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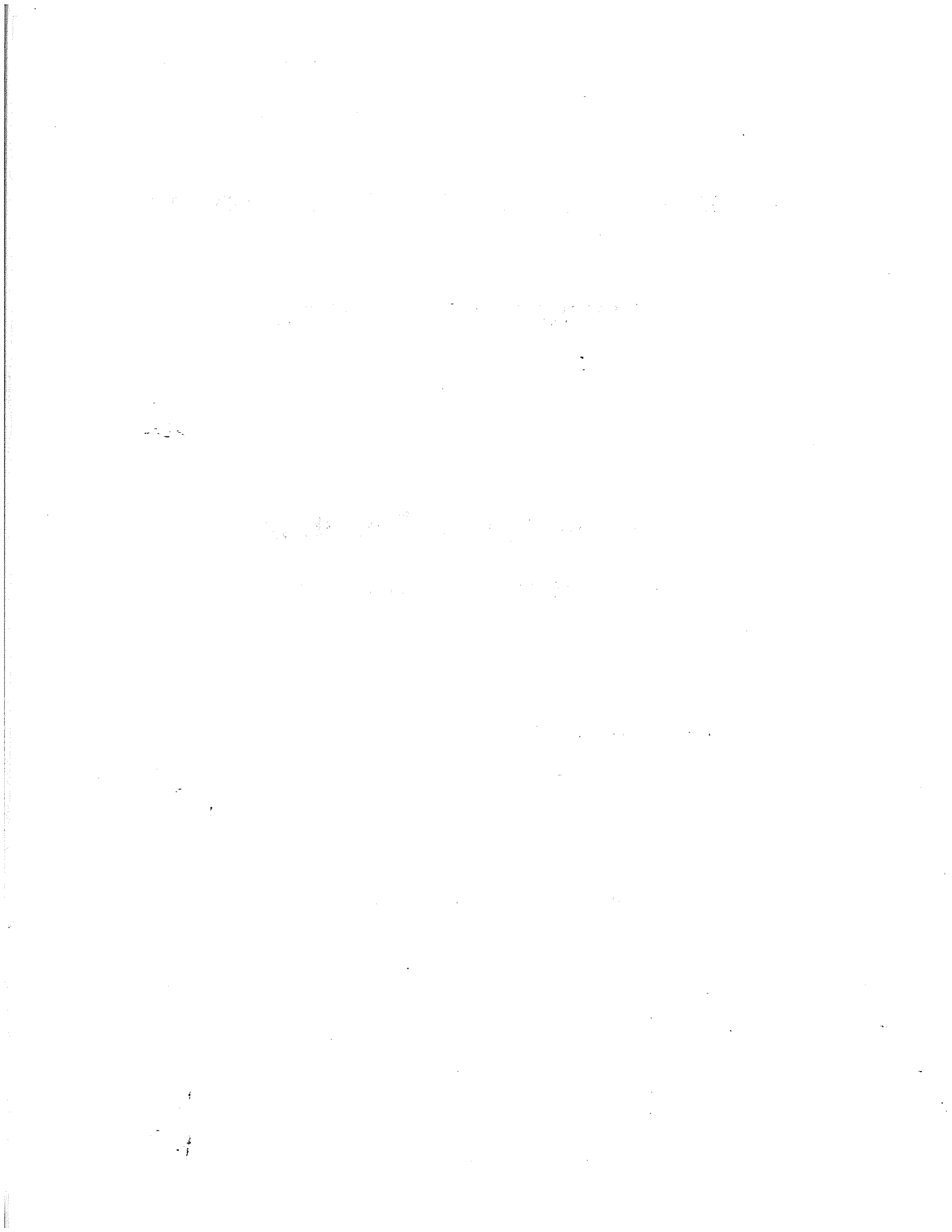
**Pacific Oyster Breeding
in Pendrell Sound, 1975.**

by

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ABSTRACT

(*Crassostrea gigas*)

A preliminary analysis of data collected by the Pendrell Sound Program in 1975 is presented. Weather, hydrographic conditions, Pacific oyster spawning, larval development, larval distribution, and spatfall intensity at different locations within Pendrell Sound are discussed. Correlations between surface plankton tow data which show relative abundance, and pipe sample data which show absolute abundance, are examined. Comparison sampling with two types of quantitative samplers is briefly discussed, as are spat growth and predator abundance.

INTRODUCTION

The oyster industry in British Columbia has become largely a culture industry, as a result of declining wild populations. Whereas Crassostrea gigas spat were once imported from Japan, the industry has now been reliant for several years nearly wholly on seed from Pendrell and Hotham sounds (see Quayle 1969 for a complete discussion of the oyster industry). In addition, seed from British Columbia is exported to the USA and France.

Collection of oyster seed requires a forecast of spatfall, so that collectors (cultch) may be immersed at the right time to collect the set while at the same time not becoming fouled. The Pacific Biological Station has provided this forecast since 1959. Although the forecast normally requires only a small amount of qualitative sampling, an expanded program was started in 1974 in order to improve the basic empirical relations used in forecasting and also to discover optimal forecasting strategies.

This report presents a preliminary analysis of the data collected under this program in 1975. Some of the results presented here, for instance the relation between abundance of larvae and intensity of spatfall, will be compared with results from other years (Quayle 1974; Bourne, in prep.) in order to develop an improved prediction tool. Other results will be used in the development of future sampling programs and in the forecasting program.

METHODS

The floating laboratory VELELLA was towed into Pendrell Sound and anchored near Station 2 (Fig. 1) on June 23, 1975. It remained there until August 19, 1975. It was supported by a 22-ft power boat and a 12-ft Boston whaler.

Weather observations

Daily weather observations were made because of the influence that weather has on the surface waters in which oyster larvae develop. Clear, calm weather produces a warm, brackish layer that is essential for successful spawning and spatfall. Mixing and cooling during storms may cause this layer to break down. Daily observations were made of rainfall, cloud cover during the day, general wind conditions during the day, and minimum and maximum air temperatures, all at the VELELLA.

Hydrographic measurements

At Stations 1, 2 and 4 (Fig. 1) rafts were anchored to support Taylor 7-day thermographs. Each instrument had two pens which recorded seawater temperatures at 1- and 3-m depths. These provided continuous temperature records during the study period, June 24 through September 12.

Temperature and salinity profiles from the surface to 20 m were measured daily at Stations 1, 2, 4, 5, 6, 8 and 10 from June 24 through July 26, then every second day until August 17. These measurements were made with a Beckman RS5-3 portable salinometer.

Plankton sampling

Plankton tows were made each evening, after direct sunlight had left the surface of the Sound, from June 24 through August 17. A 5-min tow was made at the surface, using a 66 μ m net with a 32-cm opening and a length of 51 cm, at Stations 2, 4, 5 and 6. These samples were examined immediately under binocular dissecting microscopes.

The number of each type of organism was not determined, but relative abundance of bivalve larvae, zooplankton and phytoplankton was classed subjectively on a scale of 1 through 9. Within each of these major groups, the relative abundance of components -- different species of bivalve larvae, different taxa of zooplankters -- was estimated in such a way that the total of relative abundance equalled 10 within the group. For each bivalve species, this was carried out again to estimate the relative abundance of each larval stage, in such a way that the total of relative abundance equalled 10 within each species.

These data allow relative abundances of bivalve species to be compared, by multiplying together the relative bivalve abundance and the relative species abundance. This gives a number without units, the range of which is 0 to 99. Similarly, the relative abundance of each larval stage within a species can be compared.

Quantitative samples were taken with a multiple depth running pipe sampler (Westley 1954, Fig. 2) at least every second day from June 26 through August 14. The sampler was mounted on the stern of the Boston whaler and driven through the water at a standard speed, determined by the level of water in a reservoir on the sampler. Water emerging from the sampler was filtered through a plankton net (described above). Samples were decanted into counting dishes and examined under dissecting microscopes. Counts were made of each stage of Pacific oyster larvae and of mussels (Mytilus edulis), clams, shipworms (Bankia setacea), and native oysters (Ostrea lurida). Subsampling was necessary when larvae were very abundant.

On each day that sampling was carried out, the sampler was run along the transects shown in Fig. 3. The time run along the transect was recorded and used to calculate the number of liters of water sampled (the rate of

sampling was initially calculated by measuring the output from the sampler). Numbers of larvae could then be converted to density (no./100 l was the standard unit used).

Relative numbers of larvae in each part of the Sound were calculated as follows. The area of the Sound adjoining each transect, from shore to shore and between the boundaries of the next transects, was calculated from the chart with a planimeter (Table 1). Larval density was then multiplied by this area to give a figure whose units have no meaning, but which is proportional to the total number of larvae in that part of the Sound. (The density of larvae could have been multiplied by the volume of water in the surface layer to give the absolute number of larvae. This was not done because the depth of the layer containing larvae and the distribution of larvae within the layer were not measured.)

From these data, a figure proportional to the total number of larvae in the Sound was calculated by adding the relative abundances of larvae along transects 1, 3, 5, 7 and 9 (even-numbered transects were omitted because the areas adjoining these transects were already included in the areas adjoining the odd-numbered transects).

Quantitative sampling methods were compared on four occasions using the modified multiple depth running sampler and a standing perforated pipe sampler (Quayle and Terhune 1967). Standing samples were collected at both ends and the midpoint of a transect sampled with the running sampler and the catches compared.

Spatfall sampling

When counts of late stage oyster larvae in the plankton began to rise, test strings of collectors were immersed daily at the VELELLA (Station 2) and the spat were counted at the end of a 24-hr period. By watching the counts of spat/shell each day the peak of the set could be found.

Each week one string of test shell was immersed at Stations 1, 2, 3, 4, 5, 6 east, 6 west (lost between July 28 and August 4), and 10. One week later a sample of 6 or 7 shells from each Station was removed and the spat were counted. The old string was left at the Station and a new string was immersed. This procedure was repeatedly carried out until the end of the study period. At the end of the study period (September 12) all collectors were removed. The number of oysters on the top and bottom of each piece of cultch was determined, and a sample of 10 oysters, randomly chosen on each side of each piece, was measured. Dead oysters, starfish (Pisaster ochraceous) and flatworms (Pseudostylochus sp.) were counted. In 1974 many oyster spat were destroyed by starfish predation, so predator counts were made in order to warn the industry if necessary and to gain insight into settlement of predators.

RESULTS

Weather

In the summer of 1975, weather was generally favourable for the breeding of Pacific oysters in Pendrell Sound. Beginning on June 29, there was a 2-week period of sunny, calm weather which allowed the surface water layer in Pendrell Sound to warm and deepen. After this period of very warm weather there were 5 days of overcast weather, but very little wind or rain. The weather then became warm again with sunshine during the day and cloud at night, for approximately 1 month. During this period there were only 6 days with overcast skies (Fig. 4). This long period of good weather resulted in a highly stable surface layer containing very good growing conditions for Pacific oyster larvae and spat.

During the 56-day study period, 17 days were completely overcast, 20 days were partially overcast and clear, sunny weather was recorded on 19 days (Fig. 4). Rain fell on 21 days and the heaviest rainfall was 16.3 mm on August 1. The highest air temperature recorded was 31.0 C on July 9, and the lowest was 10.0 C on June 25 and 26, with temperatures of 25 C, or higher, occurring on 25 of the 56 study period days.

Water temperatures and salinities

The warm weather at the end of June caused warming in the surface waters of Pendrell Sound. Water temperatures increased rapidly at all stations in the Sound and a distinct thermocline formed between 2 and 3 m. The thermocline reached a depth of 10 m on July 15 and the surface water temperature reached a high of 25.5 C on July 9 at Station 1. Surface water temperatures remained at 20 C, or higher, at all stations from July 2 to August 2; except for a short period at Station 6 where a temperature inversion took place. A temperature inversion also occurred at Station 2 (Fig. 5) in mid-July but the surface temperature remained above 20 C.

Contour plots of the temperature profiles at Stations 2 and 4 (Fig. 5 and 6) show the thermocline forming below the very warm surface layer of water. The thermocline was very distinct in the first half of July, then began to weaken as the cooler, overcast weather in August took effect.

Salinities remained above the 10‰ level, below which larval survival may be affected (Quayle, 1969). Surface salinities began to decrease in early July and a halocline remained throughout the Sound at depths of 2 to 3 m from early to late July. Surface salinities then increased until sampling ended in mid-August. Contour plots of salinity profiles at Stations 2 and 4 (Fig. 7 and 8) show the intrusion of less saline water in July and the gradual breakdown as the summer progressed.

The retention of the surface layer of warm, low salinity water in Pendrell Sound for the entire summer resulted in ideal conditions for Pacific oyster larval production and survival. Tables 2 and 3 show mean daily water temperatures from Stations 1, 2 and 4 at depths of 1 and 3 m. Water temperatures remained at, or above 20 C at the 1 m depth for 37 days at Station 1,

36 days at Station 2, and 33 days at Station 4. At a depth of 3 m, water temperatures remained at, or above, 20 C for 34 days at Station 1, and 28 days at Stations 2 and 4. Blanks in temperature records occurred when recording pens ran out of ink because of high air temperatures.

Table 1. The length of each running pipe sample transect and the area of the Sound adjoining it.

Transect	Length (km)	Area (ha)
1	1.98	148
2	1.59	189
3	1.20	194
4	1.89	254
5	1.59	321
6	1.26	282
7	1.59	220
8	1.02	201
9	4.85	631

Table 2. Mean daily seawater temperatures at 1 m depth at three stations as observed by recording thermographs.

Date 1975	Station 1	Station 2	Station 4
June 24	19.7	19.9	19.2
25	19.6	18.5	19.3
26	18.5	17.5	17.8
27	18.2	17.5	17.3
28	17.5	17.0	17.4
29	17.7	17.8	16.7
30	18.8	19.0	18.5
July 1	19.5	19.7	18.5
2	21.0	20.8	19.3
3	21.8	21.5	20.2
4	22.0	22.3	21.3
5	23.3	23.5	22.1
6	24.2	24.2	22.4
7	25.2	24.5	23.4
8	25.5	25.3	24.2
9	25.2	25.8	24.8
10	25.0	25.3	25.2
11	24.9	25.8	25.3
12	24.8	25.5	24.7
13	24.4		24.5
14	23.8	24.0	23.6
15	22.7	23.0	22.3
16	22.2	22.0	21.7
17	21.3	22.2	21.0
18	20.8	20.6	20.5
19	21.5	20.4	20.0
20	21.7	20.7	20.0
21	21.0	21.0	20.0
22	21.5	21.0	20.5
23	21.5	21.5	21.0
24	22.0	22.0	21.0
25	21.5	21.0	21.0
26	22.0	22.0	22.0
27	21.5	22.0	21.5
28	21.2	21.3	20.4
29	20.3	20.2	20.2
30	20.3	20.5	20.3
31	21.0	21.0	20.3
Aug. 1	21.0	20.8	20.3
2	20.3	20.0	20.0
3	20.0	20.7	20.2
4	19.5	19.6	18.9
5	19.4	19.4	18.8
6	19.5	19.2	19.0
7	18.9	18.5	18.0
8	18.6	18.2	

Table 2 (cont'd)

Date 1975	Station 1	Station 2	Station 4
Aug. 9	18.7	18.2	
10	18.7	17.8	17.0
11	19.0	19.0	18.6
12	18.7	19.0	18.3
13	20.0	18.8	19.2
14	20.5	20.7	19.3
15	20.7	20.9	20.2
16	20.3	20.5	19.5
17	19.6	20.1	19.3
18	19.4	19.0	
19	19.7	19.6	
20	19.6	19.6	
21	19.0	18.7	
22		18.0	
23		18.0	
24			
25	17.0	17.2	17.0
26	17.0	16.5	17.0
27	17.5	16.0	15.8
28	17.5	15.5	15.5
29	17.5	15.8	15.6
30	17.3	15.8	15.5
31	17.0	16.0	16.0
Sep. 1	17.0	15.5	16.0

Table 3. Mean daily seawater temperatures at 3 m depth at three stations, as observed by recording thermographs.

Date 1975	Station 1	Station 2	Station 4
June 24	19.3	17.8	18.0
25	19.2	18.3	17.8
26	18.3	17.7	17.0
27	18.5	17.8	17.3
28	18.0	17.4	16.6
29	18.0	17.2	17.2
30	18.5	18.3	18.0
July 1	18.5	18.2	17.3
2	18.8	19.0	17.7
3	19.0	18.5	17.7
4	21.7	20.5	19.0
5	19.0	19.6	20.2
6	20.7	20.8	20.0
7	20.3	20.0	19.4
8	20.6	19.5	19.3
9	22.0	21.0	20.7
10	24.2	23.8	23.0
11	24.0	24.5	23.7
12	24.3	24.8	24.3
13	24.3		23.9
14	20.8	18.0	22.3
15	23.5	22.5	22.3
16	23.3	22.5	22.0
17	23.4	22.7	22.7
18	22.7	22.2	21.5
19	22.6	22.0	21.7
20	22.3	22.0	21.3
21	22.5	22.0	22.0
22	22.0	21.5	21.5
23	22.5	21.0	21.5
24	22.0	21.5	21.0
25	22.0	21.5	21.0
26	21.5	21.0	20.0
27	21.5	21.0	20.5
28	21.3	21.5	21.5
29	21.0	20.8	21.5
30	20.7	20.5	21.3
31	21.1	20.9	20.8
Aug. 1	21.0	20.8	20.5
2	20.5	20.0	19.8
3	20.7	19.5	20.5
4	20.2	20.8	19.6
5	20.0	20.0	19.7
6	20.1	19.5	20.2
7	19.8	19.1	19.3
8	19.7	18.9	18.3

Table 3 (cont'd)

Date 1975	Station 1	Station 2	Station 4
Aug. 9	19.5	18.4	17.1
10	18.7	17.7	16.7
11	19.2	18.7	17.2
12	19.1	18.8	18.0
13	19.0	18.3	17.0
14	19.2	18.6	17.2
15	20.0	19.0	18.0
16	19.2	18.5	17.0
17	18.5	18.6	17.2
18	19.3	19.0	
19	19.6	19.3	
20	19.8	19.0	
21	18.7	18.4	
22	19.1	18.6	
23	18.3		
24	18.5		
25	17.5	16.0	17.0
26		16.0	16.0
27		17.0	16.5
28	16.5	16.8	16.5
29	16.0	16.8	16.4
30		16.8	15.8
31		16.7	15.0
Sep. 1	16.0	16.7	15.0

Spawning

Spawning was directly observed only once, on July 24; and white water was also observed only once, on July 21. Times of spawning must therefore be inferred from relative numbers of straight-hinge larvae observed in daily plankton tows (Fig. 9) and density of straight-hinge larvae in running pipe samples (Fig. 10). Straight-hinge larvae are formed within 48 hr after spawning (Quayle 1969).

Small numbers of straight-hinge larvae were present when sampling began on June 26. These disappeared, and after several days on which no larvae were found, large numbers of larvae appeared from July 5 through July 8. From then until August 9, straight-hinge larvae appeared every day in plankton tows. Numbers, however, never reached those of the early July spawning.

A comparison of surface temperature at Station 1 with numbers of straight-hinge larvae along transect 1 two days later (Fig. 11) shows that 20 C appeared to be the temperature below which spawning did not occur. The largest spawning of the year took place when surface temperature had reached 23 C.

