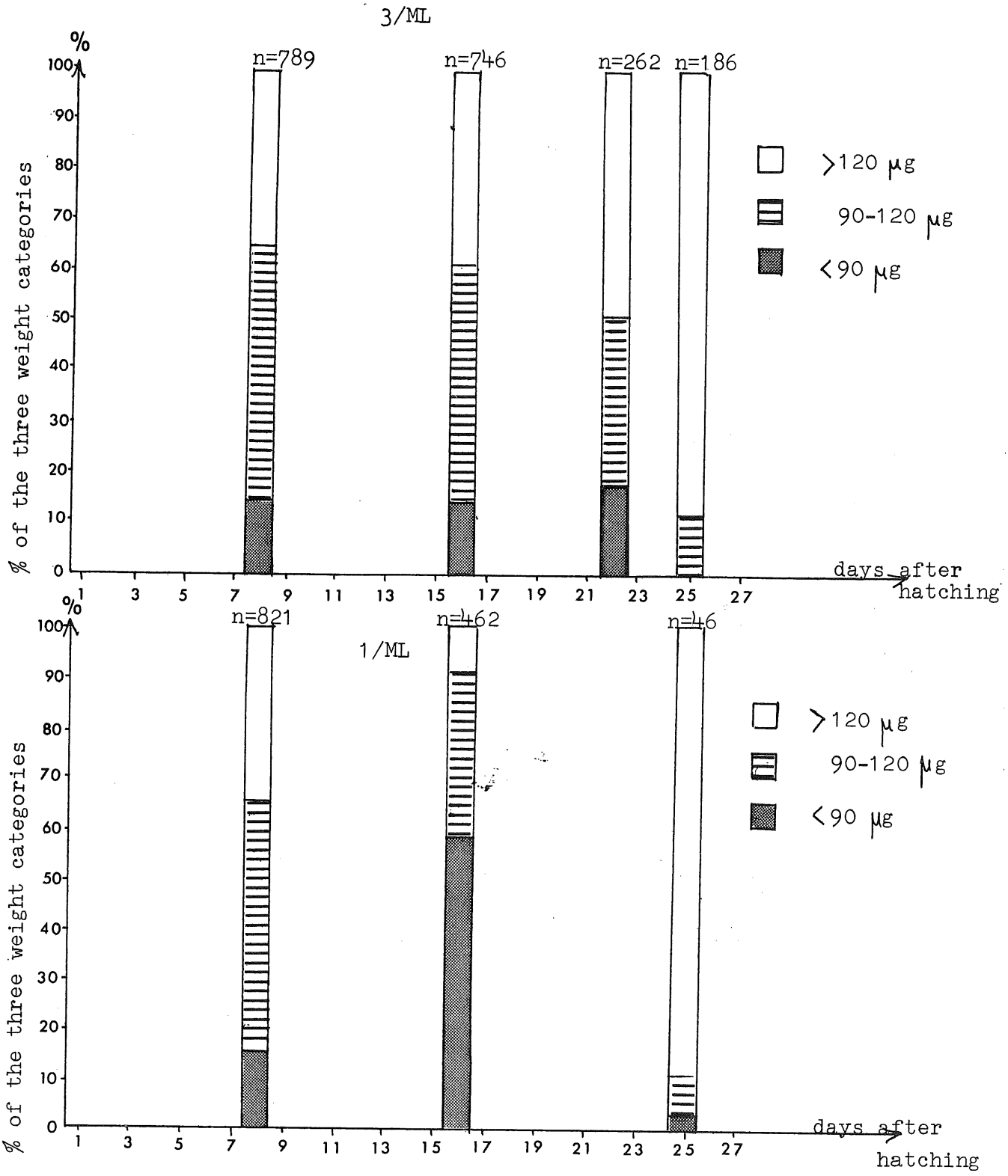


Fig. 5 Larval condition at different age.
The larvae is from parallel no. 3.

