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# DISTRIBUTION AND TRANSPORT MECHANISM OF THE UPSTREAM MIGRATING FLOUNDER LARVAE, *Pleuronectes flesus* Linnaeus 1758, IN THE TIDAL ELBE RIVER, GERMANY

by

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## ABSTRACT

The present study, carried out in 1995, aimed to clear the questions to the **occurrence**, **distribution** and **migration mechanism** of flounder larvae in the tidal Elbe. The distribution of the migrating flounder larvae in the tidal Elbe was studied through Bongo-net hauls taken at 13 stations from the Wadden Sea to the Hamburg harbour. Flounder larvae were first recorded on 16 March, with the highest density of 1.8 ind·m$^{-3}$ occurring on 25 April. The standard length of the larvae ranged from 5.88 to 17.43 mm. Samples, which were taken over several tidal cycles from an anchored pontoon in the retention area at three different depths in the water column (bottom, middle and surface), showed a preference of the larvae for specific positions in the water column during different directions of the current. During flood currents, the larvae preferred to stay higher in the water column, whereas less flounder were caught at these layers during ebb currents. Based on two 24-h sampling on 11/12 April and 8/9 May two different length-weight relationships were calculated for the flounder larvae. These **different groups of flounder** probably originate from two separate hatching areas in the North Sea.

## 1. INTRODUCTION

The flounder is one of the dominant fishes of the tidal Elbe river (Möller, 1991; Thiel et al., 1995). The adult flounder have been observed to leave the river for spawning in the southern North Sea (Schnakenbeck, 1926). Recently, a study on the distribution of the eggs and early larval stages of the flounder in the North Sea was carried out by Campos et al. (1994). They found that part of the newly-hatched larvae were drifted from the North Sea into the Wadden Sea and reached the brackish waters. After reaching the brackish waters flounder larvae prefer to migrate into fresh water regions.

The first study to the distribution of fish larvae and juveniles in the tidal Elbe was carried out by Dieckwisch (1987) between May 1985 and June 1986. This study was edited by Möller (1988) and resulted in a collective publication (Möller & Dieckwisch, 1991), but several questions concerning the distribution and migration of the pelagic flounder larvae stayed unanswered. While juvenile flounder has been observed to migrate upstream in tidal rivers by moving only during flood tide, it is unknown to what degree larvae possess this ability (Wheeler, 1988). When entering the Elbe estuary the relatively small flounder larvae are also expected to utilise the flood tide for upstream transport in either a passive or active manner. During ebb tide the larvae may appear at depths with relatively lower current velocitities.

In this light the present study was carried out with the following objectives:

(1) Estimation of the time of occurrence and the pattern of distribution of the flounder larvae in the tidal Elbe,

(2) Description of the mechanism by which the flounder larvae migrate upstream in the Elbe.

## 2. MATERIALS AND METHODS

The facultative catadromous flounder has been cited as *Platichthys flesus* for years, but Wheeler (1992) recently suggested to change the name to *Pleuronectes flesus* again since this species has many similarities with the genus Pleuronectes. In the present study the name *Pleuronectes flesus* will be used.

## 2.1 Sampling along the river

The sampling program started on 1 March 1995 at 13 stations in the tidal Elbe from the mouth of the river to the harbour of Hamburg (Fig. 1). Table 1 shows the different stations with their exact locations. Sampling of the 13 stations usually took a full day, and therefore, it could not be avoided that samples were taken at different stations during both ebb and flood currents. The research vessel „Tromperwiek“ from the University of Hamburg was used for the sampling. Since the length of the larvae at which they reach the estuary was not known, a bongo frame (diameter 60 cm), equipped with 500 and 1000 µm mesh size nets, was towed from the starboard side of the vessel. A depth depressor was used to keep the net under water. A hydraulic winch was used to control the height of the net in the water column. At every station hauls were taken for 5 minutes at the surface layer between 0.5 and 2.5 m depth. Average tow speed was 1.5 $m \cdot s^{-1}$. To estimate the quantity of water flowing through the net a flowmeter (General Oceanics) was placed at the opening of the bongo, to which the 1000 µm net was attached. On 16 March the first flounder individuals were caught, thus from then on weekly sampling were performed. At every station hydrological parameters (i.e. conductivity, oxygen concentration, salinity and temperature) were collected.