When the numbers of straight-hinge larvae found in pipe samples taken at different parts of the Sound are compared (Fig. 12), it can be seen that they appeared simultaneously at different places in the upper half of the Sound. This indicates either that larvae disperse very rapidly after spawning or that spawning is general and not highly localized. Numbers of straight-hinge larvae were consistently greatest near the head, and decreased toward the mouth. The same pattern appears when plankton tows taken at each of four stations are compared (Fig. 13). A forecaster with limited resources might therefore be justified in taking only a single daily plankton tow, rather than samples from each part of the Sound. To be most certain of detecting spawning, the forecaster would take his one sample near Station 1.

Larval development

Relative numbers of each larval stage, observed in running pipe samples in the whole Sound, are shown in Fig. 14. Relative numbers of each stage at one location (transect 1) are shown in Fig. 15.

The first spawning, which produced small numbers of straight-hinge larvae in late June, produced a spatfall in mid-July. This was surprising, since no mid-umbone or late umbone larvae from this spawning were observed in the plankton.

The large spawning in early July also resulted in spatfall, which was successfully forecast and was used by the industry. Although there were further spawnings, and straight-hinge larvae were observed in the water throughout July, survival of later stage larvae was poor and no significant spatfall took place after July 25.

The time between the first appearance of straight-hinge larvae and the first observed spatfall was 15 days. However, there may have been some straight-hinge larvae in the water before the first plankton tow was made on June 26, and spat may have set before the first experimental cultch was exposed on July 11. The actual development time may therefore have been longer.

The average water temperature at 1 m (Station 2) during this period was 21.8 C.

The straight-hinge larvae which appeared in large numbers on July 6, 7 and 8 resulted in spatfall from July 20 through July 23. This indicates an average development time of 14.5 days. During this period the average water temperature was 23.2 C.

Total relative numbers of larvae of each stage observed in evening plankton tows are shown in Fig. 16. Although these data are based on a purely subjective estimate of relative abundance, they closely follow quantitative data obtained from running pipe samples (Fig. 14). The subjective estimate appears to be logarithmic in character: when larvae are highly abundant the subjective estimate is lower than the quantitative data, while when larvae are rare the subjective estimate is higher than the qualitative data. Correlations between the two estimates are given in Table 4. The two estimates correlate best with straight-hinge larvae and least closely with late umbone larvae.

Distribution of larvae

Because of the problems of anchorage and exposure to wind waves, spat collection has traditionally been carried out in the head of the Sound. The head may not be the best location when other factors are considered, so data from each running pipe sample transect were therefore examined in order to determine whether there is dispersal or concentration of larvae after spawning, and whether there is much loss of larvae from the Sound.

The best way to study larval distribution in the Sound, using the quantitative pipe sample data, would be to watch the dispersal of one cohort of larvae. This proved impossible for several reasons: spawning was spread over a period of several days, producing a poorly defined cohort; time of development was apparently quite variable so the point at which the cohort had grown from one stage into the next was hard to determine; and finally the classification of larvae into stages is not entirely objective, so that different observers classify slightly differently. Two alternative approaches were used.

For each day on which data were available, a total relative number of larvae in each stage was determined from pipe sample data. The percentage of this total found in each part of the Sound was then determined, and an average percentage calculated for the whole season in each part of the Sound. If larvae of a particular stage tended to concentrate in one area, then the average percentage would be high for that part of the Sound.

Table 4. Correlations between relative numbers of larvae observed in running pipe samples and in plankton tows on the same days, June 26 through August 14.

Days on which no larvae were observed were not included in the analysis so the number of data pairs varies.

Larval stage	N	Correlation coefficient
Straight-hinge	31	.758
Early umbone	33	.727
Mid-umbone	31	.654
Late umbone	23	.576

Results are shown in Fig. 17. They show almost no clear overall trend. It is interesting that few late stage larvae are found along transect pipe sampling transect 1, which is the head of the Sound where most spat collection takes place. However, this may not be significant, as no attempt was made to calculate confidence intervals for this approach.

This way of looking at the data is probably misleading, because it gives equal weight to periods with both low and high larval abundance. It has already been seen in Fig. 12 and 13 that, at the time that large numbers of straight-hinge larvae appeared, these were most abundant in the head of the Sound. The second way of looking at this data was simply to plot the relative abundance of larvae on days when each larval stage was at its peak of abundance (Fig. 18).

These data show clearly that early larvae were most dense near the head, with very low relative numbers of straight-hinge larvae in the lower two-thirds of the Sound. This is an important fact to take into account if forecasting resources do not allow sampling in the entire Sound. Mid-umbone larvae, however, were distributed much more evenly throughout the upper part of the Sound, as are late umbone larvae. The late stage larvae may show a slight tendency to be concentrated in the centre part of the Sound near Station 5.

Relatively few larvae of any stage were seen, at least on the days illustrated in Fig. 18, in the lower part of the Sound. As might be expected, virtually no straight-hinge larvae were seen in the lower part of the Sound at the time of the major spawning, but there was increased abundance of later stage larvae in the lower Sound.

The distribution of late stage larvae was thought to merit further attention, as these are the larvae that are near to becoming spat. From the viewpoint of one wishing to collect spat, the interesting value is the density of late larvae in various parts of the Sound. There may be a relation between larval density and spatfall intensity, but not necessarily one between spatfall intensity and total larval numbers in a given part of the Sound. In Fig. 19 the density of late umbone larvae in July is shown on July 15, 17 and 19, during which time the late stage larvae were at the peak of their abundance. There appears to be no consistent trend in density of late larvae in various parts of the Sound.

Abundance of other bivalve species

The average density of oyster larvae of all stages was compared with the average density of other bivalve species observed in pipe samples (Fig. 20) and plankton tows (Fig. 21). Linear correlation coefficients for the relation between Pacific oysters and other species are given in Table 5.

Low positive correlations indicate little interrelation between Pacific oysters and mussels, and between Pacific oysters and clams. There was a high positive correlation between oysters and Bankia, which was significant ($P = 0.01$), and a significant correlation between native oysters and Pacific oysters also. While it is difficult to make any inference about larval interactions from these results, the absence of negative correlations indicates a lack of serious competition, at least at these planktonic density levels.

Table 5. Linear correlation coefficients between the density of Pacific oyster larvae and that of other bivalve species. The number of data pairs for each comparison was 37.

Species compared with Pacific oysters	Correlation coefficient r
<u>Bankia setacea</u> shipworms	.828**
<u>Mytilus edulis</u> mussels	.151
<u>Ostrea lurida</u> native oysters	.534**
Clams (all species)	.227

**Significant at P = 0.01.

Correlation coefficients were also calculated in order to compare data from plankton tows and pipe samples (Table 6). Positive correlations significant at $P=0.05$ or less were found in each case, which indicates that the two methods of observation are not radically different in effectiveness.

Spatfall

Settlement of Pacific oysters occurs soon after the development of an eye spot in the veliger larva. The first 'eyed' larvae were observed on July 11, and accordingly a string of asbestos cultch was exposed at the barge. The mean spatfall after 24 hr was 28 per piece, suggesting that setting may actually have begun earlier, even though no eyed larvae had been observed in plankton tows or pipe samples. This was apparently confirmed when, on July 18, a string of cultch immersed on July 2 was examined, and found to have spat considerably larger than those which set on July 11. It is difficult to explain how a set could occur without eyed larvae being observed.

Daily spatfall is shown in Fig. 14. Spatfall declined steadily after July 11 until July 17, when a small set took place. The main set, which was forecast to the industry, began on July 20 and peaked on July 22 at 62 spat per shell, quickly declining after this date. No further spatfall was observed during this season, although straight-hinge larvae continued to appear in the plankton.

Mean weekly spatfall from Stations 1, 2, 3, 4, 5, 6 East, 6 West and 10, indicates that the heaviest settlement occurred between July 14 and 28 (Tables 7 and 8). Settlement then rapidly declined. Tables 7 and 8 indicate that the heaviest spatfall took place at Stations 4, 3 and 6 West respectively. Spatfall was thus concentrated in the large central area of Pendrell Sound while spatfall in the head of the Sound was much lighter. These data agree with those of Quayle's studies from 1952 to 1956 (Quayle 1969) which show that spatfall was heaviest in the central area of the Sound.

In Table 9, the mean weekly spatfall at Stations 1 and 2 is compared with the total of the daily spat counts during the same week at the VELELLA. The table shows that the sum of each daily spatfall is roughly comparable to the set on collectors exposed for the entire week.

Two kinds of comparisons were made in order to examine the relation between larval density and spatfall. First, daily spatfall at the VELELLA was compared with density of late stage larvae in running pipe samples along transect 1. Table 10 shows correlation coefficients for the relation when an increasing lag is used between larval density and spatfall, and these are also shown in Fig. 22. The best correlation was found when spatfall was compared with larval abundance 5 days previously. Quayle (1969) stated that "... larvae per unit volume of water about a week before setting is the ultimate basis for prediction." Considering the warm surface water in 1975, this correlation agrees well with Quayle's statement.

Table 6. Correlation coefficient for the relation between evening plankton tow data and running pipe sample data. In each case, the number of data pairs was 37.

Species	r
<u>Bankia setacea</u> shipworms	.679**
<u>Mytilus edulis</u> mussels	.815**
<u>Ostrea lurida</u> native oysters	.506**
Clams (all species)	.409*

**Significant at P = 0.01.

*Significant at P = 0.05.

Table 7. Mean weekly spatfall and the mean number of oysters observed at the end of the season at various stations.

Date immersed	Stn.	Weekly spat/shell		End of season spat/shell	
		mean	range	mean	range
1975					
July 14	1	42.57	8-77	101.59	27-196
21	1	66.57	23-106	71.29	26-136
28	1	1.00	0-2	2.94	0-6
Aug. 4	1	0.25	0-1	1.69	0-3
11	1	0.26	0-1	0.57	0-4
July 7	2	179.00	95-235	156.71	4-358
21	2	71.57	22-102	88.47	12-222
28	2	2.13	0-5	4.82	0-10
Aug. 4	2	0.76	0-2	2.63	1-5
11	2	0.76	0-3	1.31	0-4
July 14	3	182.38	75-275	126.25	66-207
21	3	448.14	115-783	182.57	74-375
28	3	2.13	0-6	5.57	2-14
Aug. 4	3	1.38	0-3	4.00	0-11
11	3	1.26	0-3	4.44	1-11
July 14	4	497.38	236-801	320.19	40-562
21	4	280.88	119-432	209.60	108-363
28	4	2.38	0-7	6.20	0-13
Aug. 4	4	1.51	0-4	2.63	0-7
11	4	0.13	0-1	2.00	0-6
July 14	5	171.01	14-374	140.06	2-426
21	5	269.29	82-492	140.13	73-276
28	5	0.76	0-4	3.63	2-11
Aug. 4	5	0.00	-	1.33	0-5
11	5	0.00	-	0.06	0-1
July 14	6E	127.38	90-177	86.67	0-174
21	6E	223.86	102-362	97.94	44-195
28	6E	2.75	1-5	2.76	0-7
Aug. 4	6E	1.00	0-2	1.00	0-4
11	6E	0.13	0-1	1.13	0-4
July 14	6W	246.25	95-391	lost	-
21	6W	204.86	157-289	lost	-
July 14	10	163.13	65-230	205.06	57-300
21	10	68.29	35-103	63.06	34-113
28	10	2.00	0-3	8.63	0-13
Aug. 4	10	1.26	0-2	2.93	0-7
11	10	0.76	0-2	3.06	1-9

Table 8. A comparison of mean weekly spatfall at various stations in the Sound. Station 6W was lost after the first 2 weeks.

Date	Station								Mean
	1	2	3	4	5	6E	6W	10	
July 14-21	42.6	179.0	182.4	497.4	158.5	127.4	246.3	163.1	199.5
July 21-28	66.6	71.6	448.1	280.9	269.1	223.9	204.9	68.3	204.3
July 28-Aug. 4	1.0	2.1	2.1	2.4	0.8	2.8	-	2.0	1.9
Aug. 4-11	0.3	0.8	1.4	1.5	0.0	1.0	-	1.3	0.9
Aug. 11-18	0.3	0.8	1.3	0.1	0.0	0.1	-	0.8	0.4
Aug. 18-25	0.1	0.6	1.1	0.4	0.3	0.4	-	0.5	0.4
Aug. 25-Sept. 1	0.5	0.0	0.0	0.0	0.0	0.0	-	0.0	0.1

Table 9. The mean weekly spatfall at Stations 1 and 2 compared with the total daily spatfall at VELELLA during the same week.

Date in	Weekly spatfall		Total daily spatfall at VELELLA
	Station 1	Station 2	
July 14	42.57	179.00	61.45
21	66.57	71.57	89.05
28	1.00	2.13	0.35

Table 10. Correlation coefficients for the relation between late larval density along pipe sample transect 1 and daily spatfall at VELELLA various numbers of days later.

Lag in days	Correlation coefficient
0	.1221
1	.0436
2	.0539
3	.1233
4	.1637
5	.7152
6	.1594
7	.3439
8	.1221
9	.1208
10	.2317

A similar comparison was made using the relative abundance of late stage larvae in evening plankton tows (Table 11, Fig. 23). Correlations observed here were poor, indicating that quantitative sampling is a much better basis for predicting intensity of spatfall than subjective estimation of larval abundance.

The second kind of comparison was made by using the 5-day lag to relate mean weekly spatfall in various parts of the Sound and mean late larval density on the nearest pipe sampling transect. In Fig. 24 spatfall measured on experimental cultch immersed during the weeks of July 14 and July 21 is compared with the mean density of late larvae during the same week, with a 5-day lag. As expected, there is a linear positive relation between larval density and spatfall intensity. Some of the variability seen in the relation might be caused by variations in water movement in different places in the Sound. At the head, water moves relatively slowly; while in the centre there is a fast anticlockwise gyral current (Farmer, pers. comm. 1975). This may allow a heavier spatfall at a given larval density than in the head of the Sound. On Fig. 24 it can be seen that stations in the centre of the Sound have spatfall intensities greater than the average relation, while those at the head have lower intensities than the average relation.

Because only a sample was taken from each string of cultch to determine weekly spatfall, the rest of the string remaining immersed until the end of the summer, these data provide insight into spat settling behaviour and mortality. In Fig. 25, mean weekly spatfall after the first week of immersion is compared with the mean number of live oysters found on the cultch at the end of the season. Increases in the number of oysters over the number of spat observed during the first week can be caused only by further spatfall. Decreases can be caused only by mortality. It appears that increases occurred on cultch on which the initial spatfall was less than 150 per shell; while decreases occurred on pieces with a higher initial spatfall. This suggests that spatfall is inhibited by high densities of spat that have already set on a surface. The decreases observed indicate that mortality increases as initial settlement intensity increases.

Another approach to these questions is shown in Fig. 26. For each station at which weekly cultch measurements were made, the number of live oysters on the first string of cultch to be exposed was compared with the total of all weekly spatfall measurements made at that station. It can be seen that, regardless of the total intensity of weekly spatfall, shell cultch at all stations carried about 100 to 200 oysters per piece by the end of the summer. Where weekly spatfall intensity was lower, the final number of oysters was more closely related to total weekly spatfall. These results could be 1) because spat set at a higher intensity on unsettled cultch than on previously settled cultch (and thus that weekly spatfall measurements are higher than the spatfall older cultch); or 2) because mortality reduces spat numbers in a density-dependent way. From consideration of the results shown in Fig. 26 it is likely that both processes are operating.

Mean numbers of starfish (Pisaster ochraceus) observed on the cultch at the end of the summer show no relation with changes in oyster abundance (Fig. 27), so it is unlikely that predation by starfish is a source of density-dependent mortality.

Table 11. Correlation coefficients for the relation between relative abundance of late larvae observed in evening plankton tows and daily spatfall at VELELLA various numbers of days later.

Number of days later	Correlation coefficient
0	.3789
1	.2307
2	.0141
3	.0245
4	.0458
5	.0100
6	.0200
7	.0707
8	.2105
9	.3312
10	.1122
11	.0224
12	.4102
13	.4614

During a 5-year period Quayle (1969) found that oyster larvae preferred to settle on the upper (rough) surface of shell cultch. The 1975 spatfall records (Table 12) agree with Quayle's findings and show that settlement on the upper surface of the shells was approximately 5 times that on the lower surface.

In 1975 the seed collection industry of British Columbia immersed approximately 46,000 strings of shell cultch, 1,500 bundles of cement-coated veneer panels, and 180 bundles of cement diamond chips. Sample collectors suspended from industry-owned floats caught 15 spat/shell at Station 2, 29 at Station 5 next to shore, 41 at Station 5 in deep water, 34 at Station 6 and 44 at Station 10.

Comparison of running and standing pipe sampling

In 1975 a modified multiple depth running plankton sampler (Westley 1954) was used to obtain quantitative samples of Pacific oyster larvae for predicting spatfall, and studying larval distribution. Spot sample data, obtained using a modified perforated standing pipe plankton sampler (Quayle and Terhune 1967) was used to compare with running pipe sample data in order to compare this year's data with data from past years.

Comparison sampling was done on four different occasions and plotted in Fig. 28, which indicates that oyster larvae appear more dense on standing spot samples. Quayle (1974), with more data, found that his running pipe sampler was more efficient than his spot sampler. The discrepancy in relative sampling efficiency between the 1975 results and Quayle's 1966 results may be caused by the differences in intake depths of the Washington sampler and Quayle's perforated pipe sampler. A better comparison could be made using a spot sampler with intakes at depths identical to running sampler intakes.

Spat growth

Lengths of a random sample of 10 oysters per piece of cultch were taken from cultch that was put out for weekly spatfall measurements at various dates and removed from the water on September 12. The length frequencies of these oysters are shown in Fig. 29 and 30. A visual estimate was made of the mode in each group of oysters; these are shown with the maximum observed sizes in Fig. 31 and 32. Growth was similar in oysters that set on the upper and lower surfaces of cultch, except that in the oldest two groups it appeared that oysters on the lower surfaces had attained a larger size. This difference could not be attributed to differences in oyster density between the upper and lower surfaces, because the difference was present even on pieces of cultch with low spat densities.

Table 12. Mean numbers of oysters observed on the tops and bottoms of pieces of cultch after 1 week and on September 12, at various stations..

Date in	Station	Weekly		End of season	
		Top	Bottom	Top	Bottom
July 14	1	38	5	90	12
21	1	55	12	56	15
July 14	2	170	9	106	51
21	2	55	17	66	23
July 14	3	153	29	24	102
21	3	307	141	118	65
July 14	4	473	25	262	59
21	4	182	99	160	49
July 14	5	164	7	124	16
21	5	228	41	104	36
July 14	6E	113	14	60	27
21	6E	181	43	64	34
July 14	6W	227	20	-	-
21	6W	159	46	-	-
July 14	10	144	19	162	43
21	10	53	16	50	14

Predator abundance

Test cultch immersed at all stations on July 14 had the heaviest starfish set of all cultch inspected on September 12 (Table 13). This cultch was the most heavily fouled, which may have promoted a heavy starfish set; or the starfish set may have been maximum near the first cultch-immersion day. Cultch immersed at stations in the central Sound area had a more intense starfish set than that at stations near the head of the Sound; with Station 10 receiving the heaviest set.

Pseudostylochus setting was also heaviest on cultch immersed early in the study period and also was heaviest in the central Sound at Stations 4 and 5.

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Dr. D. B. Quayle provided invaluable technical assistance and advice during this project, for which we are most grateful.

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We wish to thank all these people who made Pendrell Sound in 1975 both a productive and enjoyable field season and without whose help this report could not have been written.