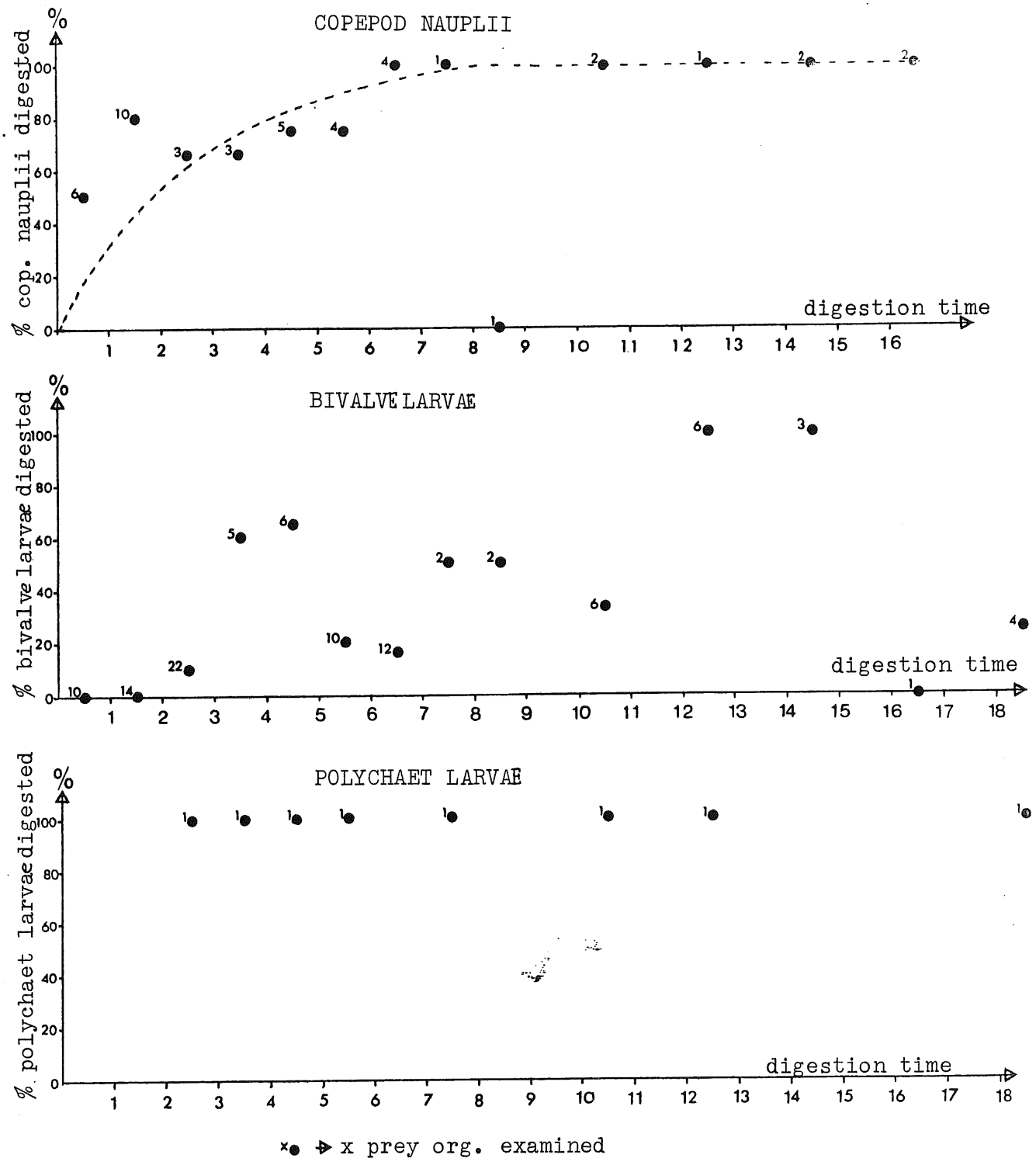


Fig. 6 Digestion rate of 8 days old larvae, % of prey org. digested during an 18 hours period.