Table 1 The 13 sampling stations in the tidal Elbe river with their specifications.

| Station | nr. | km | Latitude | Longitude |
|---|---|---|---|---|
| Meedemsand | 1 | 714 | 53°52,25'N | 8°53,50'E |
| Brunsbüttel | 2 | 692 | 53°52,50'N | 9°12,00'E |
| Brammer Bank | 3 | 677 | 53°49,20'N | 9°20,95'E |
| Glückstädter Nebenelbe | 11 | 673 | 53°46,75'N | 9°24,60'E |
| Schwarztonnensand | 4 | 665 | 53°43,62'N | 9°25,90'E |
| Pagensander Nebenelbe | 12 | 662 | 53°42,29'N | 9°31,13'E |
| Twielenfleth Reede | 5 | 651 | 53°36,42'N | 9°33,90'E |
| Lühesander Nebenelbe | 14 | 648 | 53°35,15'N | 9°36,00'E |
| Lühe | 6 | 645 | 53°34,40'N | 9°38,72'E |
| Hahnöfer Nebenelbe | 15 | 643 | 53°33,25'N | 9°40,57'E |
| Mühlenberger Loch | 16 | 635 | 53°32,82'N | 9°47,76'E |
| Blankenese | 7 | 634 | 53°33,19'N | 9°48,49'E |
| Köhlbrand | 8 | 623 | 53°31,10'N | 9°56,40'E |

## 2.2 Vertical sampling

Sampling during two 24-h periods was conducted to study the vertical migration of the flounder. Both measurements were performed from the university pontoon anchored in the Hahnöfer Nebenelbe (st. 15), which is in the expected retention area (Möller 1988) of the flounder larvae. Three different depths were sampled with the bongo net: surface, middle and near bottom, which corresponded to 0.5, 4 and 7-8 m depth, respectively. The three different depths were sampled every 2 hours. The codend of the net was removed and the catch was collected in 0.5 l sampling bottles. Samples were immediately fixed in a 5% formaldehyde solution buffered with sodium borate.

### 2.3 Laboratory work

Fish larvae were sorted from the samples additionally containing lots of dead plant material and zooplankton. Fish larvae were identified according to Petersen (1906) and Russell (1976). Larval standard lengths were measured to the nearest 0.01 mm using an electronic drawing board attached to a stereomicroscope equipped with a drawing mirror. Flounder larvae were weighted to the nearest 0.1 mg. Excess water was removed prior to weighing by placing larvae on a piece of filter paper for 5 seconds. No corrections were made to account for larval shrinkage caused by the conservation method.

The larvae were categorised in different groups of development as described by Ryland (1966) for plaice and deemed by Campos et al. (1994) for dab and flounder.

## 3. RESULTS

Sizes of the larvae caught in the tidal Elbe over the complete sampling period were large enough to be caught quantitatively with the 1000 µm net. Therefore, the results are mainly based on the 1000 µm net samples.

Eye migration had already started in most of the larvae and could be categorised as either left- or right-eyed. Only a few larvae were found to be categorised in earlier stages.

### 3.1 Occurrence and distribution

Figure 2 shows the densities of the flounder larvae caught between 22 March and 23 May 1995, whereas the first flounder specimen was observed on 16 March at Brunsbüttel (st. 2). On 22 March one individual was already caught far upstream near the mouth of the river Lühe (st. 6). On 29 March two individuals were further caught at the second most upstream station Mühlenberger Loch (st. 16), so that from this date on flounder larvae were distributed over the entire study area. At the most upstream station Köhlbrand (st. 8) no larvae were caught during the complete sampling period. This is also true for the northern margin Glückstadter Nebenelbe (st. 11) and the main stream station Blankenese (st. 7).

Starting on 19 April increased densities of flounder larvae were found at the three most downstream stations 1 (Meedemsand), 2 (Brunsbüttel) and 3 (Brammer Bank) with peak densities on 25 April. Remarkable is that the trends in the other stations more upstream did not show a parallel to these increased densities. After 25 April the densities of the larvae were decreased and on 31 May no more larvae were caught.

### 3.2 Vertical migration

During the first 24-h sampling fewer flounder larvae ($n = 46$) were caught compared to the second experiment ($n = 231$) as shown in Figure 3 and 4. During the first flood tide of the first sampling relatively high densities of larvae occurred at the surface and in the middle of the water column (Fig. 3). With the following ebb current the larvae moved more downwards and were only caught in the middle of the water column and at the bottom. During the next flood they were again found in the middle and at the end of the next ebb current highest densities were found at the surface again. Remarkable is that larvae were only caught at the water surface in the morning hours.

During the second 24-h period only 1.7% of all the larvae was caught at the surface (Fig. 4). At 4 and 7 meter depth higher densities of larvae were found during flood tide than during ebb tide. During the hours of highest light intensity, which were simultaneous with an ebb tide, no larvae were caught at the depths of 0.5 and 4 m. Only when this ebb current was most powerful some larvae were caught at a depth of 7 m.