REFERENCES

- Quayle, D. B. 1969. Pacific Oyster Culture in British Columbia. Fish. Res. Board Can. Bull. 169. 169 p.
1974. Data Report. Pendrell Sound oyster breeding 1950-1970. Fish. Res. Board Can. MS Rep. 1291. 389 p.
- Quayle, D. B., and L. D. B. Terhune. 1967. The hydronamics and field trial results of a perforated pipe plankton sampler. Fish. Res. Board Can. MS Rep. 887. 20 p.
- Westley, R. E. 1954. A multiple depth running plankton sampler. Wash. Dep. Fish. Fish. Res. Pap. 1(2): 1-4.

Table 13. Mean number of starfish and Pseudostylochus/shell at each station.

Date immersed	Station							\bar{x}
	1	2	3	4	5	6E	10	
July 14	2.59	0.06	0.13	2.06	0.56	1.76	7.19	2.05
21	0.50	0.00	0.06	2.80	0.00	0.38	2.50	0.89
28	0.50	0.12	0.06	1.53	3.53	1.06	1.88	1.24
Aug. 4	0.25	0.00	0.00	2.00	2.38	0.81	2.07	1.07
11	0.00	0.19	0.00	1.25	0.08	1.20	3.19	0.84
18	0.00	0.00	0.00	0.00	0.00	0.19	0.20	0.06
25	0.00	0.00	0.00	0.07	0.00	0.00	0.13	0.03
\bar{x}	0.55	0.05	0.04	1.39	0.94	0.77	2.45	
<u>Mean number of Pseudostylochus/shell at each station</u>								
July 14	0.59	0.00	0.00	0.06	0.06	0.00	0.00	0.10
21	0.00	0.00	0.00	1.20	0.00	0.00	0.13	0.19
28	0.06	0.00	0.00	0.27	0.31	0.00	0.00	0.09
Aug. 4	0.00	0.00	0.00	0.44	0.31	0.00	0.07	0.12
11	0.13	0.00	0.00	0.25	0.00	0.00	0.00	0.05
18	0.06	0.00	0.00	0.06	0.00	0.00	0.00	0.02
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
	0.12	-	-	0.65	0.33	-	0.03	

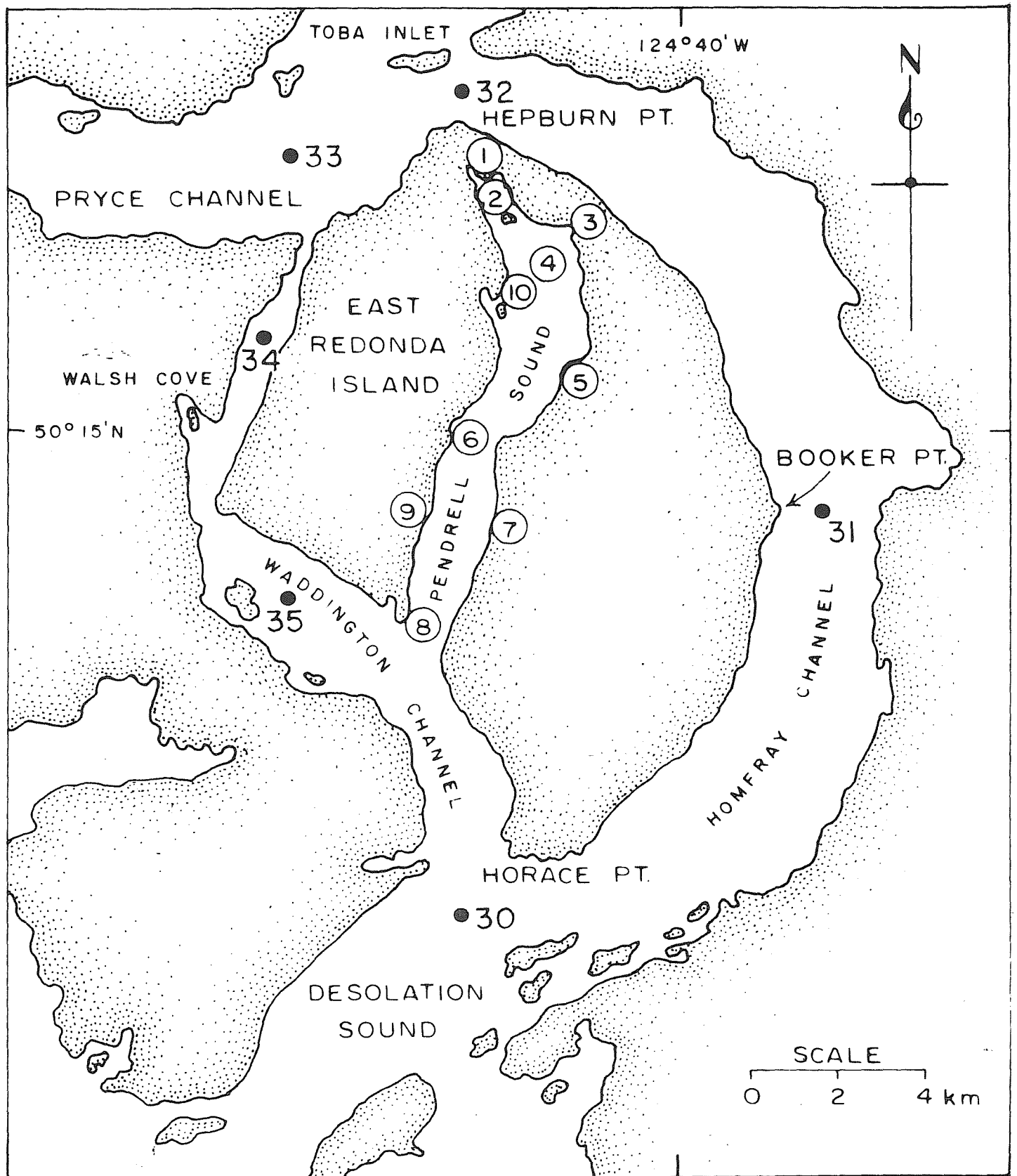
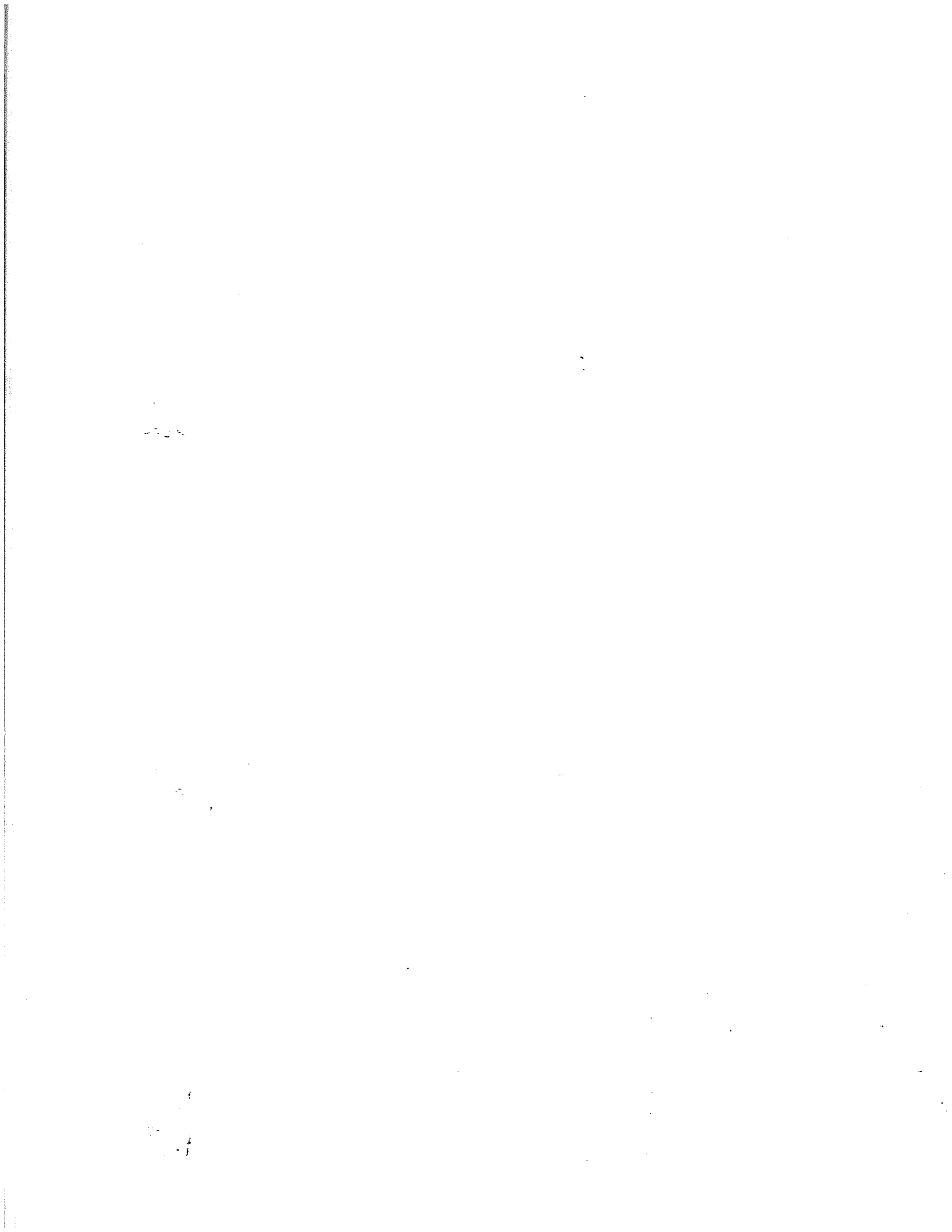


Fig. 1. Map of Pendrell Sound showing permanent sampling stations.



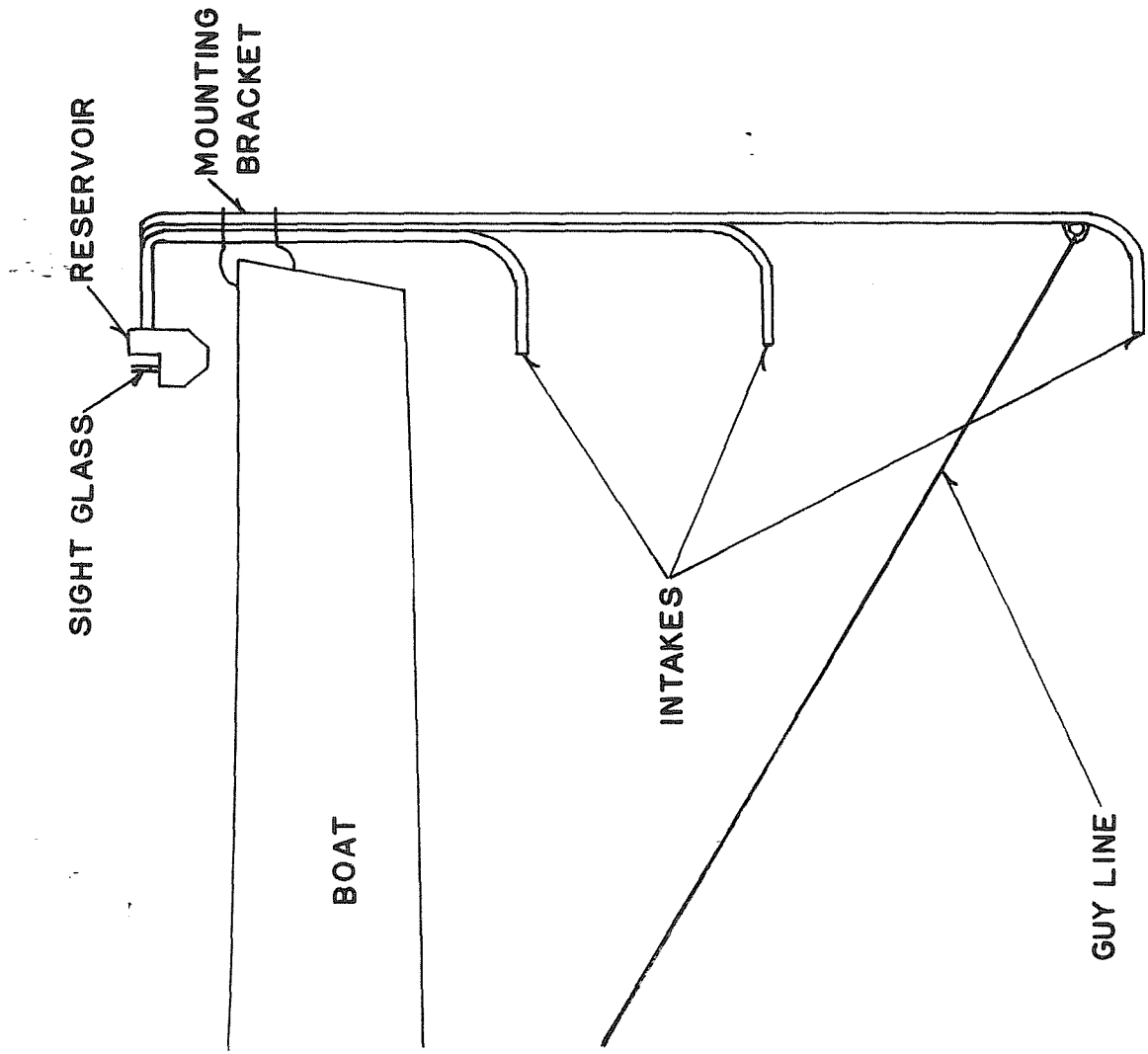
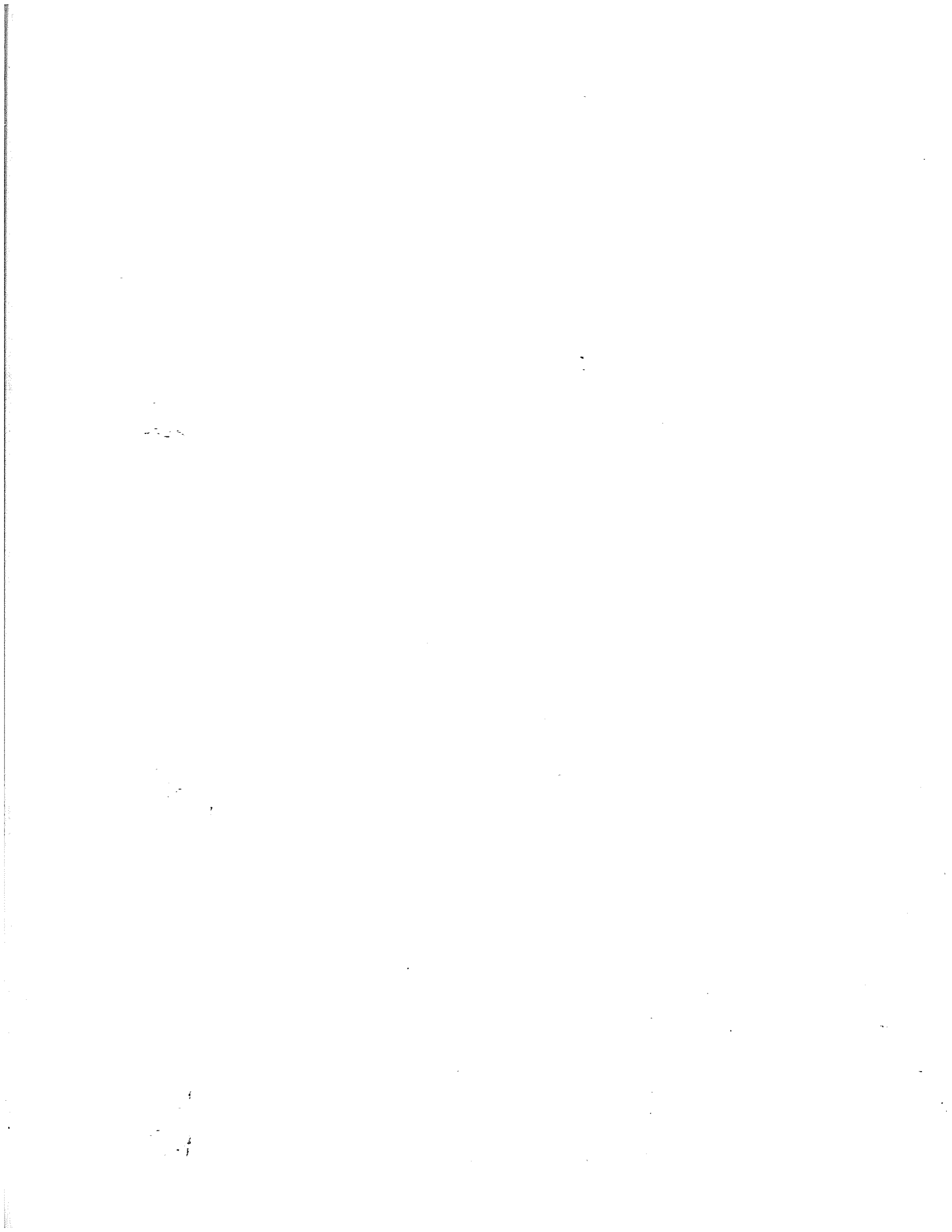


Fig. 2. Diagram of multiple depth running pipe sampler.



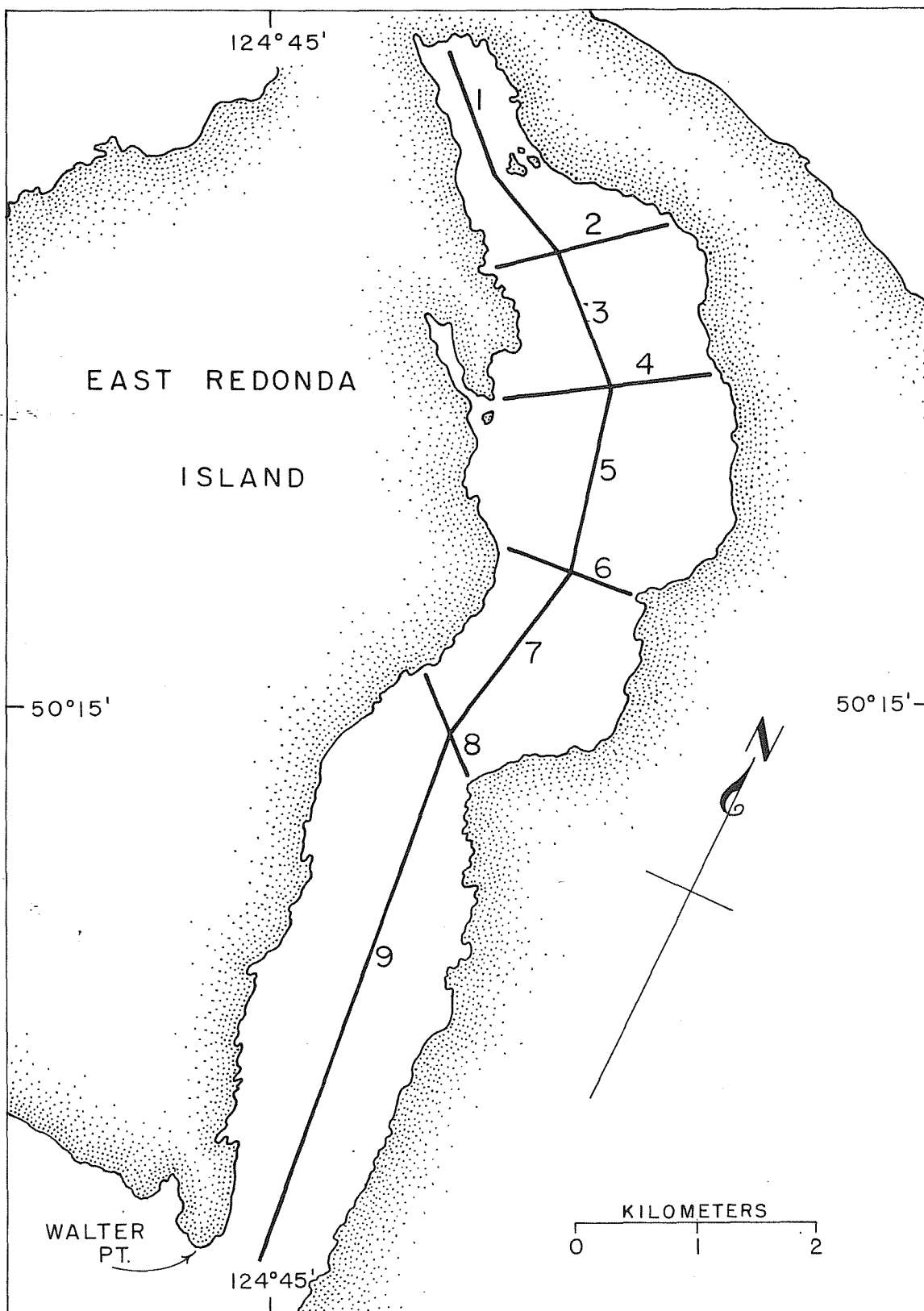


Fig. 3. Map showing locations of pipe sampling transects.