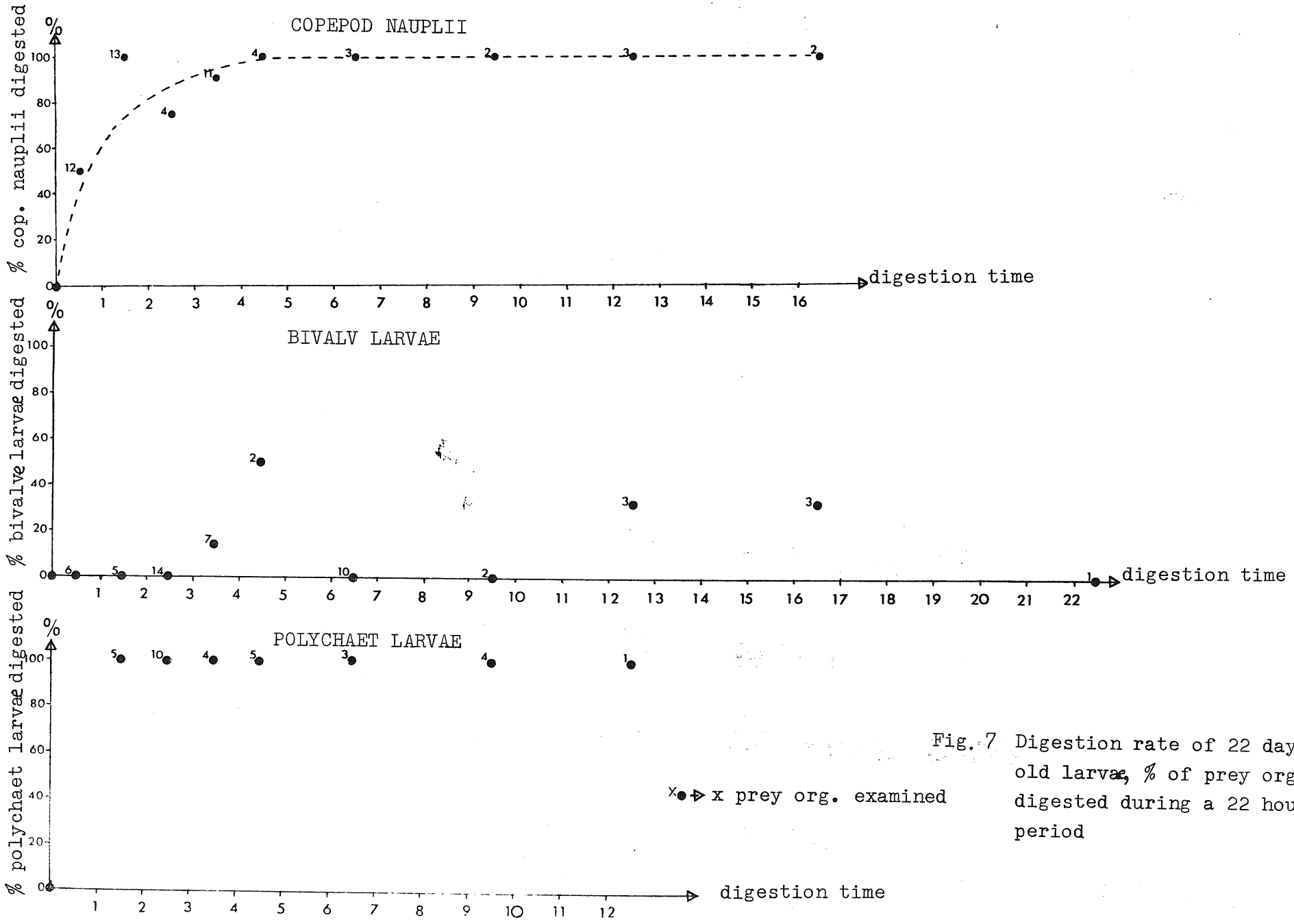


Fig. 7 Digestion rate of 22 days old larvae, % of prey org. digested during a 22 hours period