During the first 24-h sampling 7 samples were taken around the time that the current changed direction. Those samples may not correctly represent the density of the larvae because only 17 $m^3$ or even a less volume of water was filtered through the net. Densities were calculated after the catch of only one specimen. During the second 24-h period, sampling was timed prior to or after tide changed direction. Therefore, and for the higher densities, the second 24-h sampling better represents the densities of the flounder larvae at the different depths.

Figures 5 and 6 show the length distributions of flounder larvae caught during the 24-h sampling. During the first sampling standard length of the flounder larvae ranged from 6.67 to 9.11 mm (average S.L. **8.08**±0.64 mm, $n = 46$). The second sampling showed a much wider range from 5.88 to 17.43 mm (average S.L. **7.90**±1.30 mm, $n = 231$). Although the averages of both sampling do not differ much, the composition of the length distributions is different. The first 24-h sampling shows a more even length distribution than the second 24-h sampling. Larvae longer than 9.00 mm were only caught in the second 24-h sampling. The distribution of the second 24-h sampling is skewed and has a relatively higher percentage of small larvae.

The length weight relationships of the larvae of both 24-h sampling are shown in Figure 7. At a certain length the corresponding weight was lower in the first sampling than in the second sampling. All larvae longer than 8.13 mm were found to be lighter in the first 24-h sampling. A linear regression was fitted after logarithmic transformation of both data sets. The growth curves are described by the formulas $W = 0.01371 \cdot L^{2.91093}$ ($r^2 = 0.790$) and $W = 0.00193 \cdot L^{3.97263}$ ($r^2 = 0.948$) respectively. Analysis of covariance revealed a significant difference between the two regression lines ($P < 0.01$).

## 4. DISCUSSION

### Vertical migration

Flounder larvae were found to prefer the upper layers of the water during flood tides and the lower layers of the water during ebb tides (Fig. 3 & 4). Through this active vertical migration the flounder larvae were able to move upstream the Elbe. If the larvae had reached their retention area they continued to show a vertical migration to retain their horizontal position. This mechanism was also described by Sepúlveda et al. (1993) for *Osmerus eperlanus* which avoids being drifted down the Elbe.

The flounder larvae have to be able to detect tides to utilise these for their transport mechanism. Harvey et al. (1992) found that the juveniles of plaice and sole use neuromasts to detect water movements. For the flounder larvae a comparable mechanism may exist, supposing that they do not appear in the moving water column during ebb tide. In the tidal Elbe, a chemical stimulus could also motivate the larvae to increase their swimming activity, since the ebb current has a lower salinity than the flood current (ARGE ELBE, 1984).

### Occurrence and distribution

On 29 March 1995 flounder larvae were found over the entire study area, except at the most upstream station Köhlbrand (st. 8). The larvae managed to occupy the entire study area, which corresponds with a distance of 79 km, within a period of about two weeks, calculated from the larvae's first appearance at the mouth of the Elbe. When reaching the retention area, which is formed by the Hahnöfer Nebenelbe and the Mühlenberger Loch (Möller, 1988), the larvae stopped migrating upstream and no larvae were caught in the harbour of Hamburg at station 8. Flounder larvae probably prefer to stay and grow in this food-rich marginal regions of the Elbe before migrating more upstream through the harbour of Hamburg. The canalised waters and reduced banks in the harbour may even form a barrier for the larvae to continue to migrate more upstream. Möller (1988) described catches of juvenile flounder up to 35 mm in Köhlbrand, but he did not explicit mention larvae.

Up to 19 April 1995 densities of flounder larvae have been rather low (ranging from 6.3 to 36.9 ind·m$^{-3}$·10$^{-3}$), observed from the length sampling and the first 24-h sampling as presented in Figure 2. Starting at 19 April, larval densities increased (up to 1891.4 ind·m$^{-3}$·10$^{-3}$) at the downstream stations and only a few larvae were caught in the upstream region. An explanation for not catching increasing number of flounder larvae more upstream in the Elbe at the end of April could be that the larvae did not migrate upstream due to the availability of food at the mouth of the Elbe. Ladiges (1935) found that flounder caught in the Mühlenberger Loch (st. 16) mainly fed on *Eurytemora affinis* and *Tubifex*. Thiel et al. (submitted) found the copepod *E. affinis* to be the most important source of food for flounder larvae caught at stream kilometres 650 and 660 in the tidal Elbe in April 1994. Larvae caught more downstream had empty stomachs. In May 1994 larvae were only caught at the stations 2 (Brunsbüttel) and 3 (Brammer Bank) and had been feeding on different groups of copepods. Kausch and Nellen (1994) described a higher percentage of the total abundance of *E. affinis* in the Elbe for the downstream marginal waters in July 1992 than in April 1992. Fiedler (1990) found a higher number and biomass of copepods in April 1986 than in March 1986 for the downstream region. The first larvae entering the estuary in March 1995 had to migrate upstream to the areas where at that time most food was available. At the end of April 1995 food resources may have been more equally distributed over the complete study area and only a part of the then entering flounder larvae migrated more upstream than station 3 (Brammer Bank).