1948

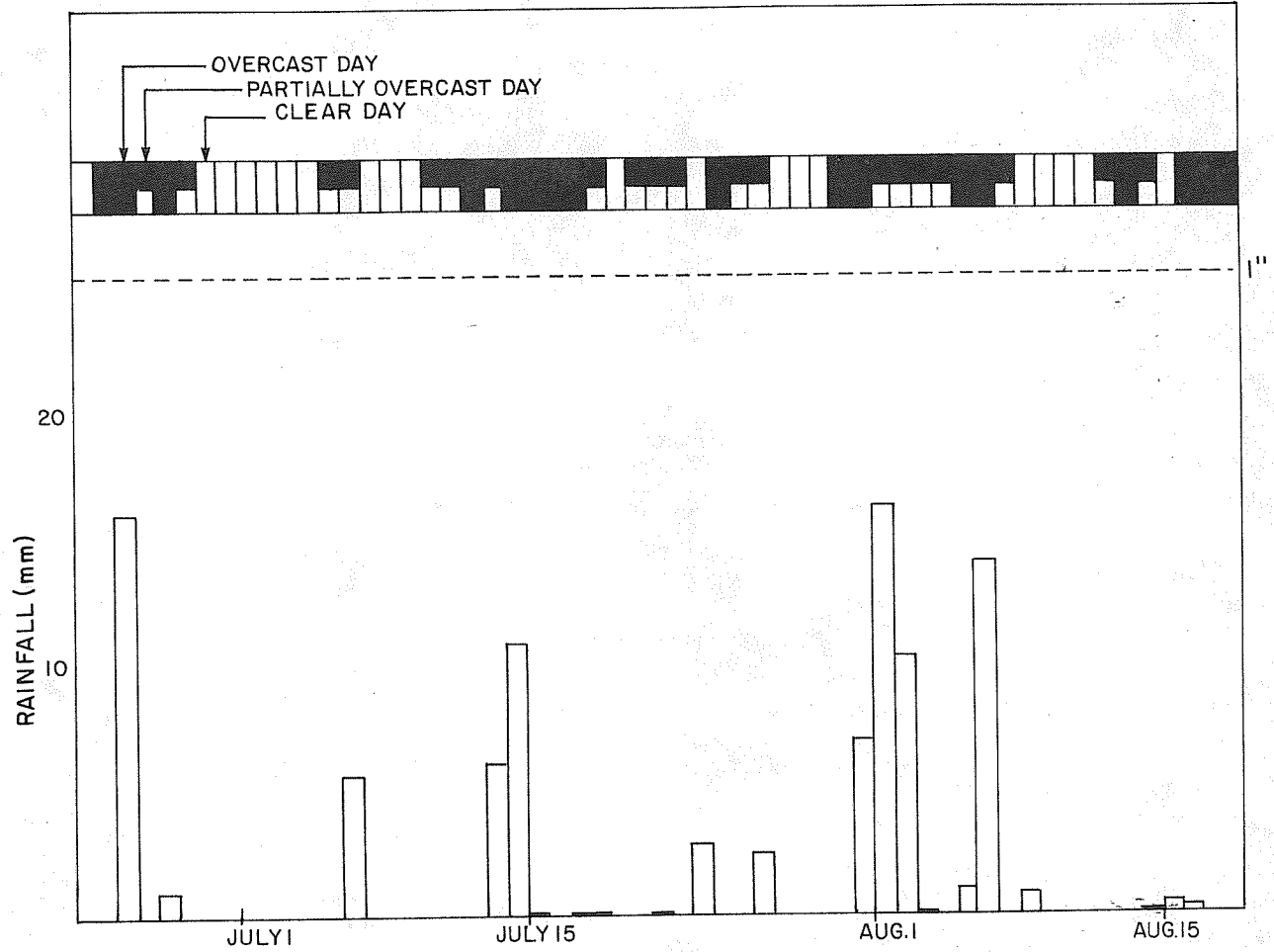
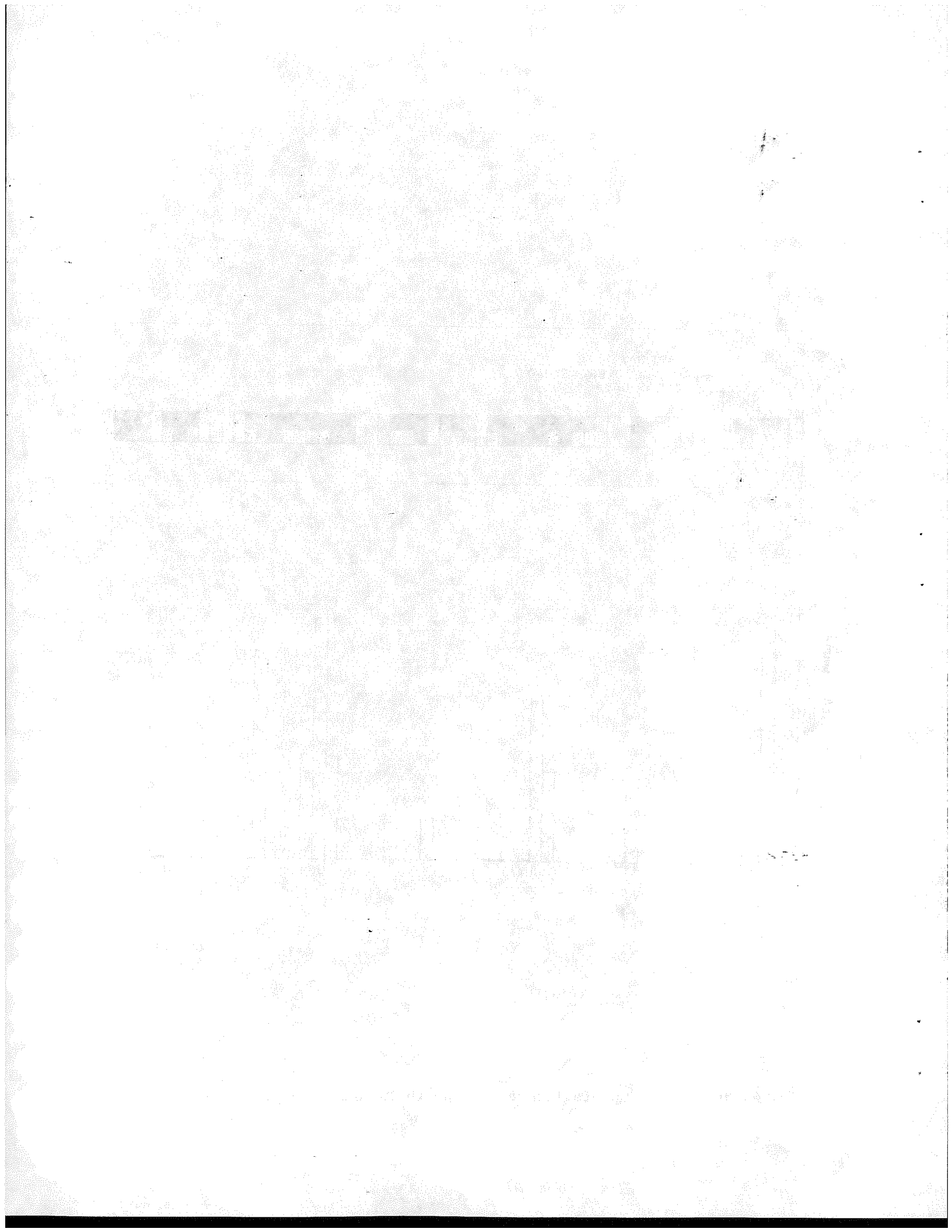


Fig. 4. Cloud and rainfall observations in Pendrell Sound during 1975.



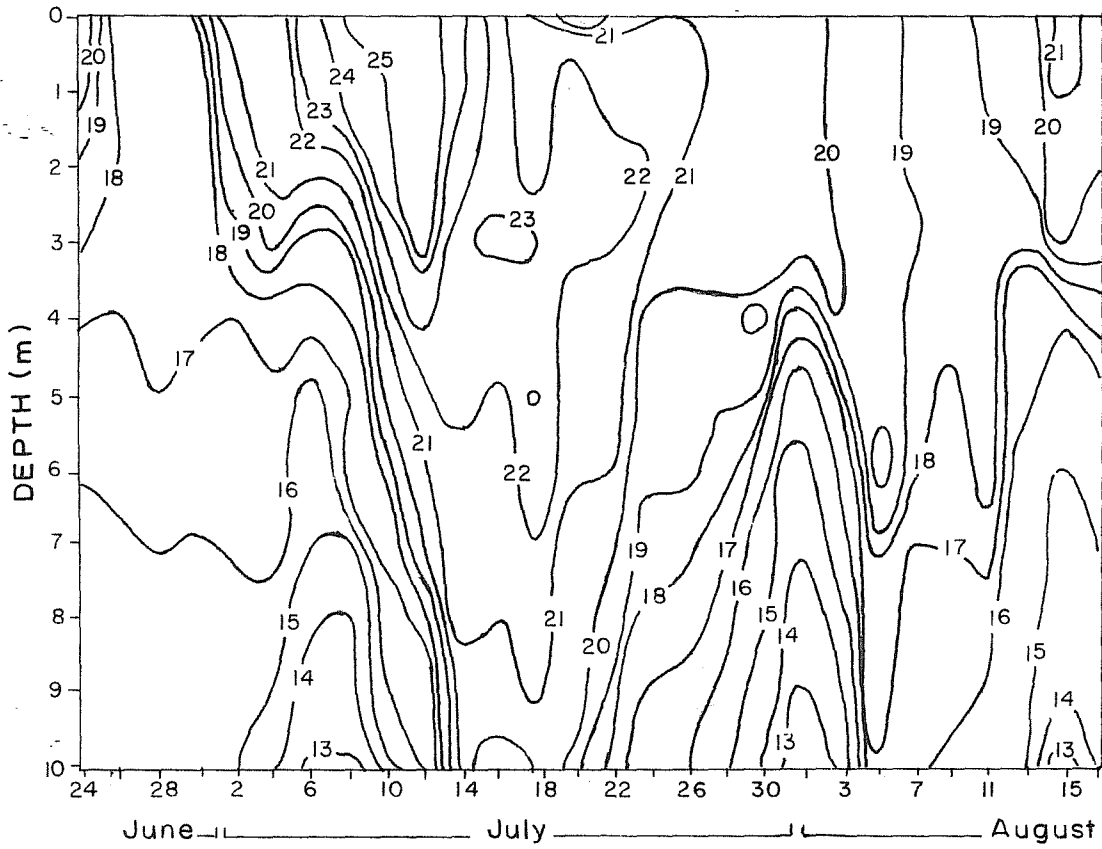
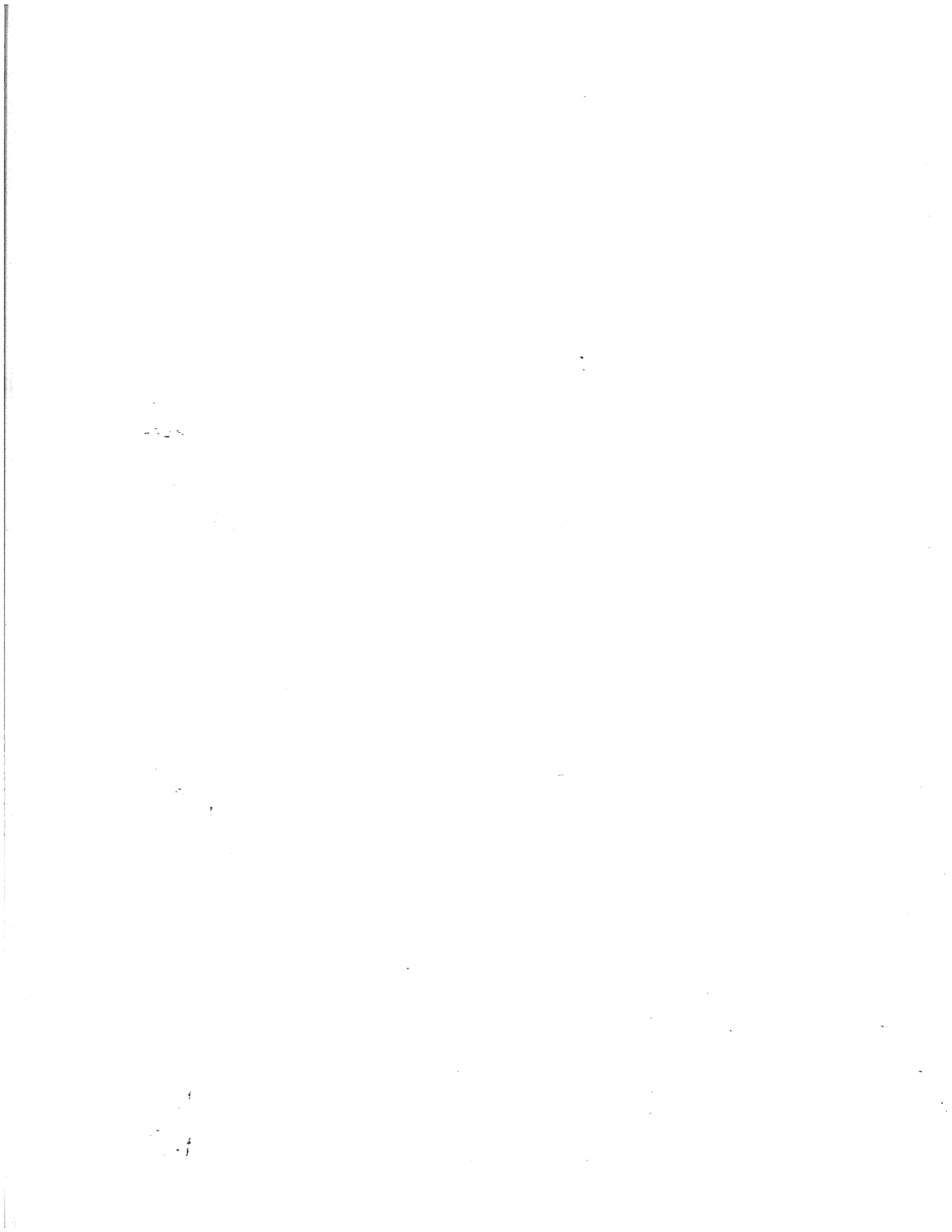


Fig. 5. Temperature profile ($^{\circ}\text{C}$) to a depth of 10 meters at Station 2, Pendrell Sound, June 24 to August 17, 1975.



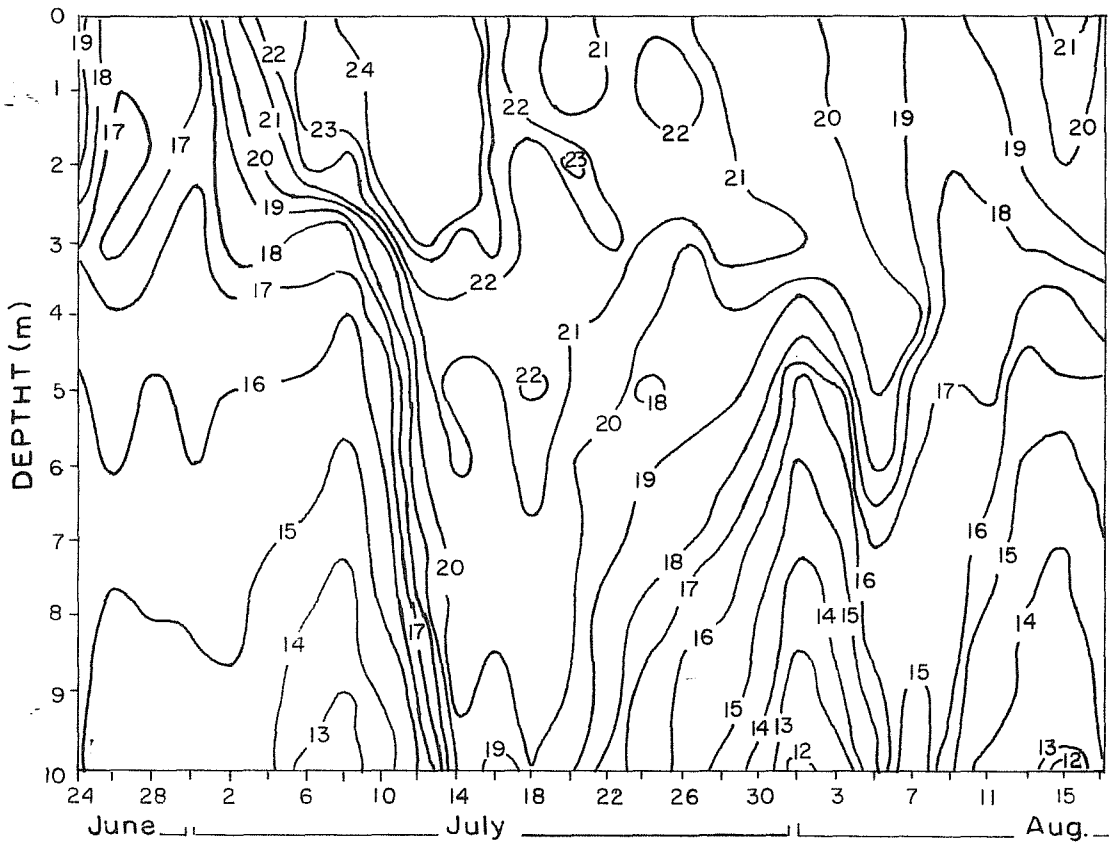
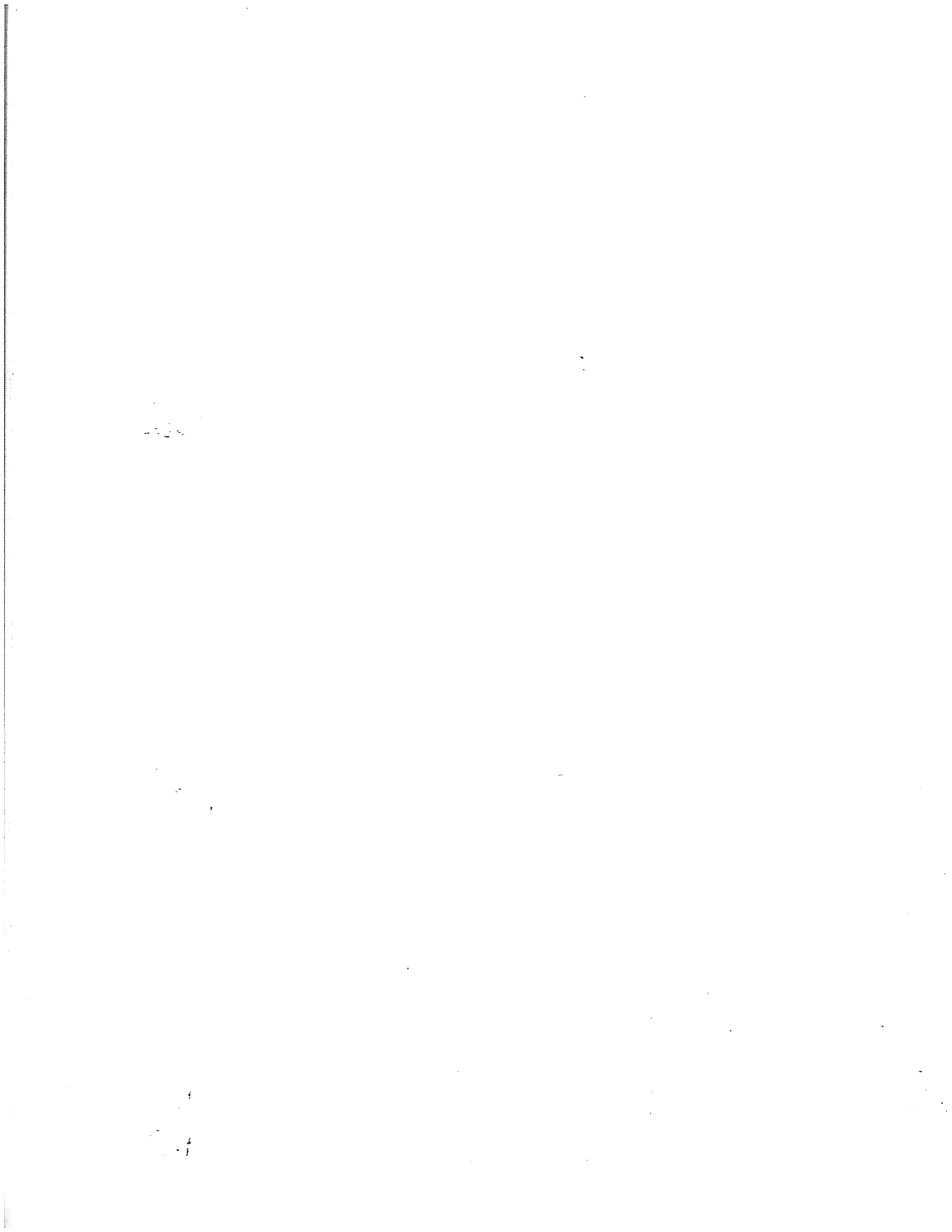


Fig. 6. Temperature profile ($^{\circ}\text{C}$) to a depth of 10 meters at Station 4, Pendrell Sound, June 24 to August 17, 1975.