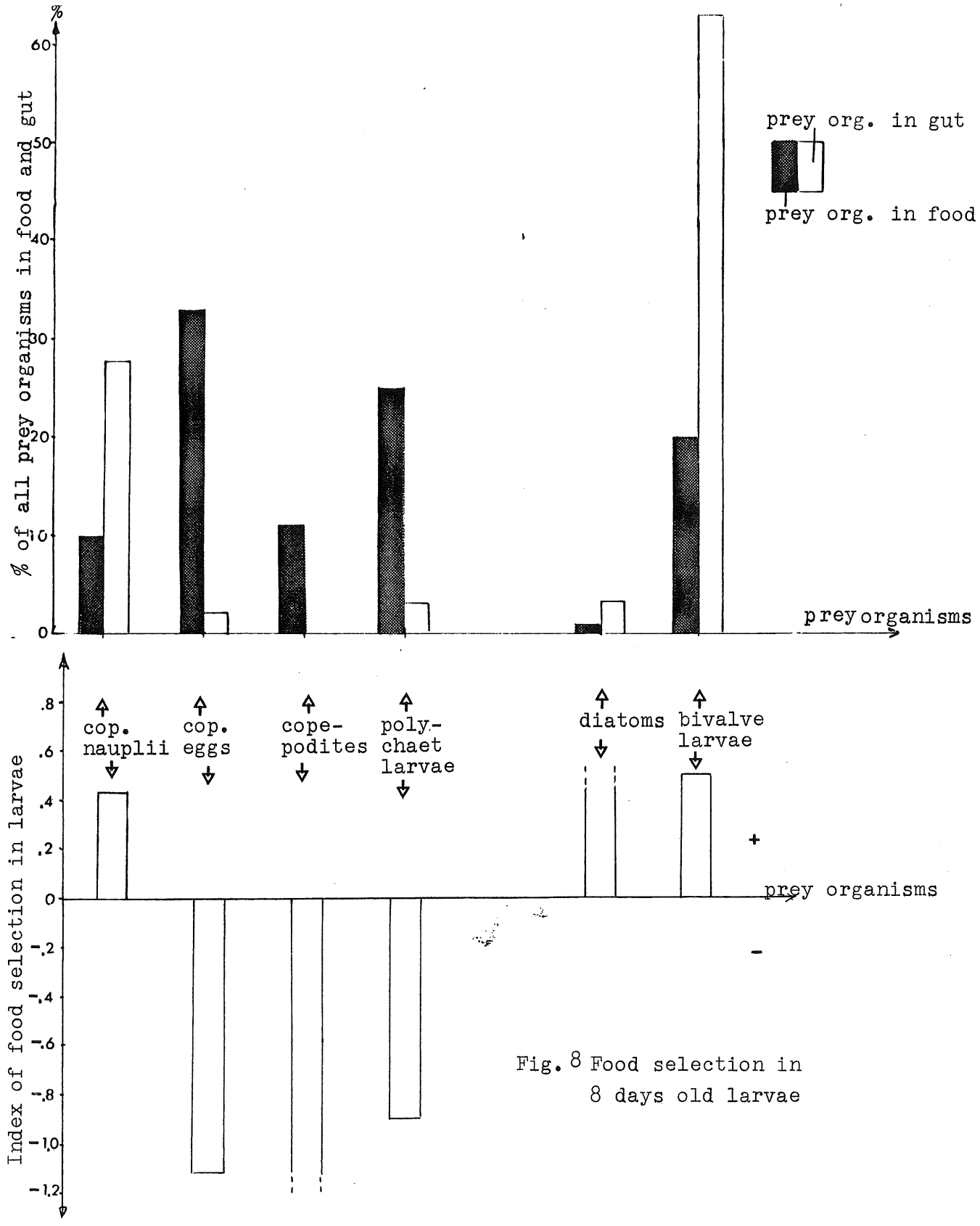


Fig. 8 Food selection in 8 days old larvae

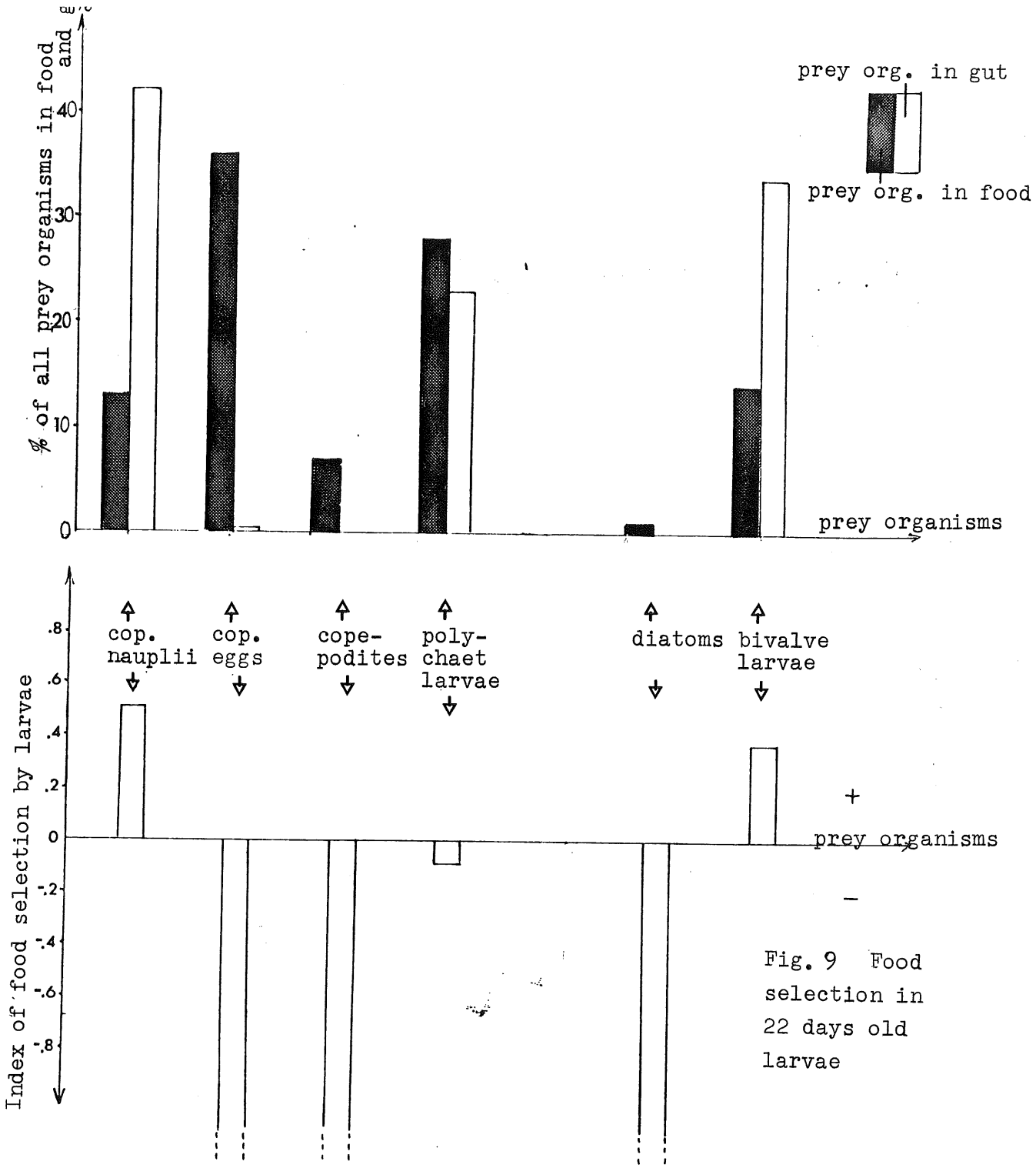


Fig. 9 Food selection in 22 days old larvae