The difference in growth curves (Fig. 7) could be explained by the availability of food resources for the flounder larvae. The first group of larvae, entering the estuary in March, had to swim much longer before they found enough food. Therefore, these larvae were growing slower than those caught in the second 24-h sampling. Water temperature differences may also have had an influence.

**Different groups of flounder**

Campos et al. (1994) studied the distribution of dab and flounder larvae in the south-eastern North Sea in the first half of 1992. He concluded that the flounder used two hatching areas in the North Sea: an area, with the highest larval densities, west of the island Texel (Netherlands) and the second area north-west of the island Helgoland in the German Bight. The appearance of the flounder larvae in the present study showed a possible migration of two groups (Fig. 2): The first group starting to enter the tidal Elbe around 16 March and the second group starting around 19 April. The two 24-h sampling, one carried out in each period, showed two different length weight relationships which supports the existence of two different groups of flounder (Fig. 7).

In May 1985 Möller (1988; Table 97) found two areas highly populated by larval and juvenile flounder: an area from Meedemsand (st. 1) to the Brammer Bank (st. 3) and the other area Hahnöfer Nebenelbe (st. 15) and Mühlenberger Loch (st. 16), described as retention area. Between these two areas only few flounder were caught. Möller also mentioned the possibility of two different flounder populations and in Möller & Dieckwisch (1991) a speculation was made about the possibility of a separate population spawning in fresh water regions of the Elbe. In the present study, almost all of the caught larvae had reached a length of at least 6 mm and showed a starting eye migration or even a complete metamorphosis. A certain period of time must have passed before the larvae reached the Elbe, which precludes the possibility of a group of flounder spawning in the fresh water regions of the Elbe. The two different highly populated areas found by Möller (1988) may also be explained by the migration of two different cohorts of flounder larvae from the two different spawning areas in the North Sea.

In extension of this paper a study to the time needed by the flounder larvae for migrating upstream the Elbe will be carried out by counting daily increments of otoliths. The two different groups of flounder larvae observed during the present study stimulate for further research and studies to the distributions and genetic differences of the flounder could be carried out.

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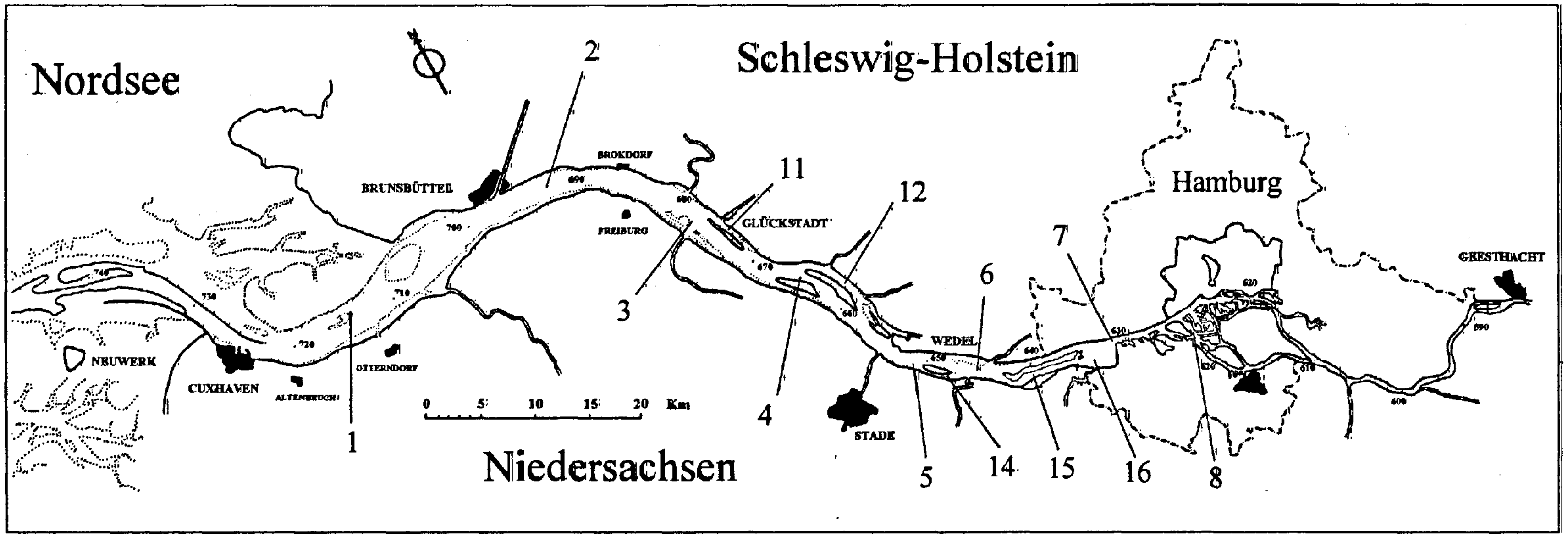