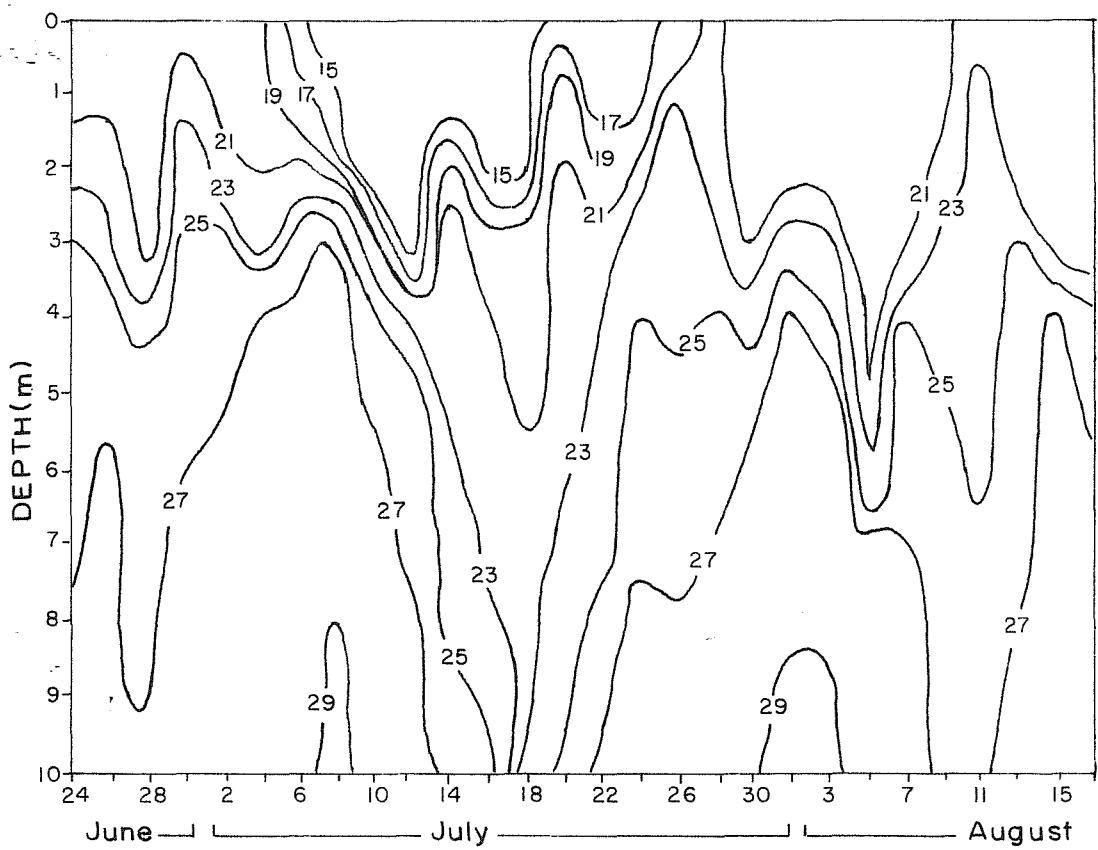


Fig. 7. Salinity profile (‰) to a depth of 10 meters at Station 2, Pendrell Sound, June 24 to August 17, 1975.

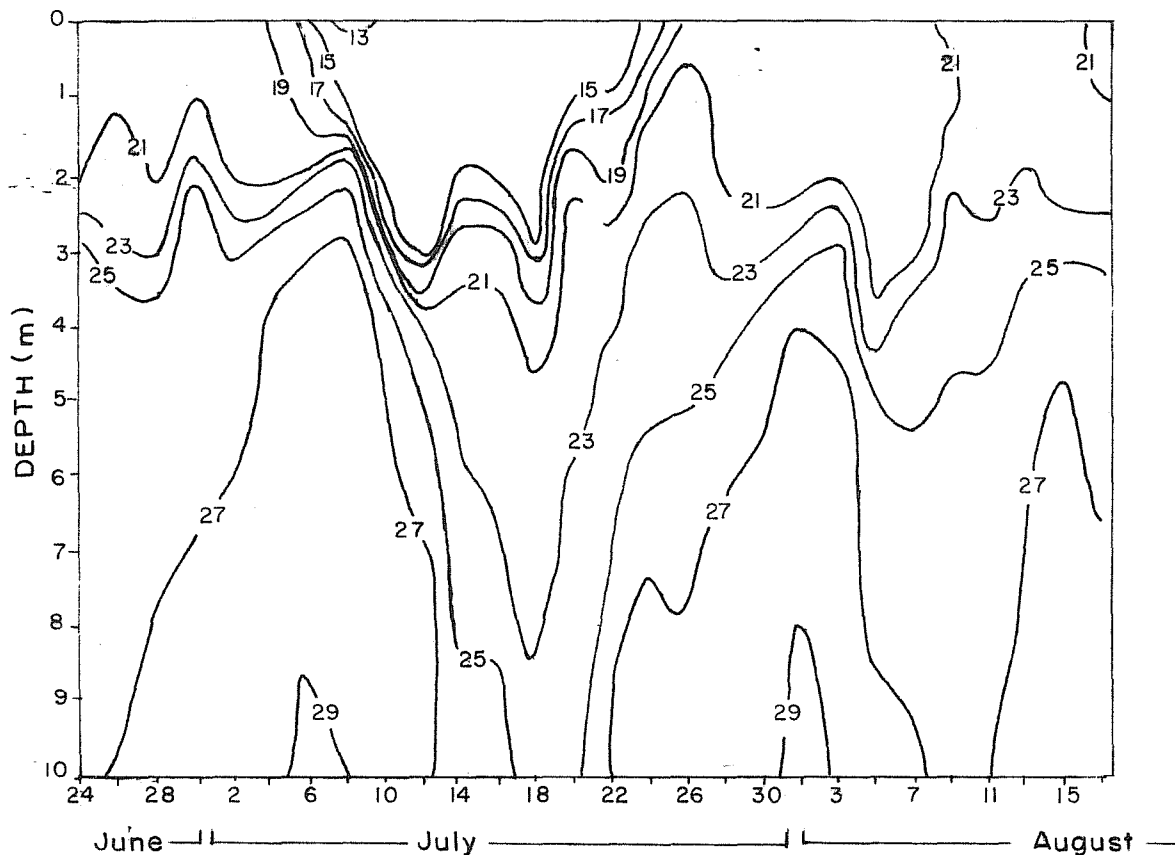
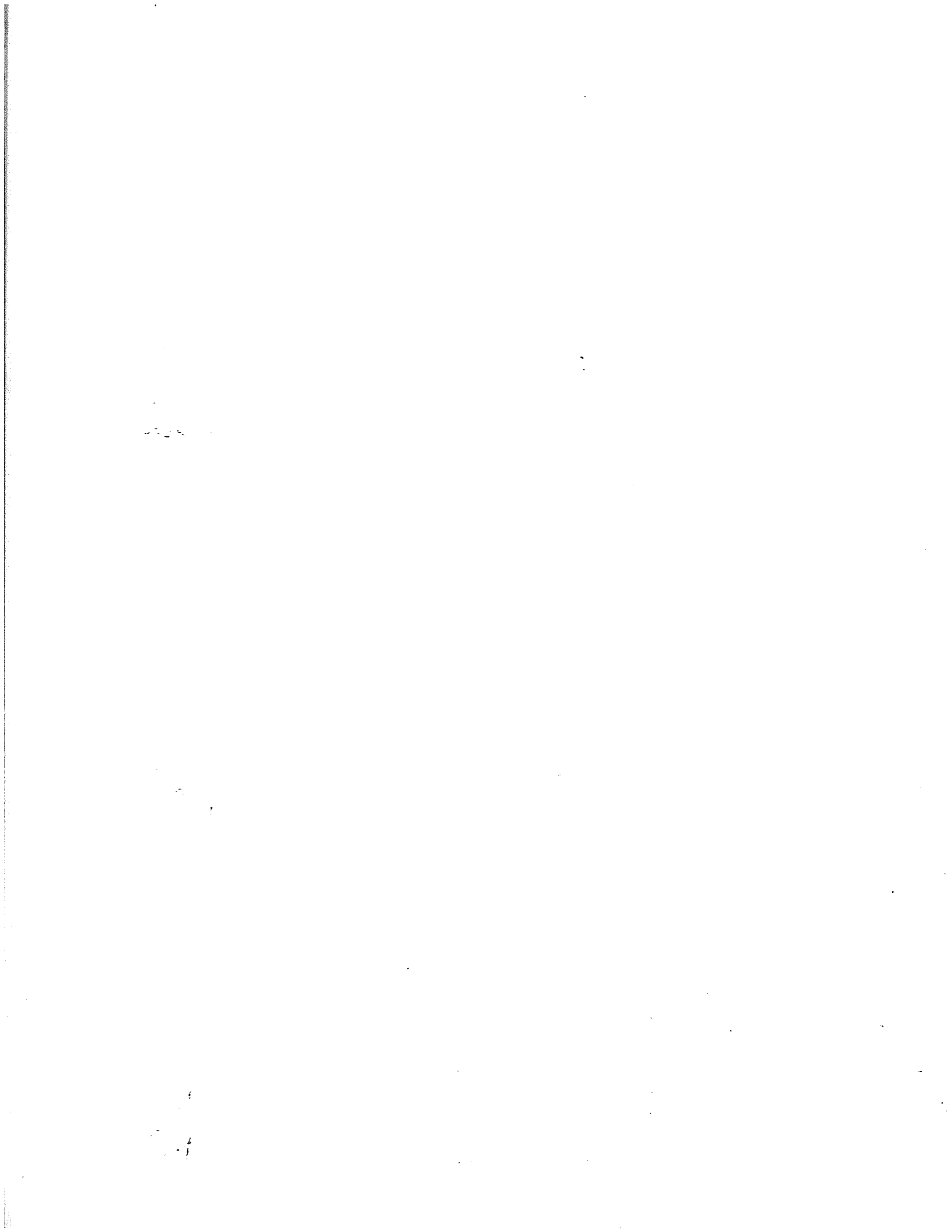


Fig. 8. Salinity profile (‰) to a depth of 10 meters at Station 4, Pendrell Sound, June 24 to August 17, 1975.



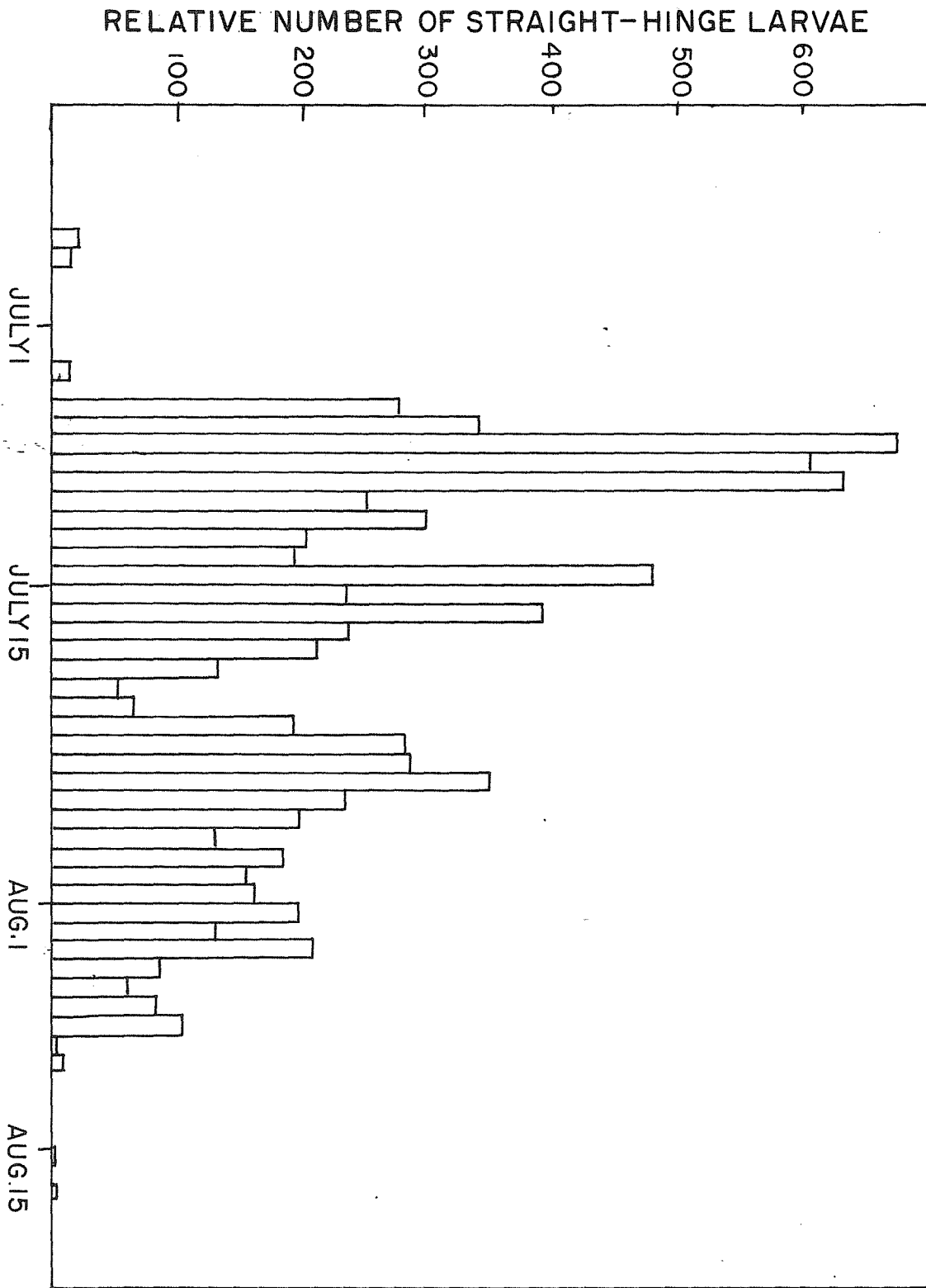


Fig. 9. Relative numbers of straight-hinge oyster larvae observed in evening plankton tows. The data are based on subjective estimates of abundance and have no units.

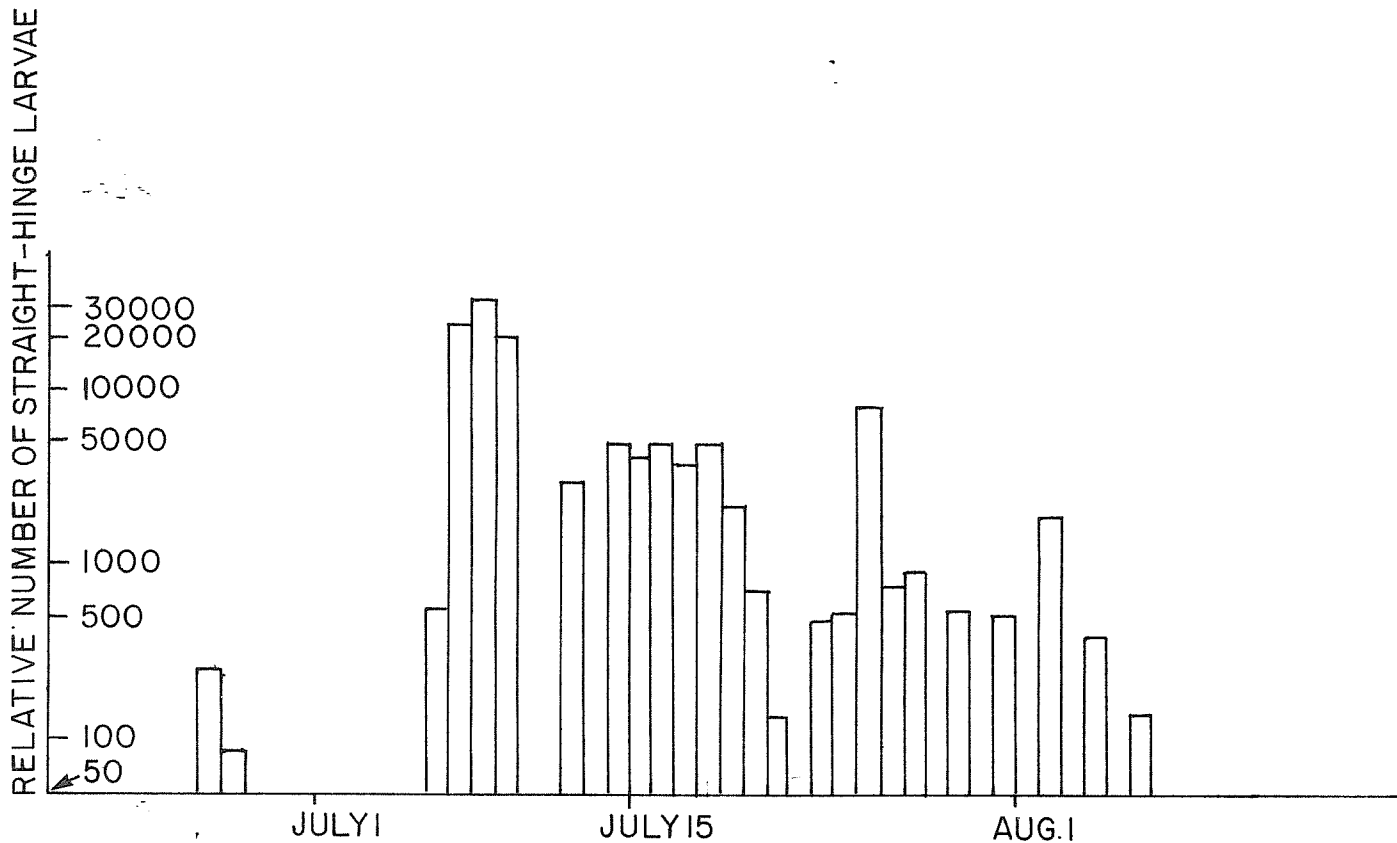


Fig. 10. Relative numbers of straight-hinge oyster larvae observed in pipe samples. The units on the y - axis have no absolute meaning, but are proportional to the total number of straight-hinge larvae in the Sound. Note log scale.