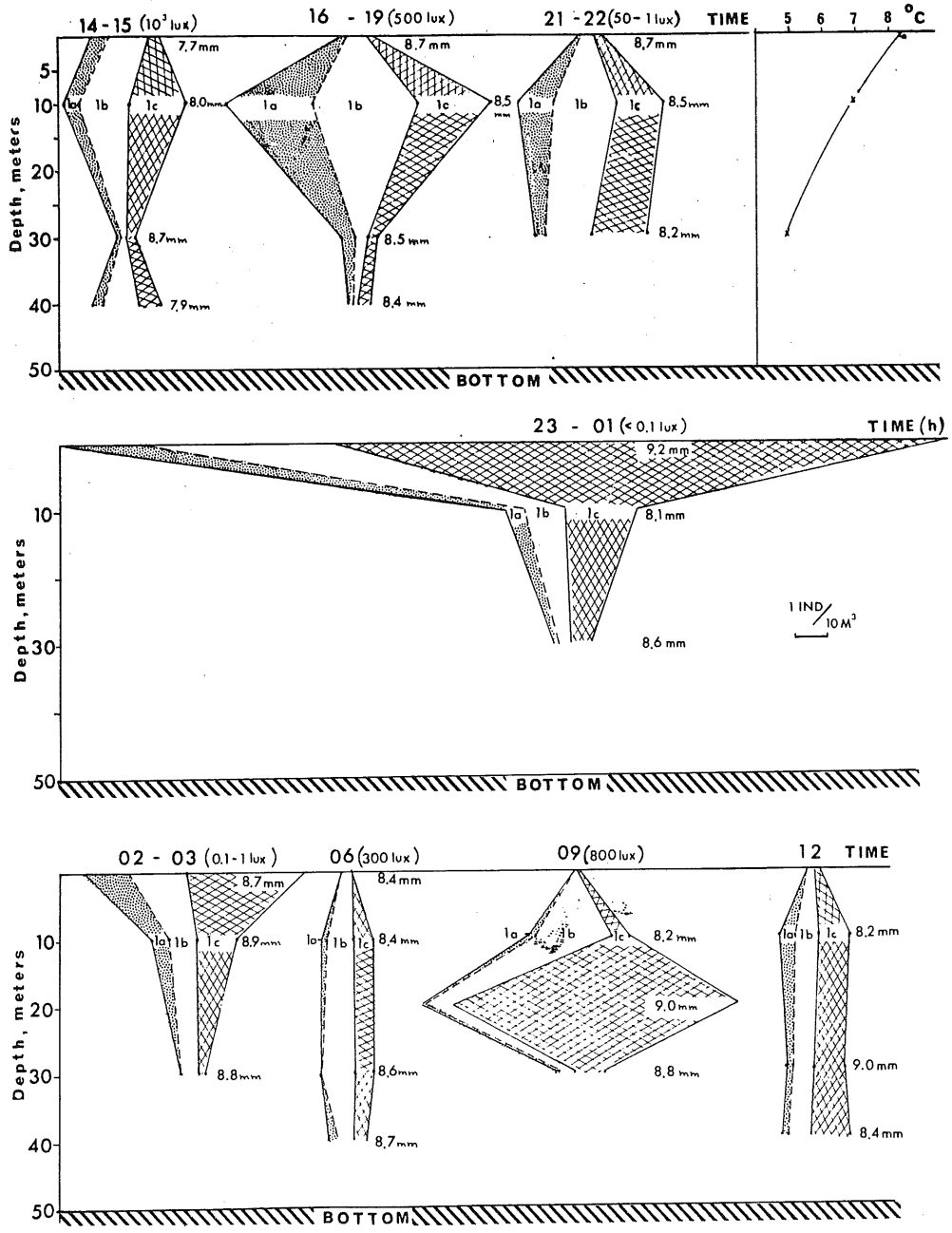


Fig. 10. Vertical distribution of 1a, 1b and 1c - larvae (0-14 days old) in relation to time of the day on 5. - 6. May 1978. Surface illumination is given in parenthesis and mean length (mm) of the larvae is indicated for different depths. Temperature is indicated on the upper right. Unit of larval density is indicated on the middle right.