Figure 1 Study area with the sampling stations from the North Sea to the harbour of Hamburg. Stations nr. 1 to 8 are in the main stream while the stations nr. 11 to 16 are in the marginal regions of the Elbe.

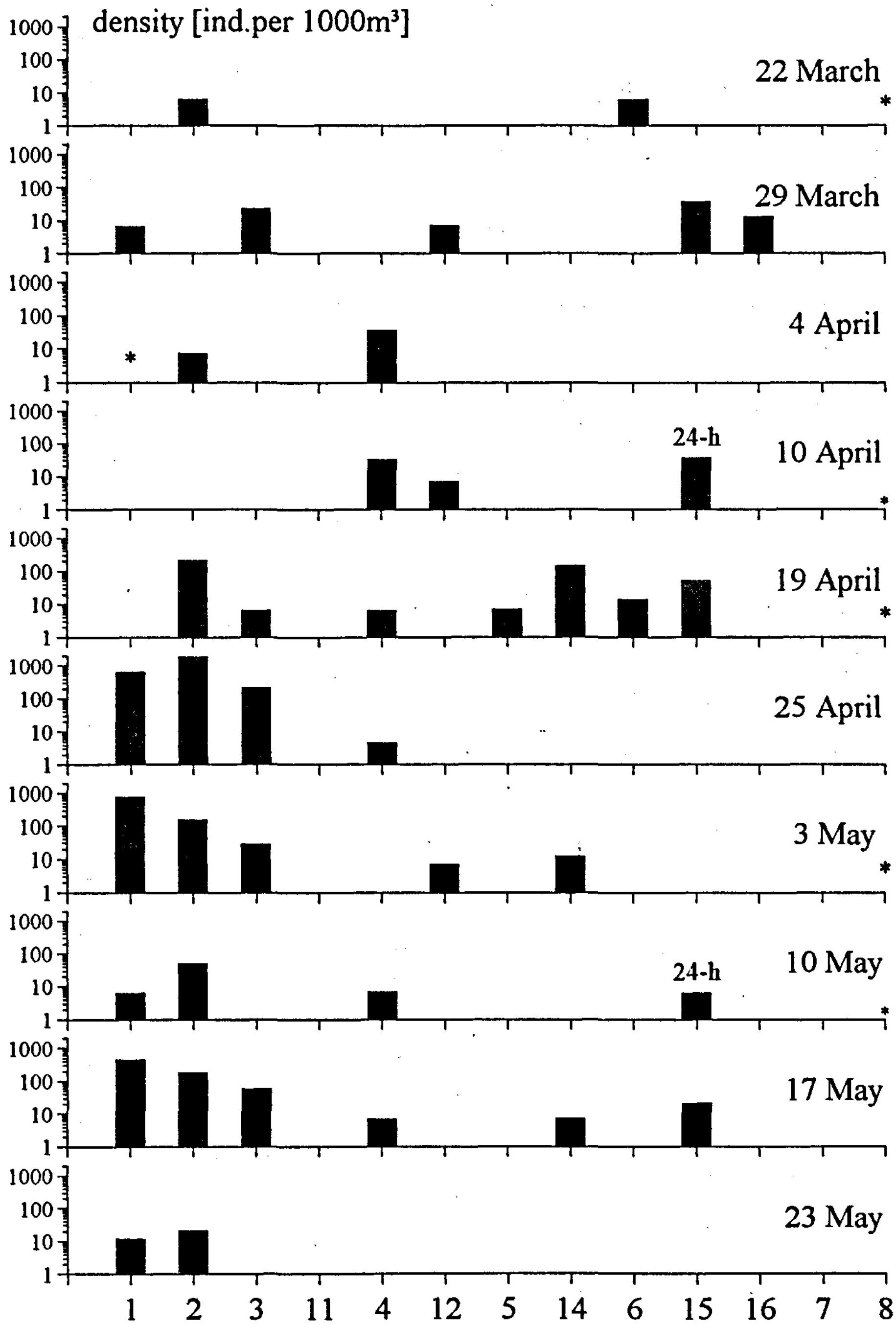


Figure 2 Larval densities [ind. $m^{-3} \cdot 10^{-3}$] found at 13 stations in the tidal Elbe from 22 March 1995 to 23 May 1995. 24-h represents the densities calculated after the two 24-h sampling. An asterisk is placed when no sample was taken.