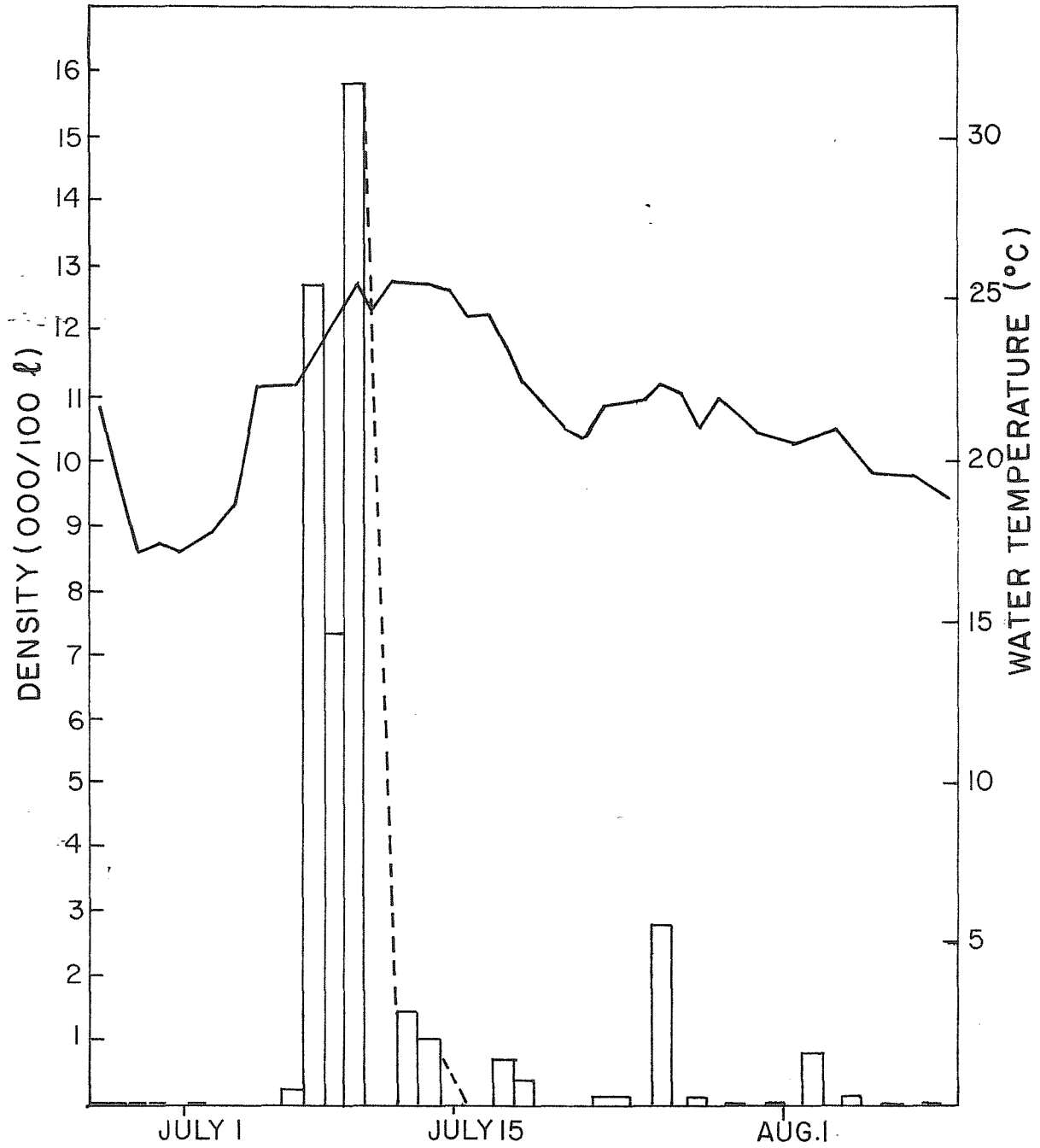
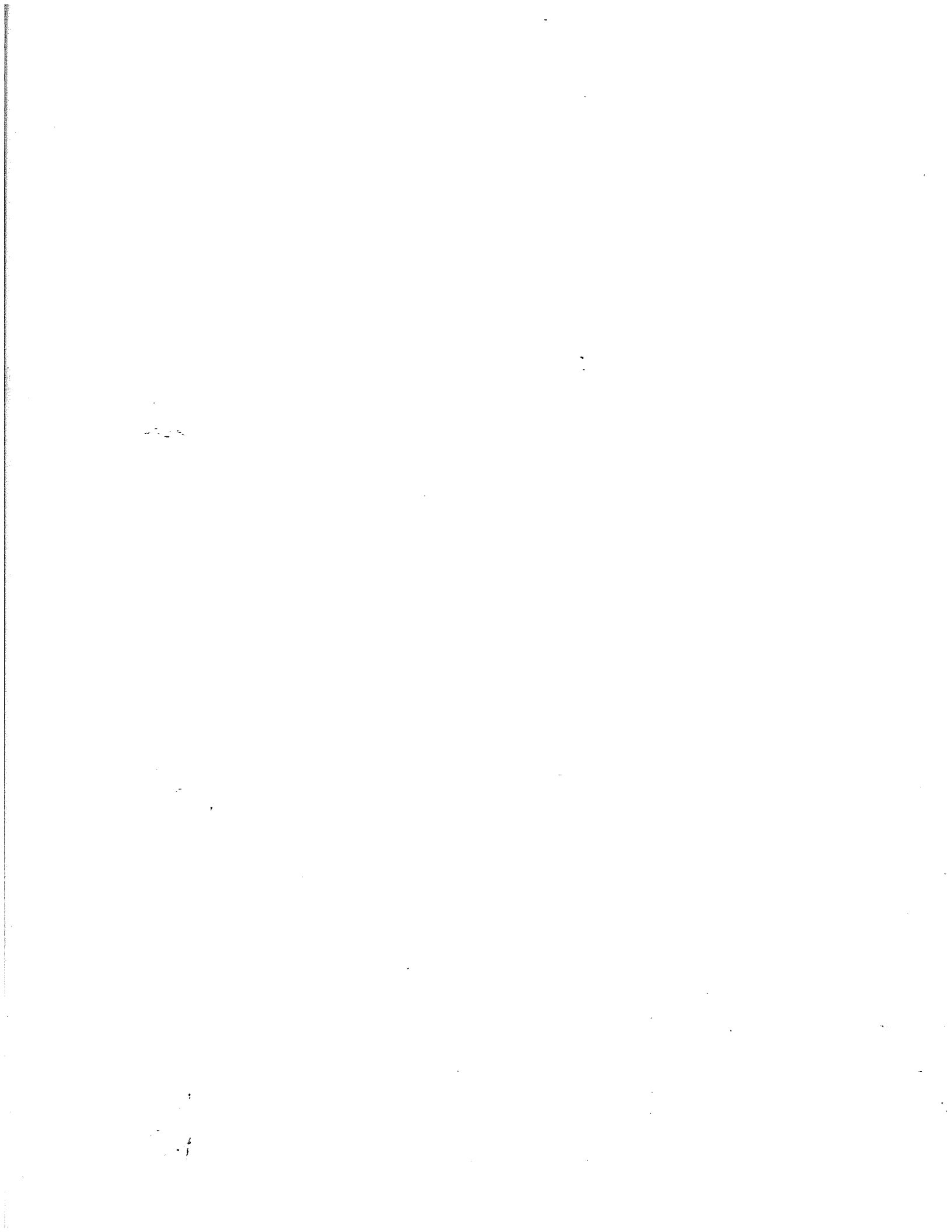


Fig. 11. Density of straight-hinge oyster larvae observed in pipe samples along transect 1, compared with surface temperature observed at station 1 two days previously.



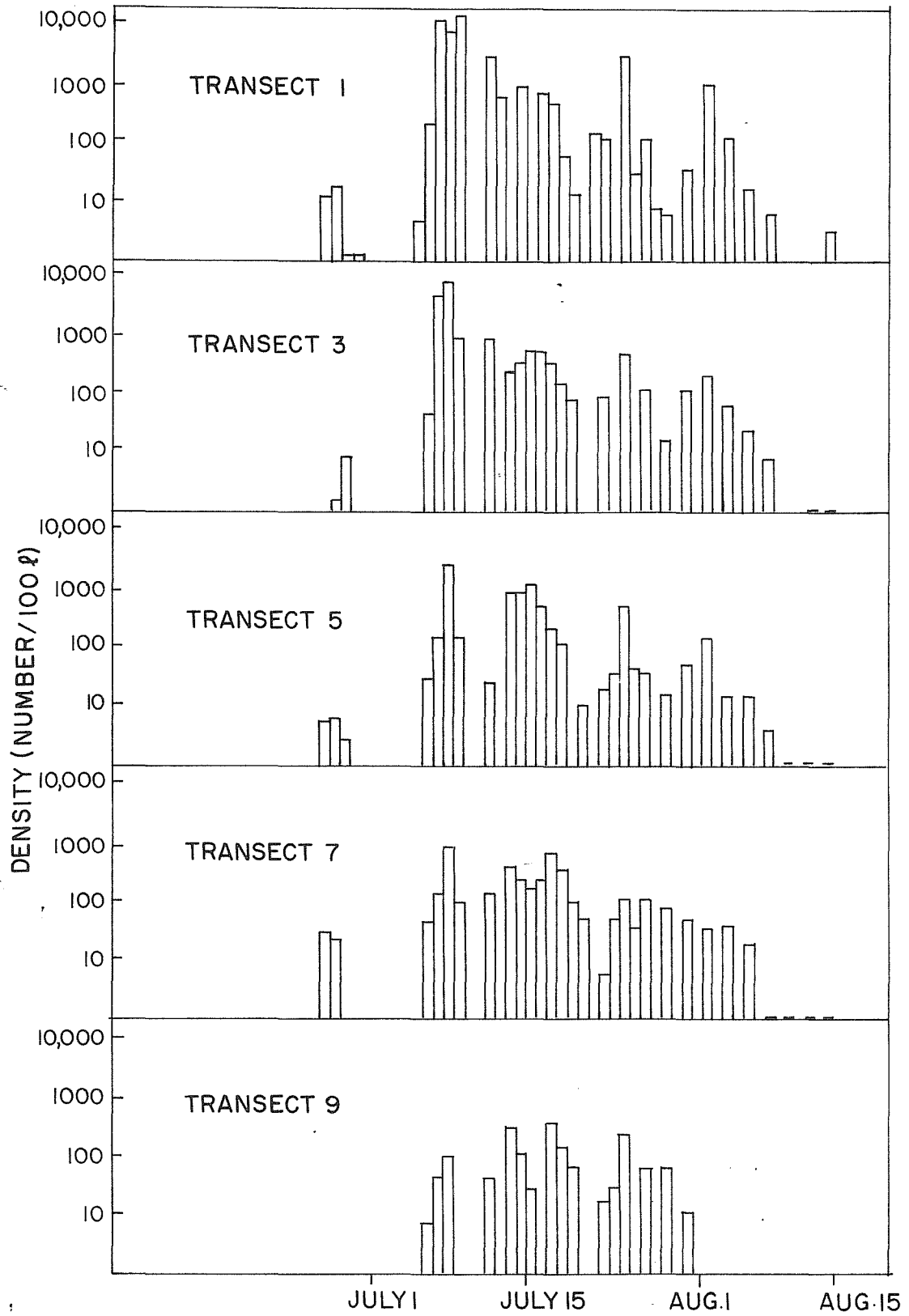
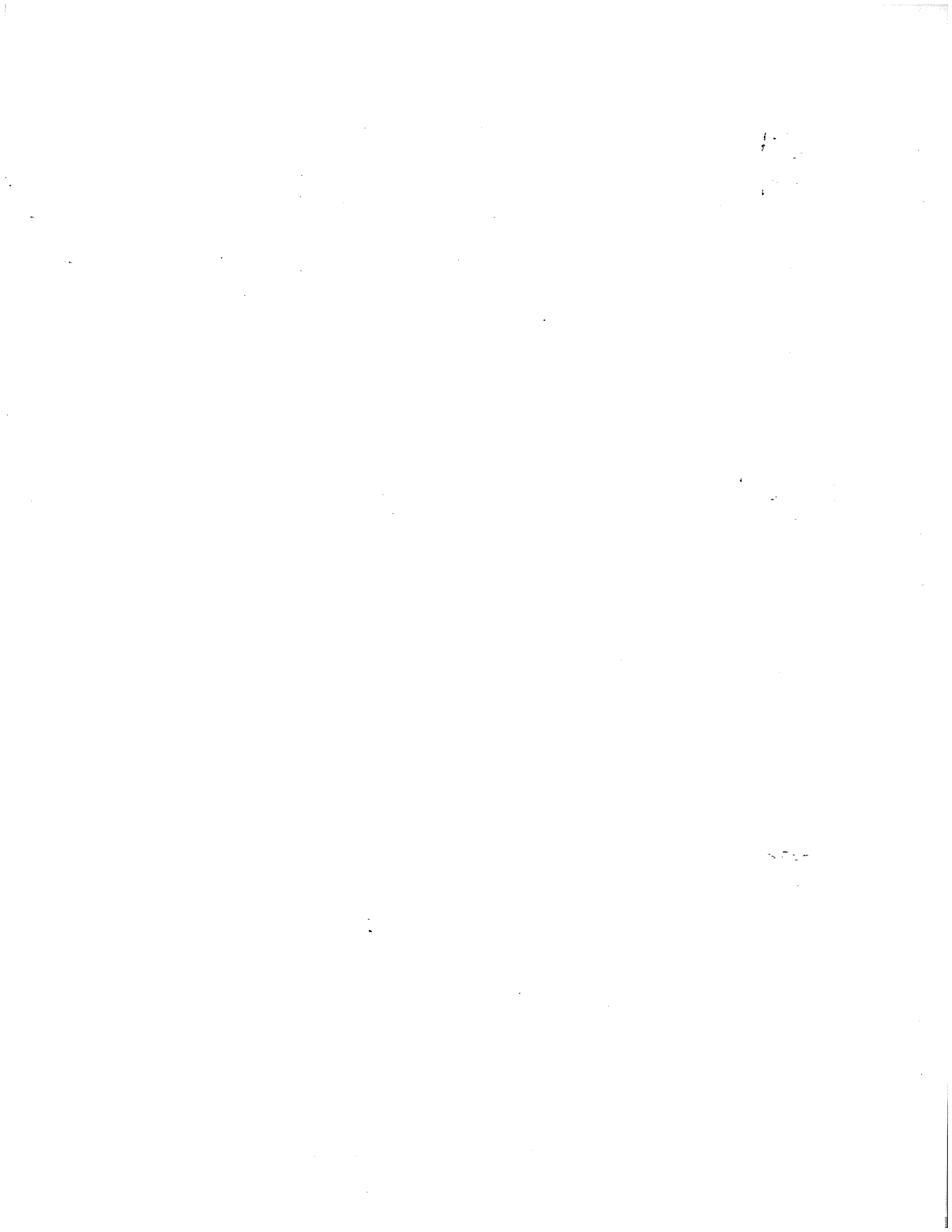


Fig. 12. Density of straight-hinge oyster larvae observed in pipe samples along various transects. Note log scale.



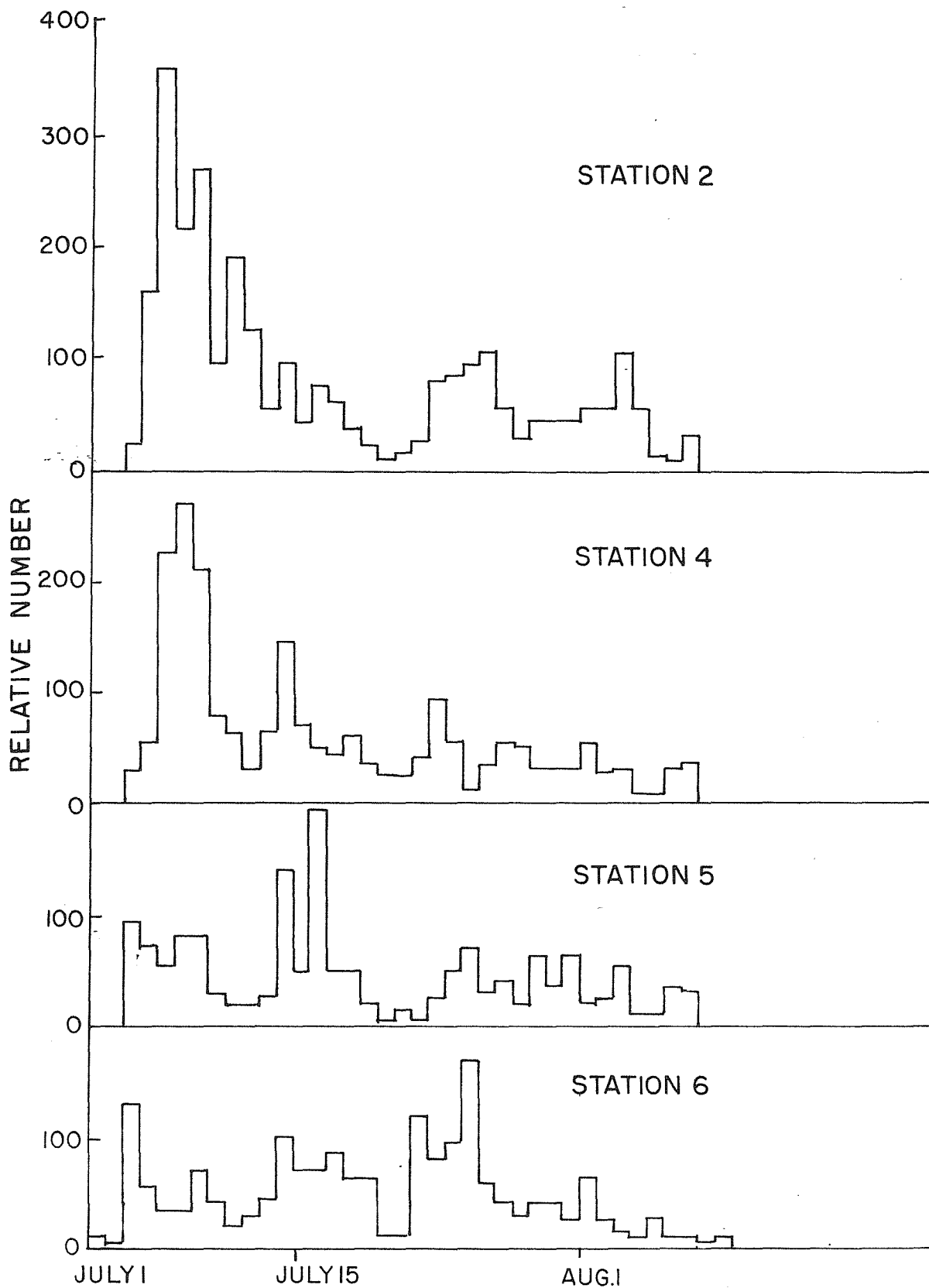


Fig. 13. Relative numbers of straight-hinge oyster larvae observed in evening plankton tows at stations 2, 4, 5 and 6.