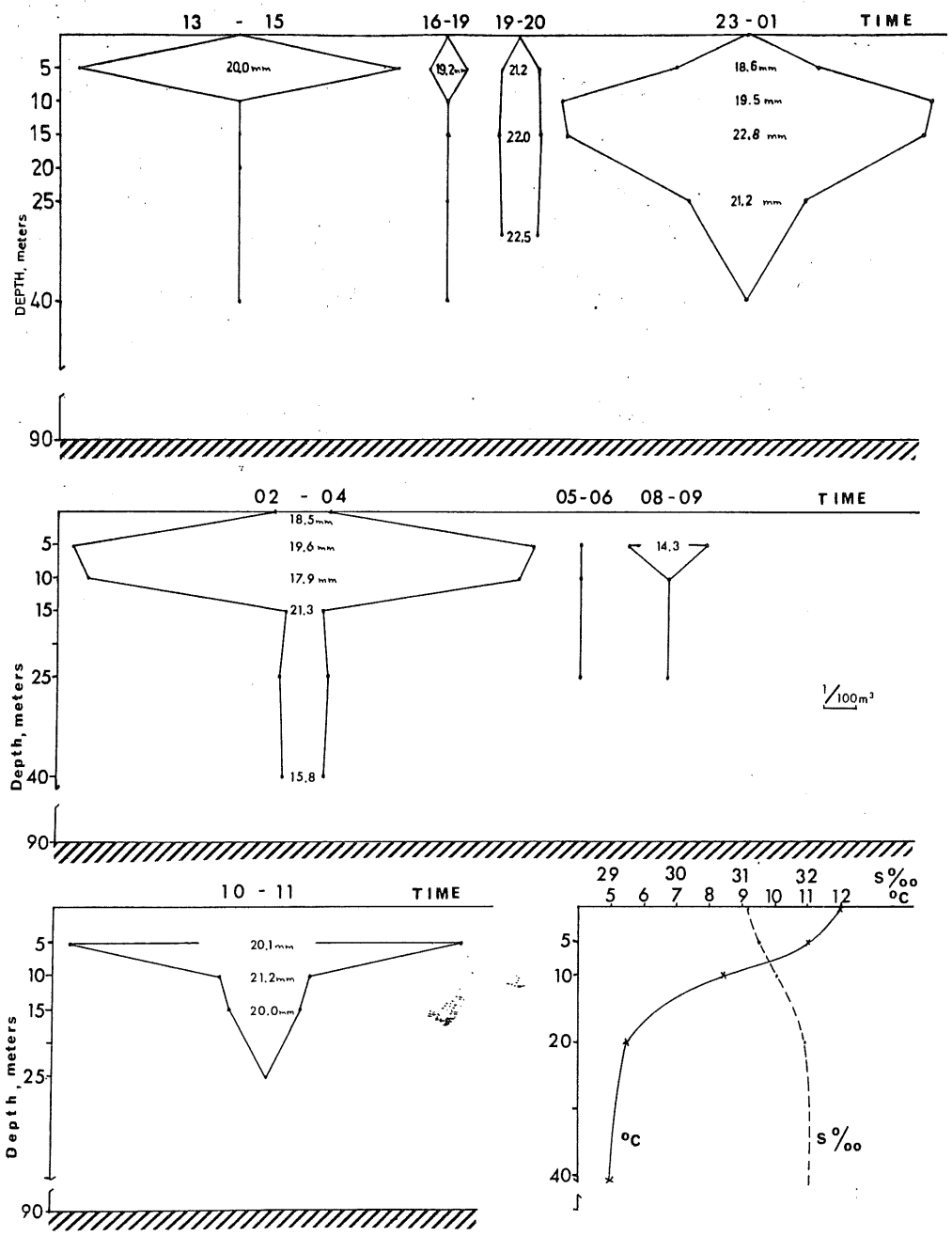


Fig. 11. Vertical distribution of 30-45 days old larvae in relation to time of the day on June 2. - 3. 1977. Mean length (mm) of the larvae is indicated for each depth. Unit of larval density is indicated on the middle right. Temperature is indicated on the lower right.

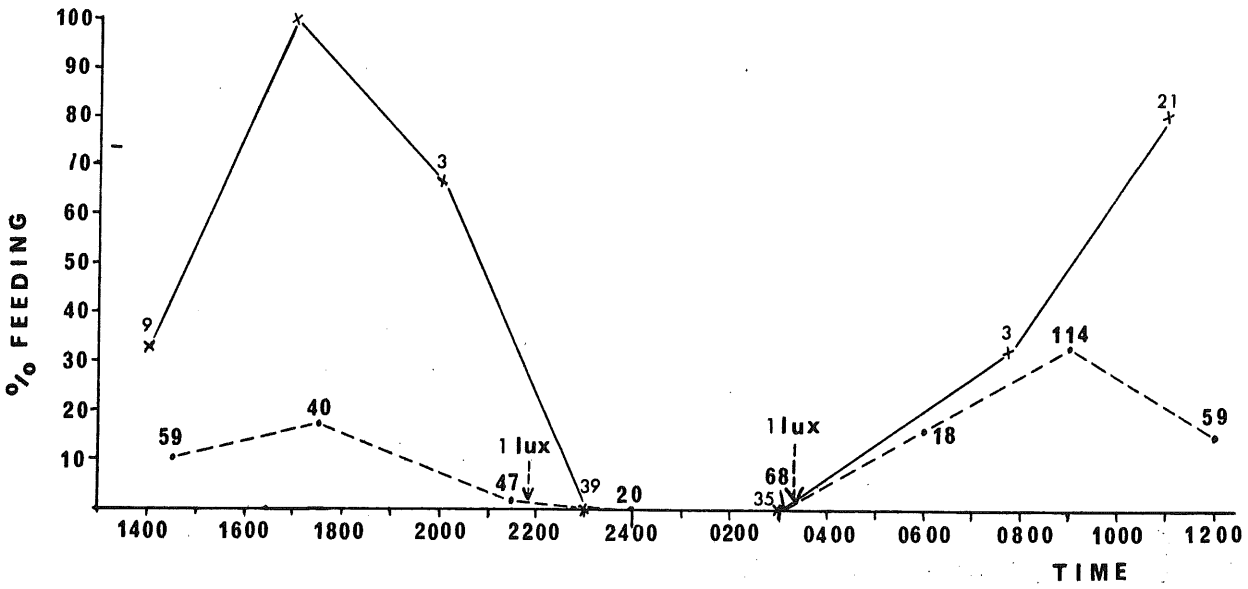


Fig. 12. Feeding incidence of herring larvae ≤ 14 days old (·----·) on May 5. - 6. 1978 and 30-45 days old larvae (x-x) on June 2. - 3. 1977 in relation to time of the day. Larvae from all depths sampled are pooled. Surface illumination 1 lux on May 5. - 6. is indicated. The number at each point on the curve indicates the number of larvae examined.