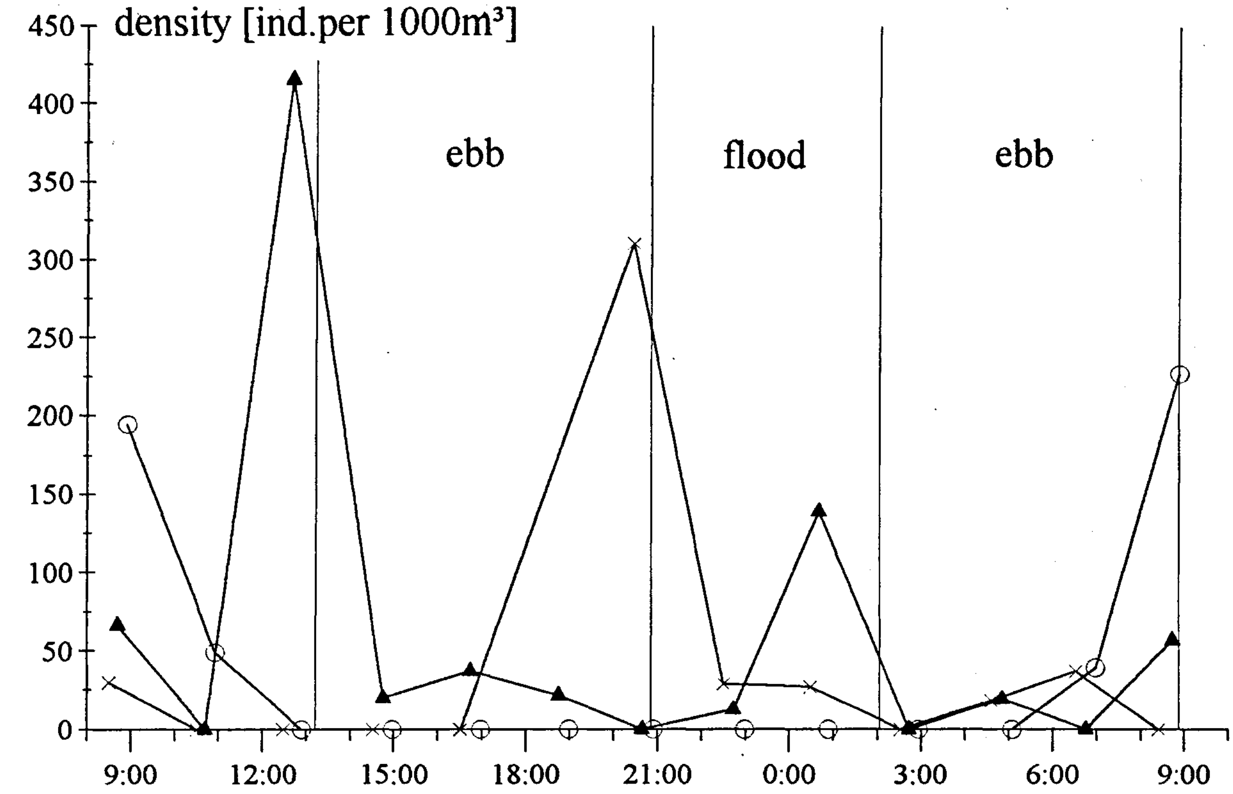


Figure 3 Larval density [ind. $m^{-3} \cdot 10^{-3}$] found during the 24-h sampling carried out on 11/12 April 1995 at three different depths: 0.5 (o), 4 (▲) and 7(×) m. Vertical lines represent high or low water.