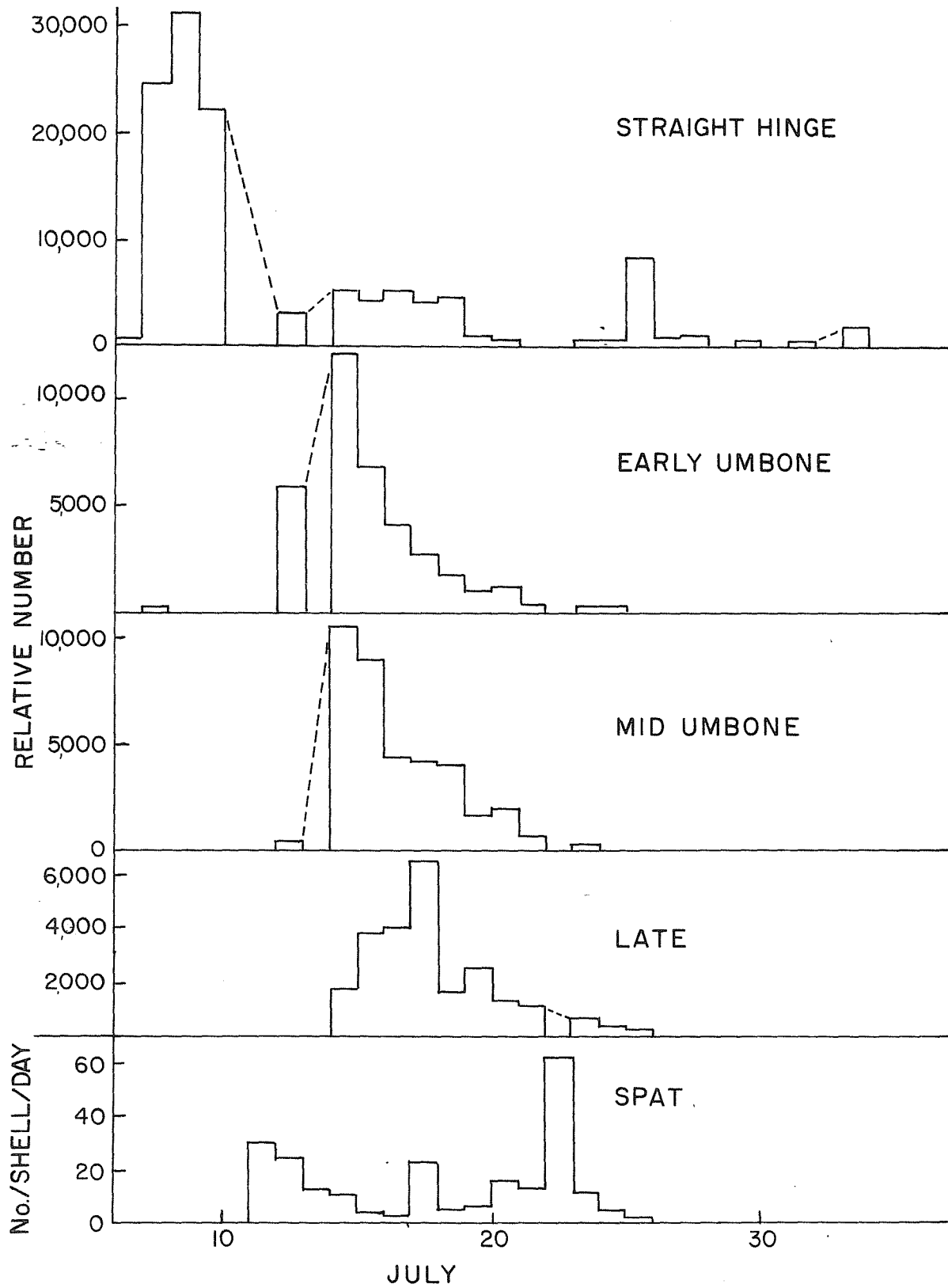


Fig. 14. The relative number of each stage of oyster larvae observed in pipe samples in the whole Sound. Note log scale and changes in scale. Daily spatfall was observed at the VELELLA.

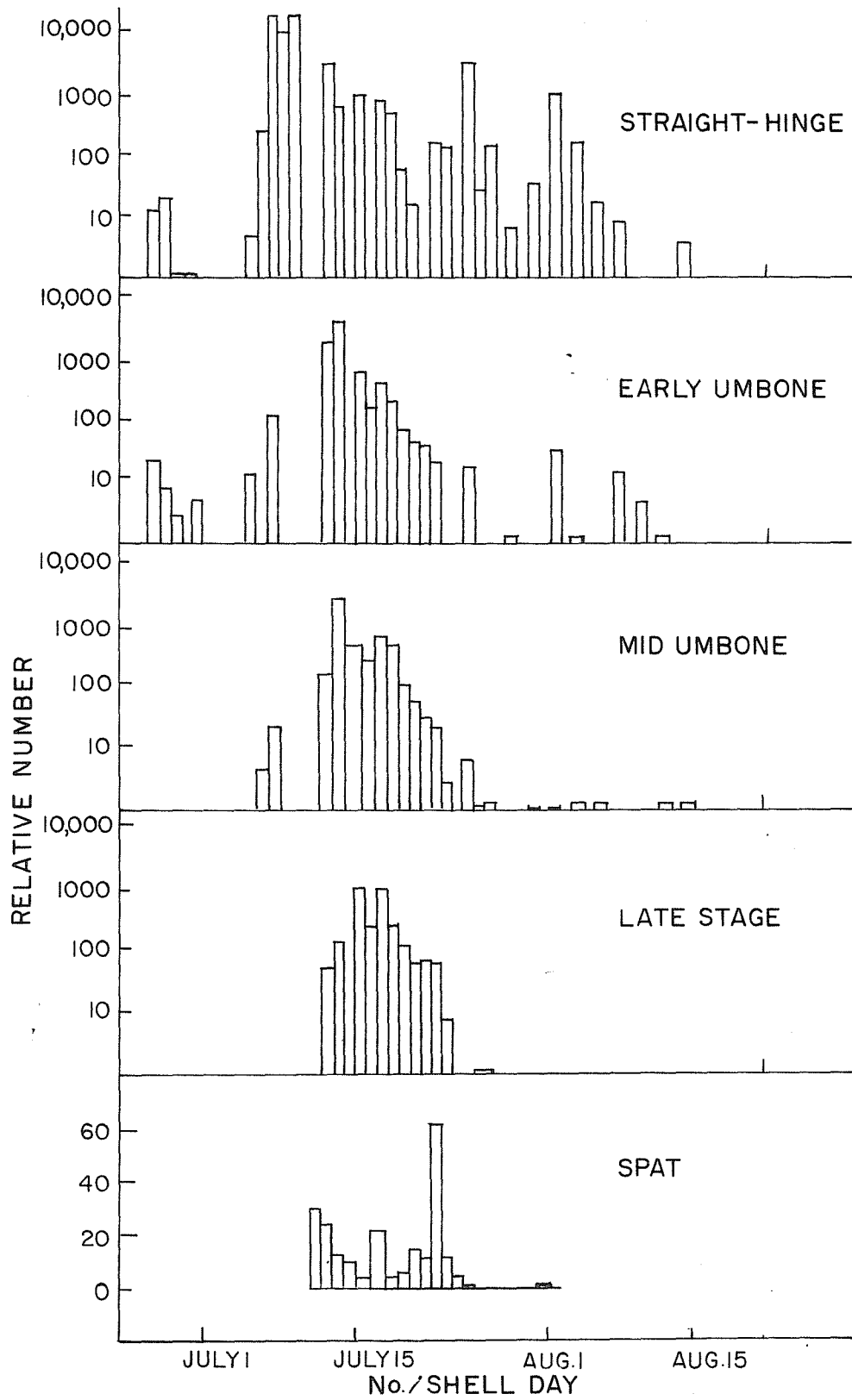
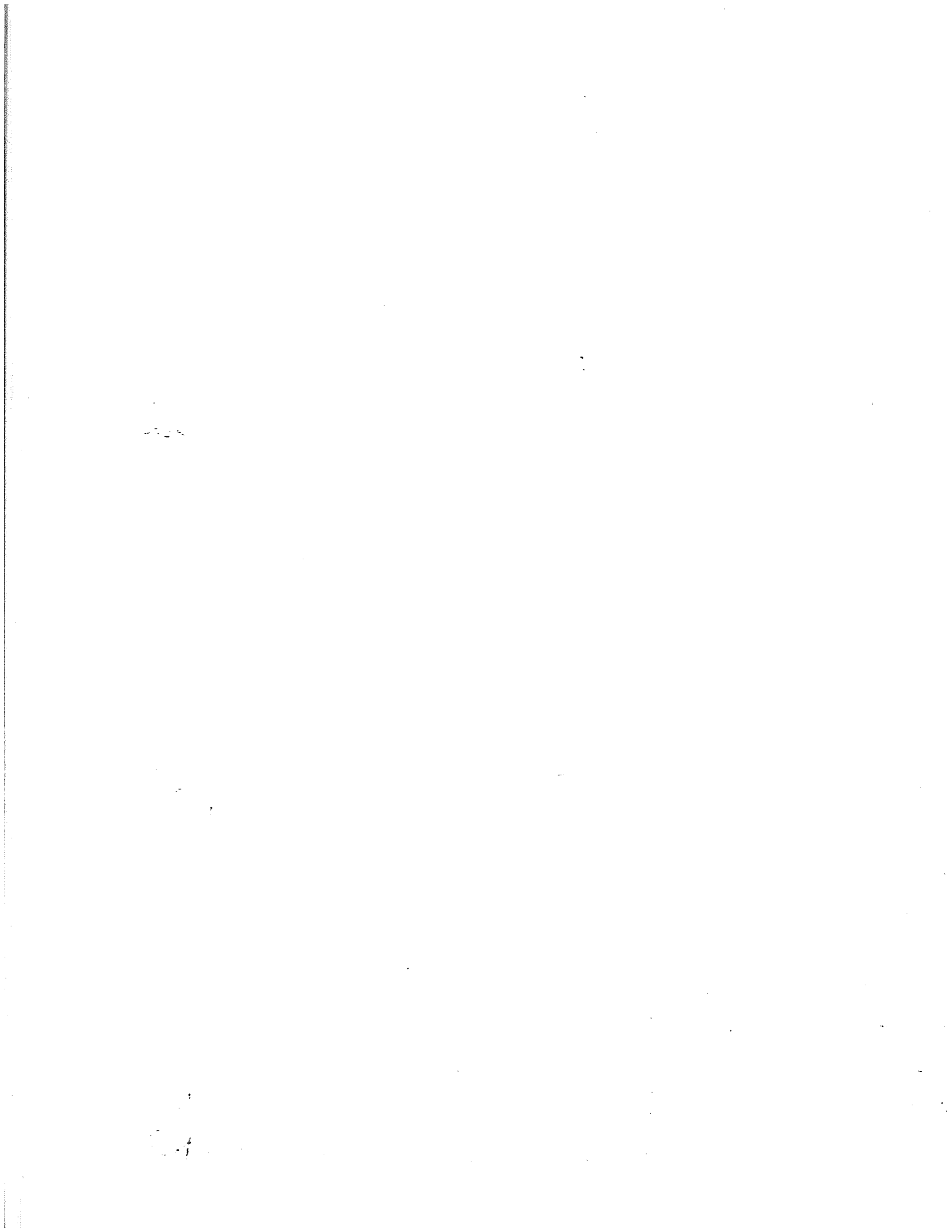


Fig. 15. Relative numbers of oyster larvae observed in pipe samples along transect 1. Note log scale. Daily spatfall was observed at the VELELLA.



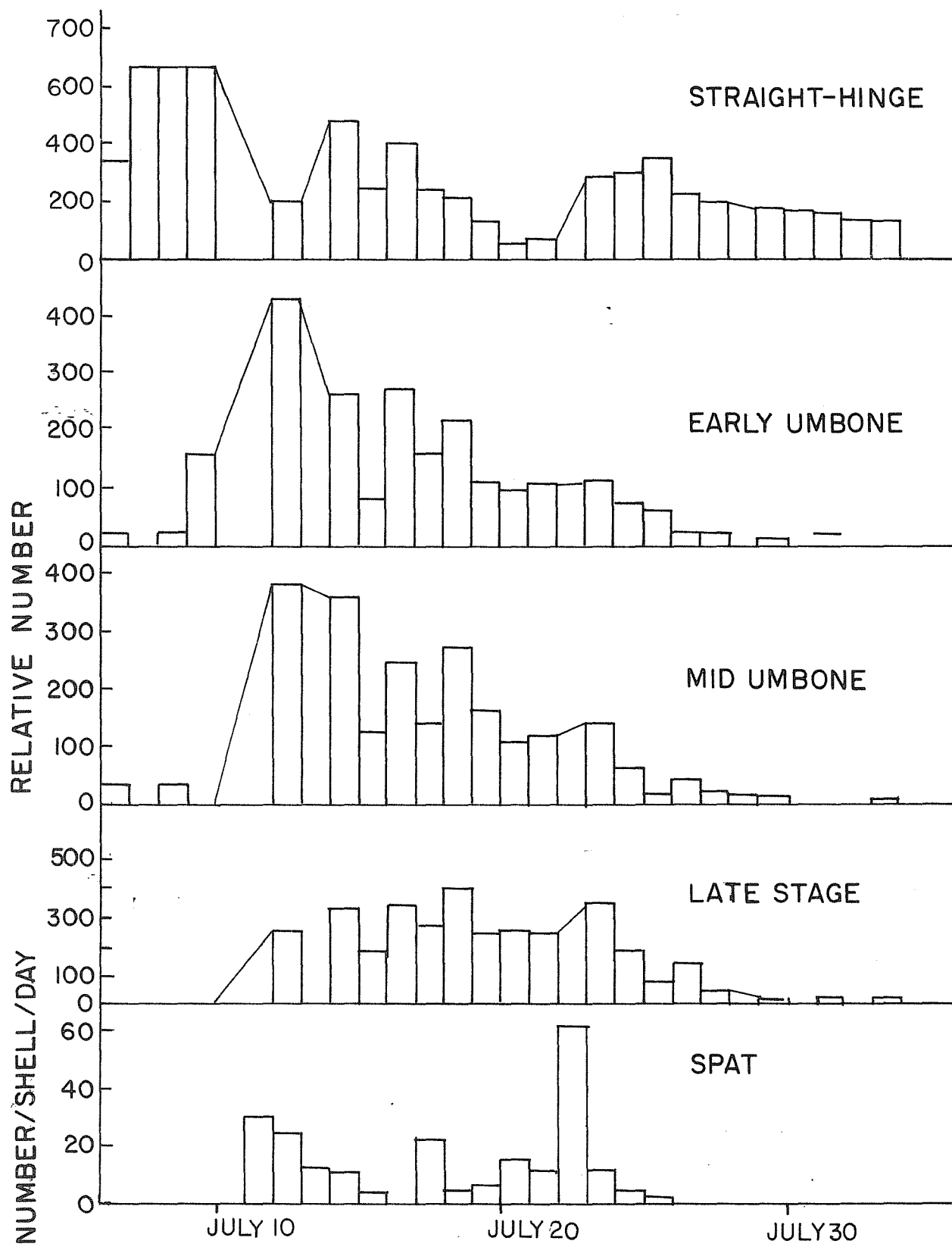
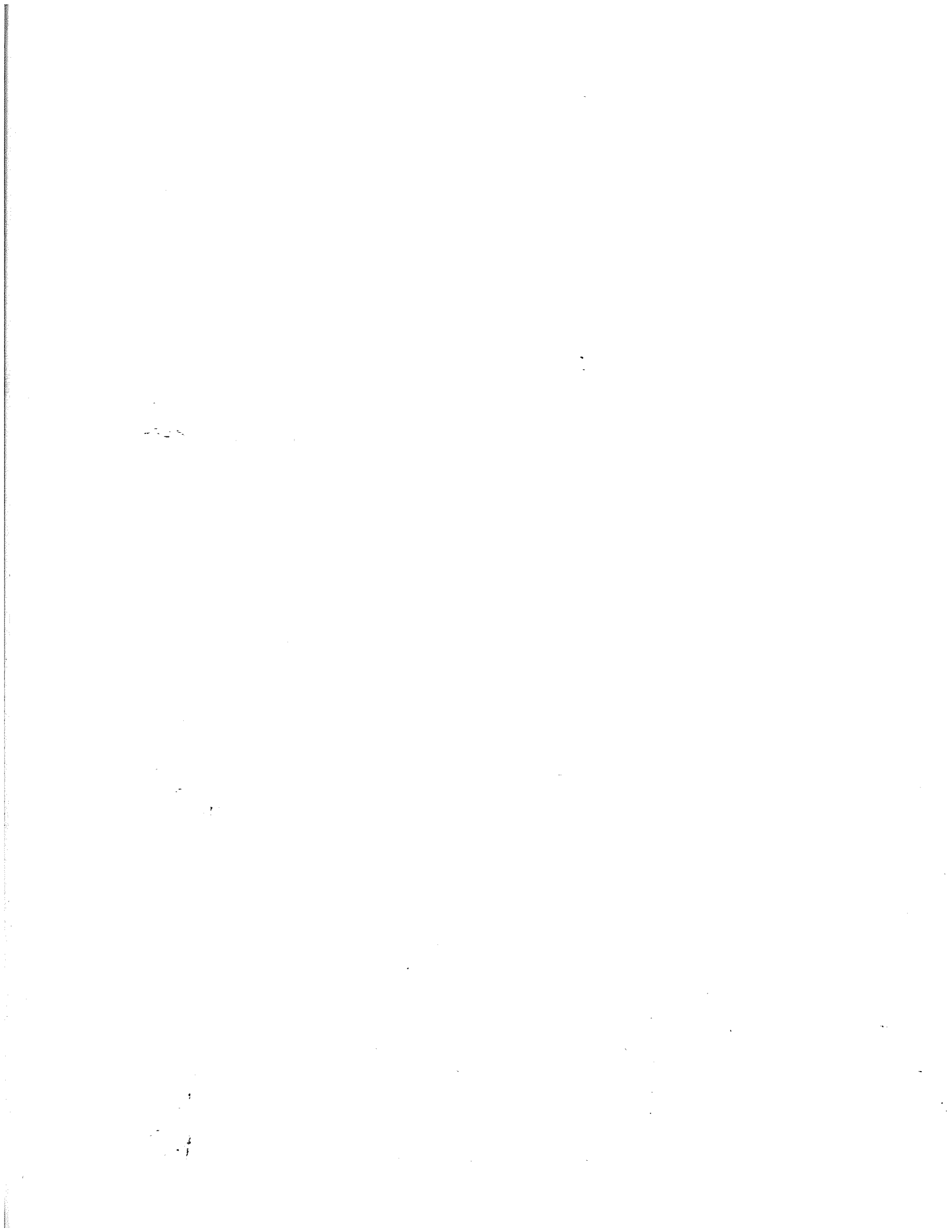


Fig. 16. Relative numbers of each stage of oyster larvae observed in evening plankton tows at four stations (combined). Note changes of scale. Spat were observed at the VELELLA.