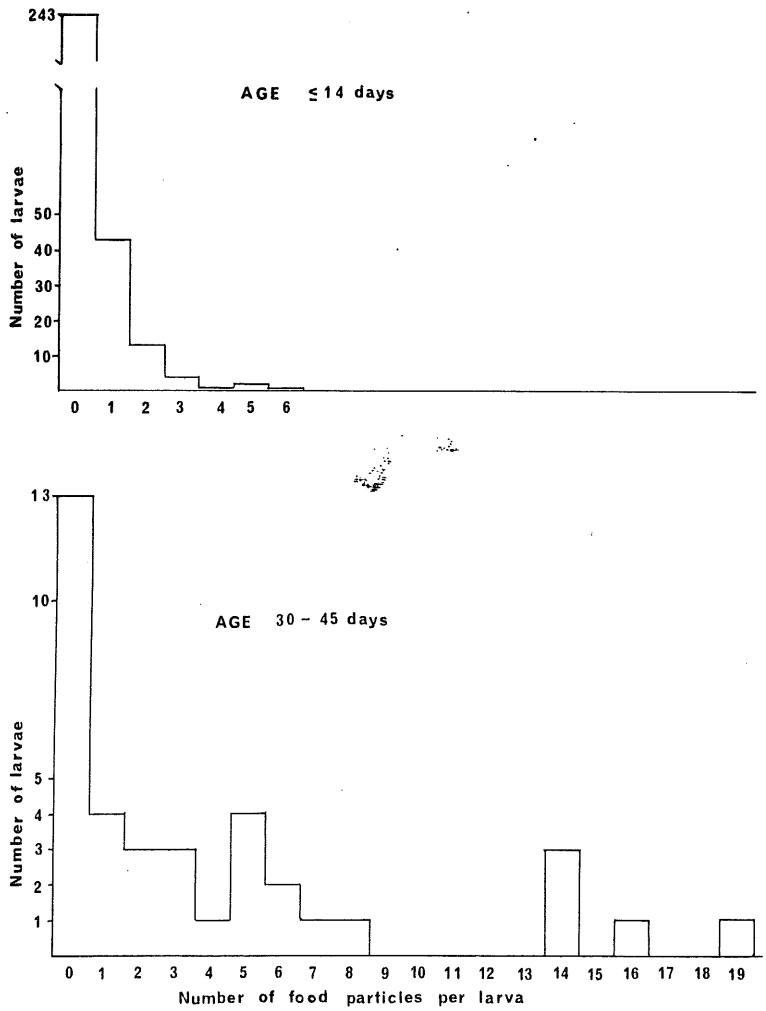


Fig. 13. Frequency distribution of herring larvae with different number of food particles per gut. a), ≤ 14 days old larvae, b), 30-45 days old larvae.

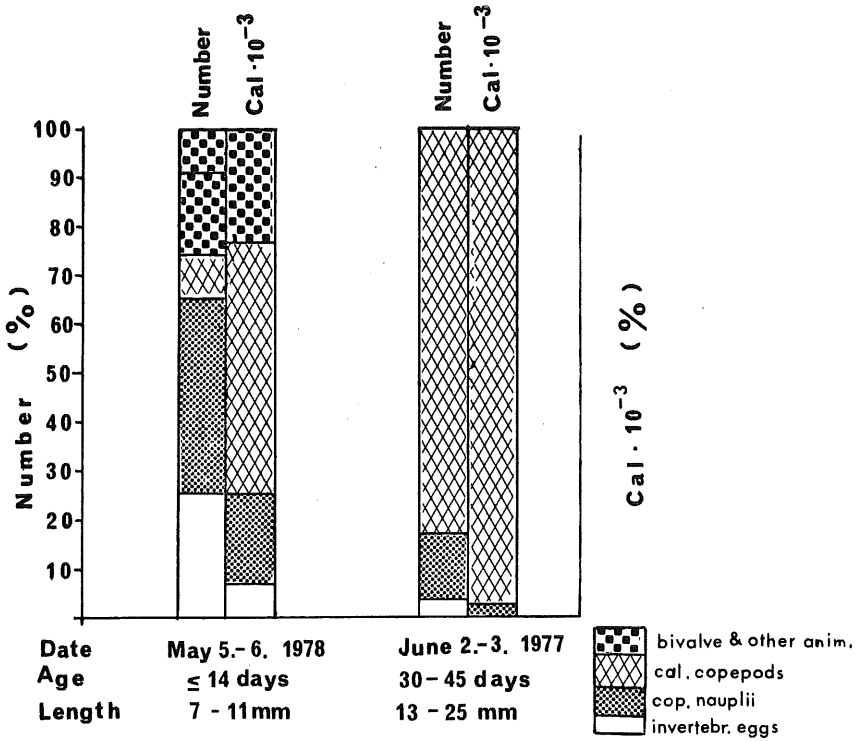


Fig. 14. Food composition (%) of the gut contents of herring larvae in terms of number (left column) and calorific content (right column) on May 5. - 6. 1978 ( $\leq$ 14 days old) and June 2. - 3. 1977 (30-45 days old).