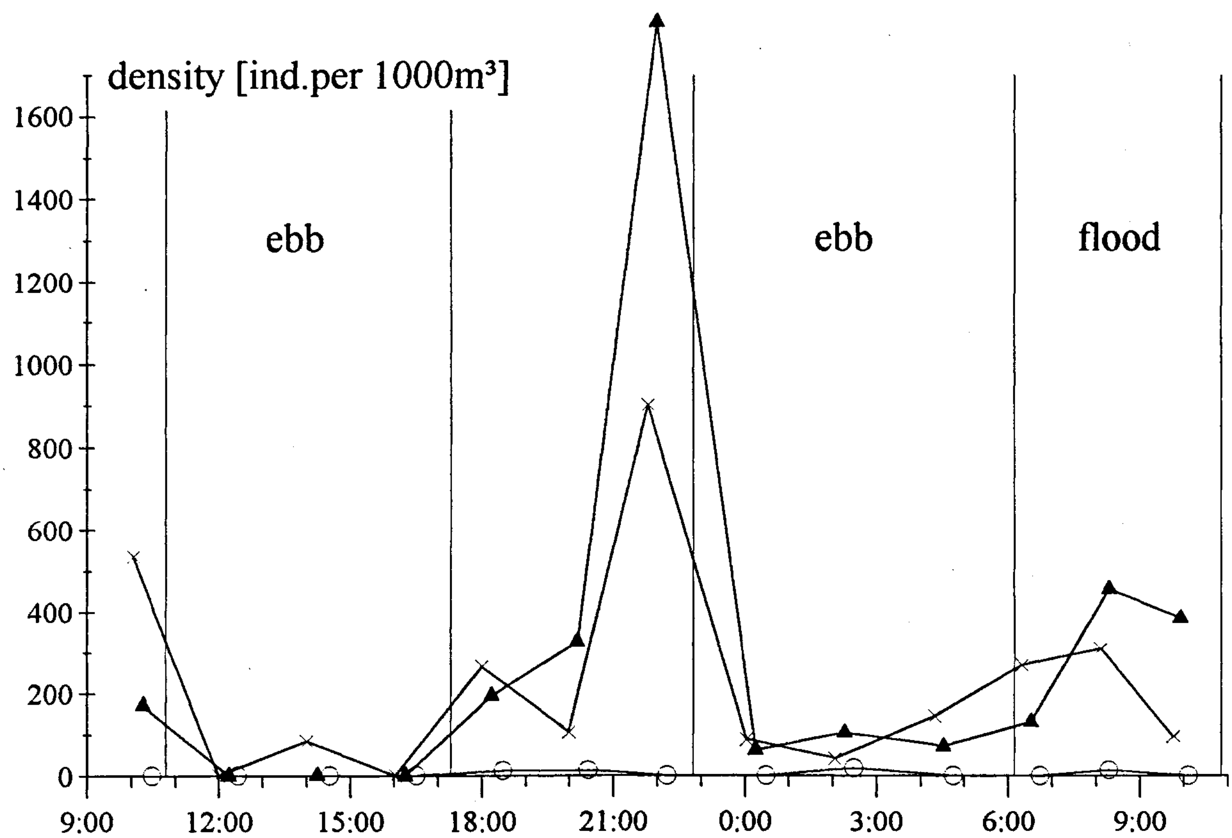


Figure 4 Larval density [ind. $m^{-3} \cdot 10^{-3}$] found during the 24-h sampling carried out on 8/9 May 1995 at three different depths: 0.5 (o), 4 (▲) and 7(×) m. Vertical lines represent high or low water.

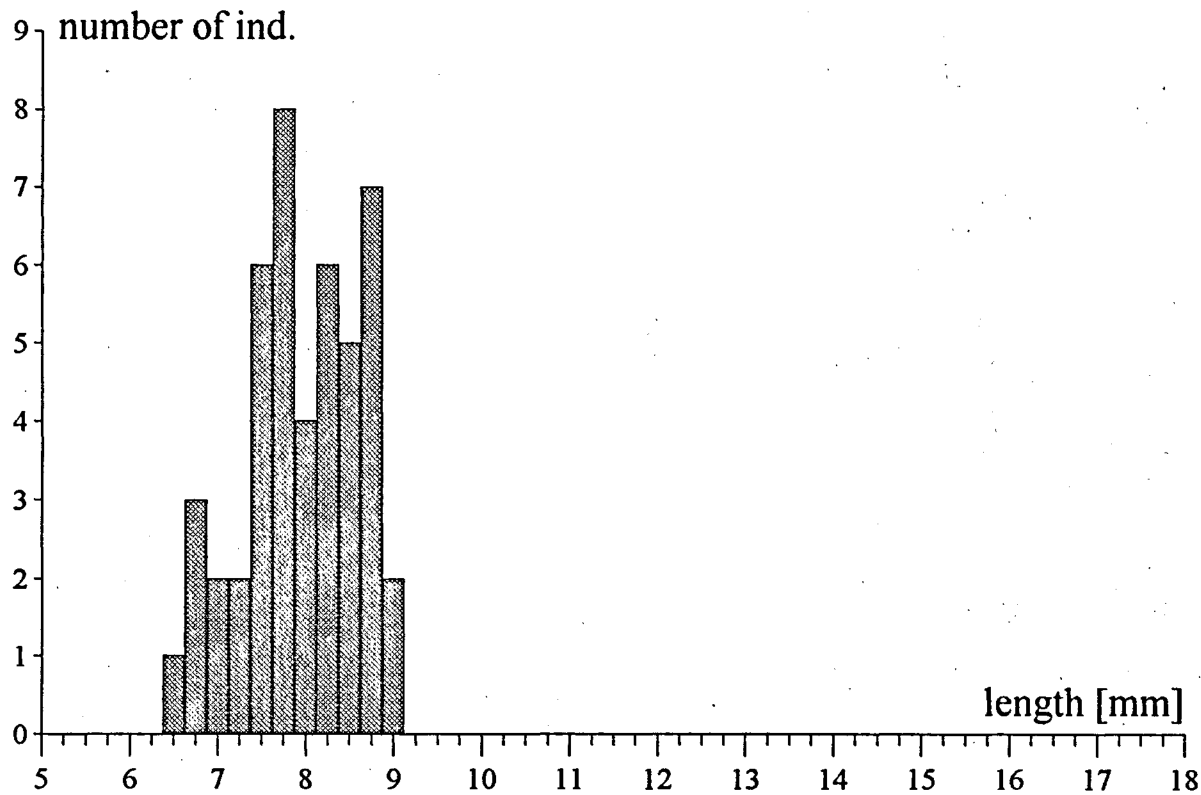


Figure 5 Length distribution of flounder larvae caught during the 24-h sampling carried out on 11/12 April 1995.

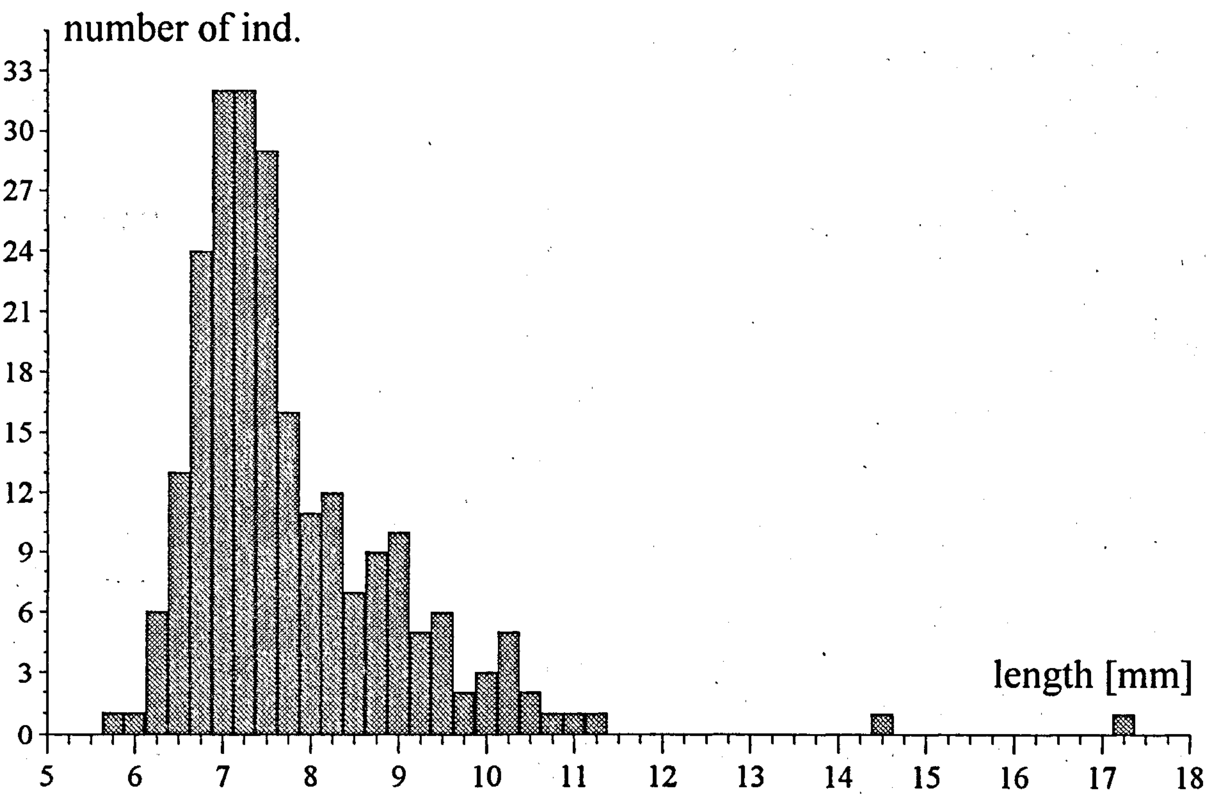


Figure 6 Length distribution of flounder larvae caught during the 24-h sampling carried out on 8/9 May 1995.

Figure 7 Length (L)-weigth (W) relationships of flounder larvae for both 24-h sampling on 11/12 April 1995 (□) and 8/9 May 1995 (•). Formulas for the fitted lines are shown.