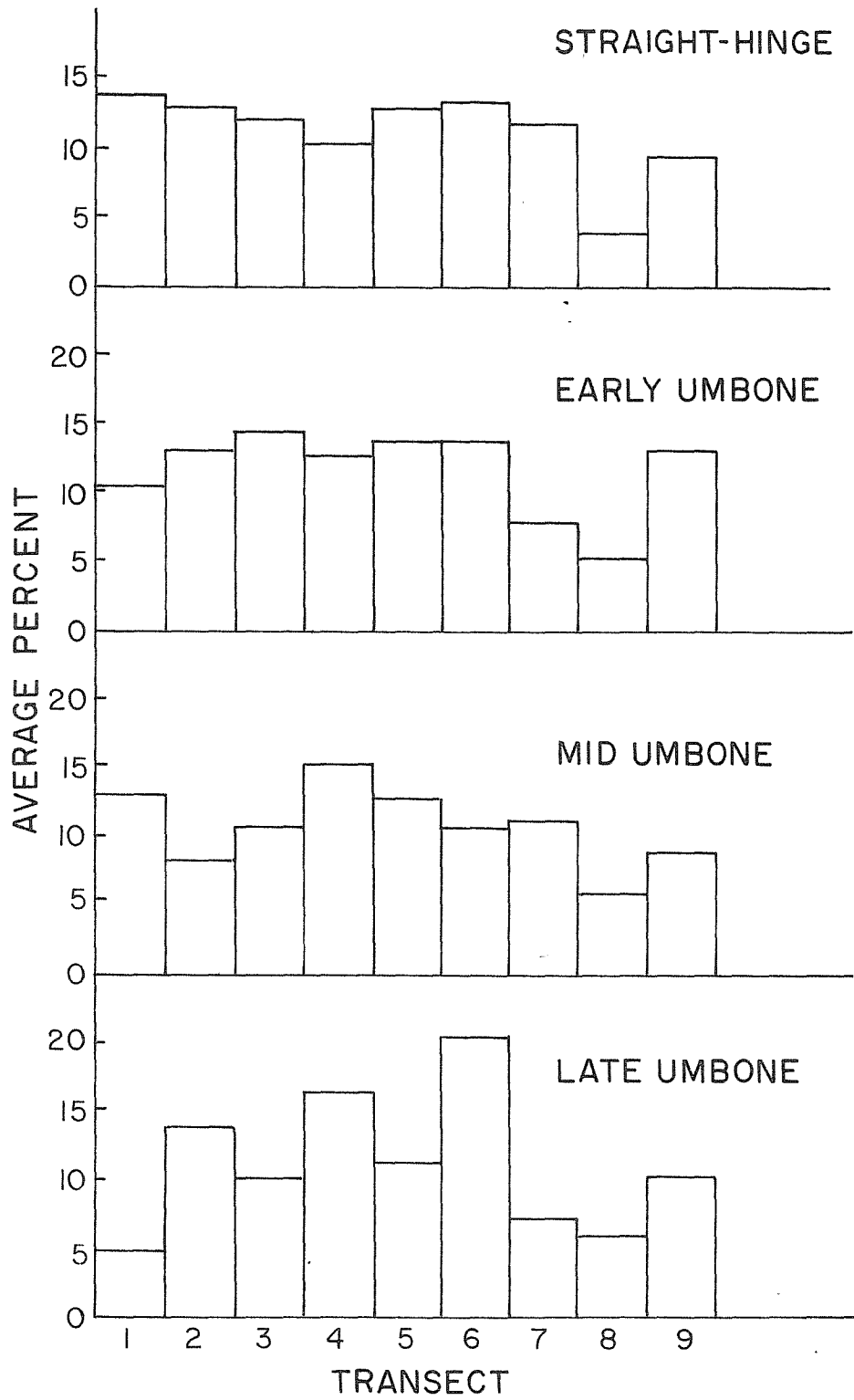


Fig. 17. The average percentage, over the summer, of the total number of larvae found in each part of the Sound.

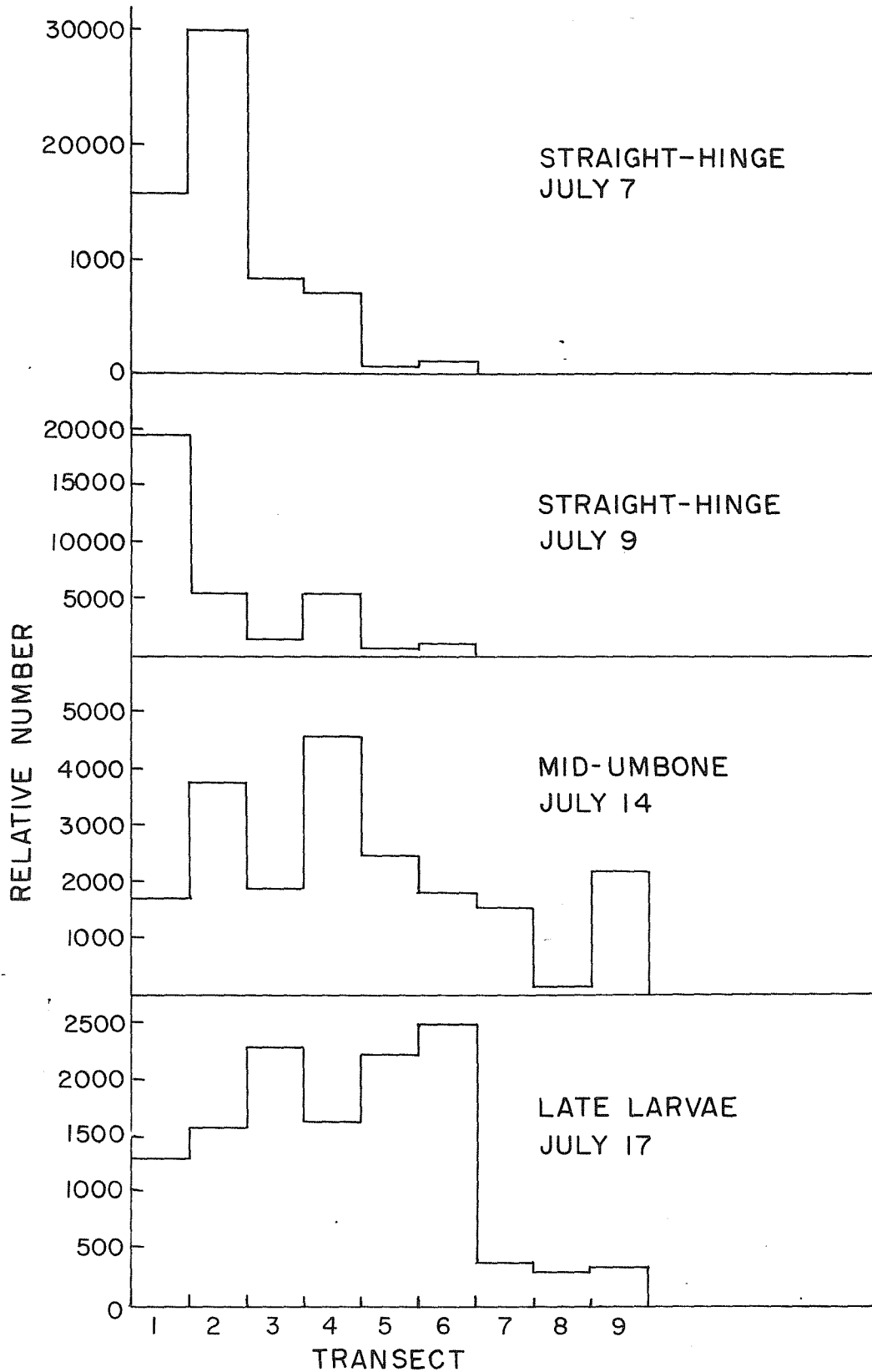
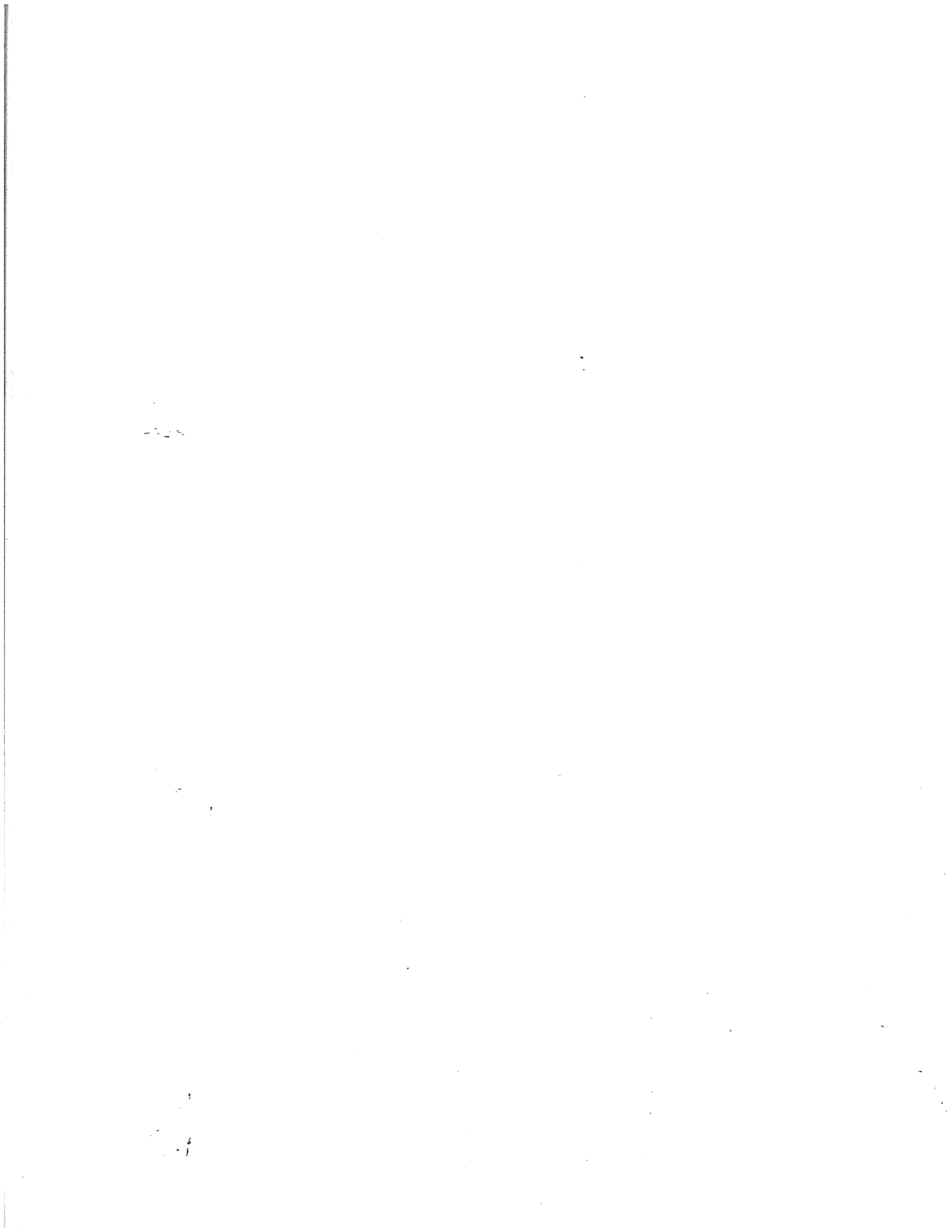


Fig. 18. Relative abundance of larvae in each part of the Sound, determined from pipe sample data, on days when each stage of larva was at its peak of abundance. Note changes in scale.



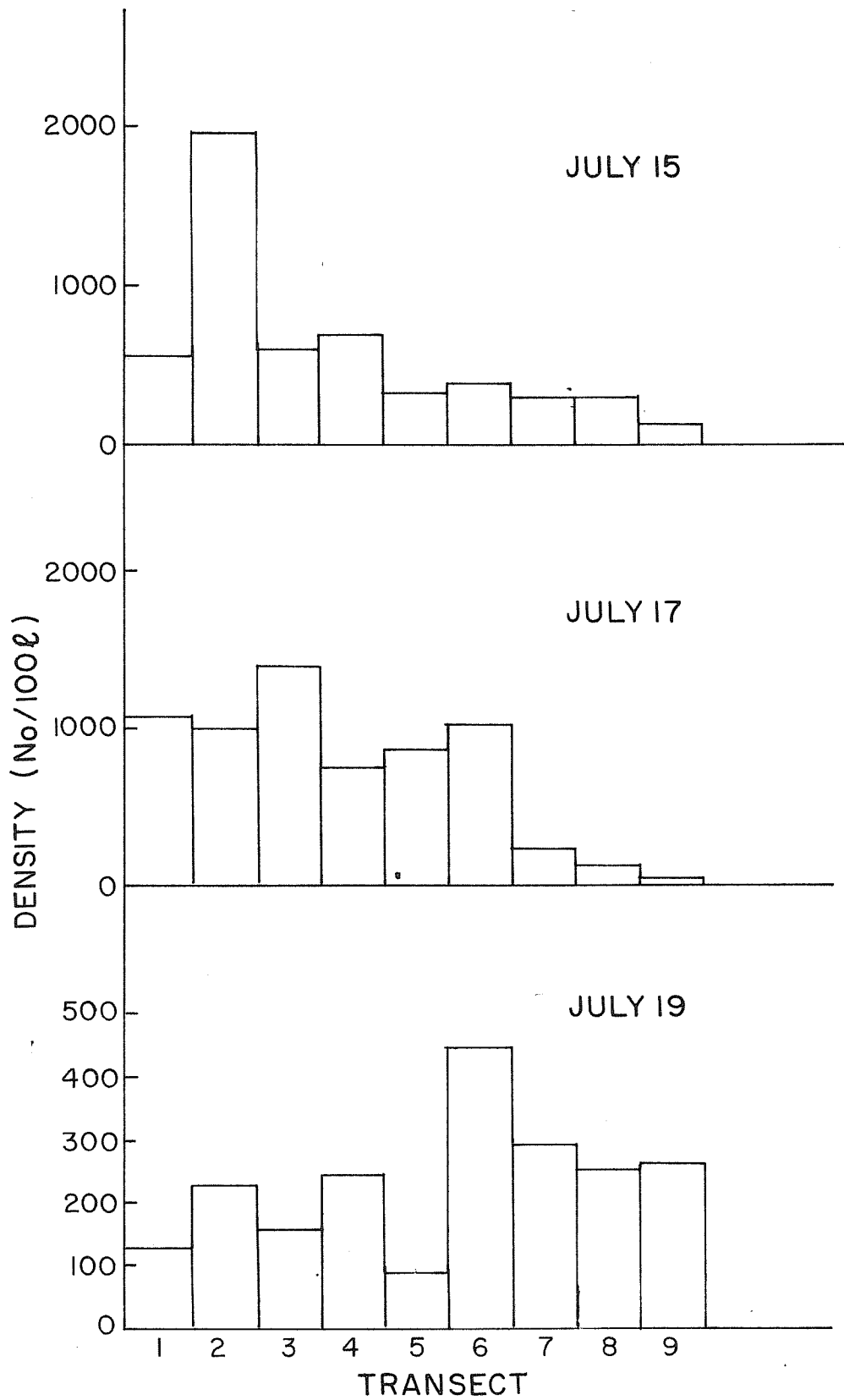
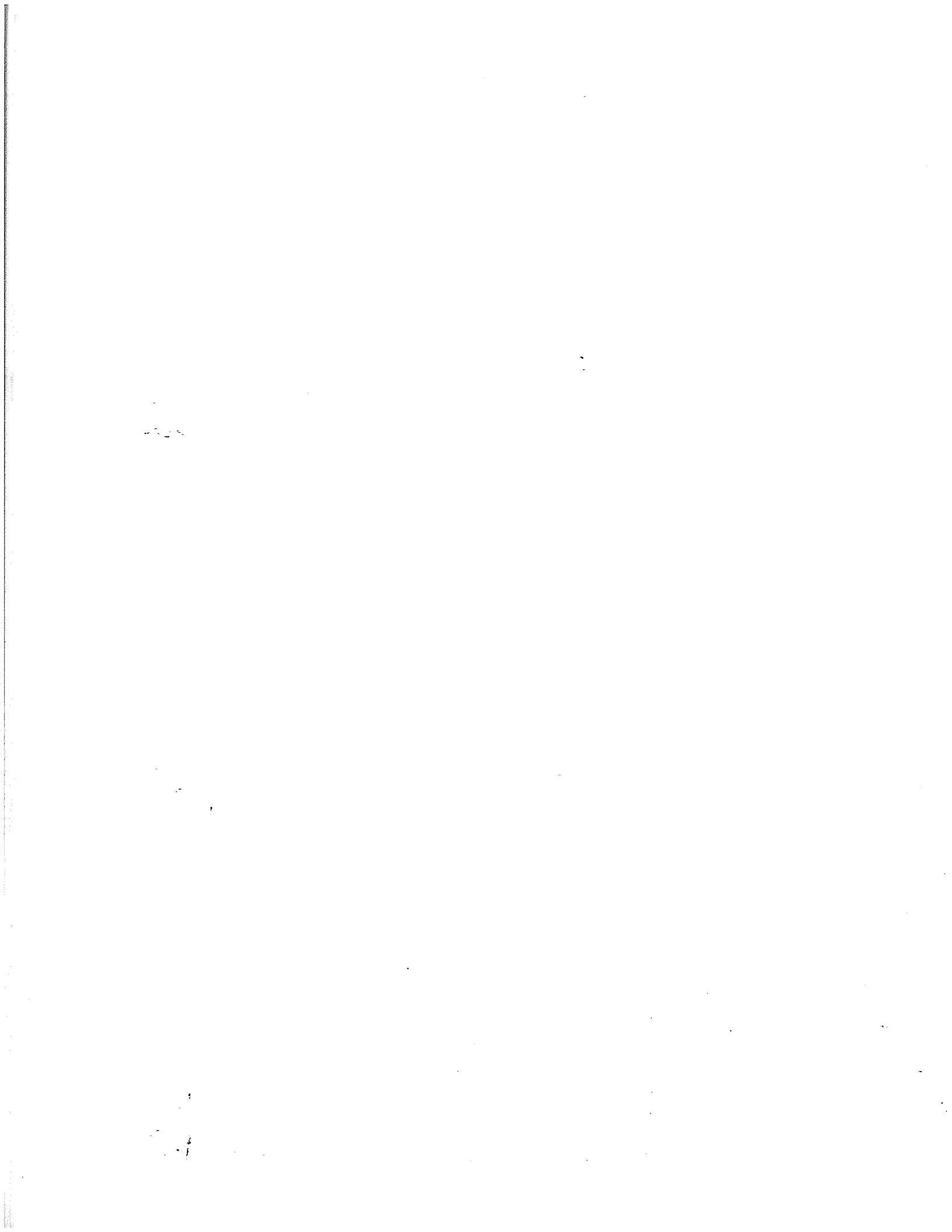


Fig. 19. Density of late stage larvae in pipe samples in various parts of the Sound on 3 days when late stage larvae were very abundant. Note change in scale.



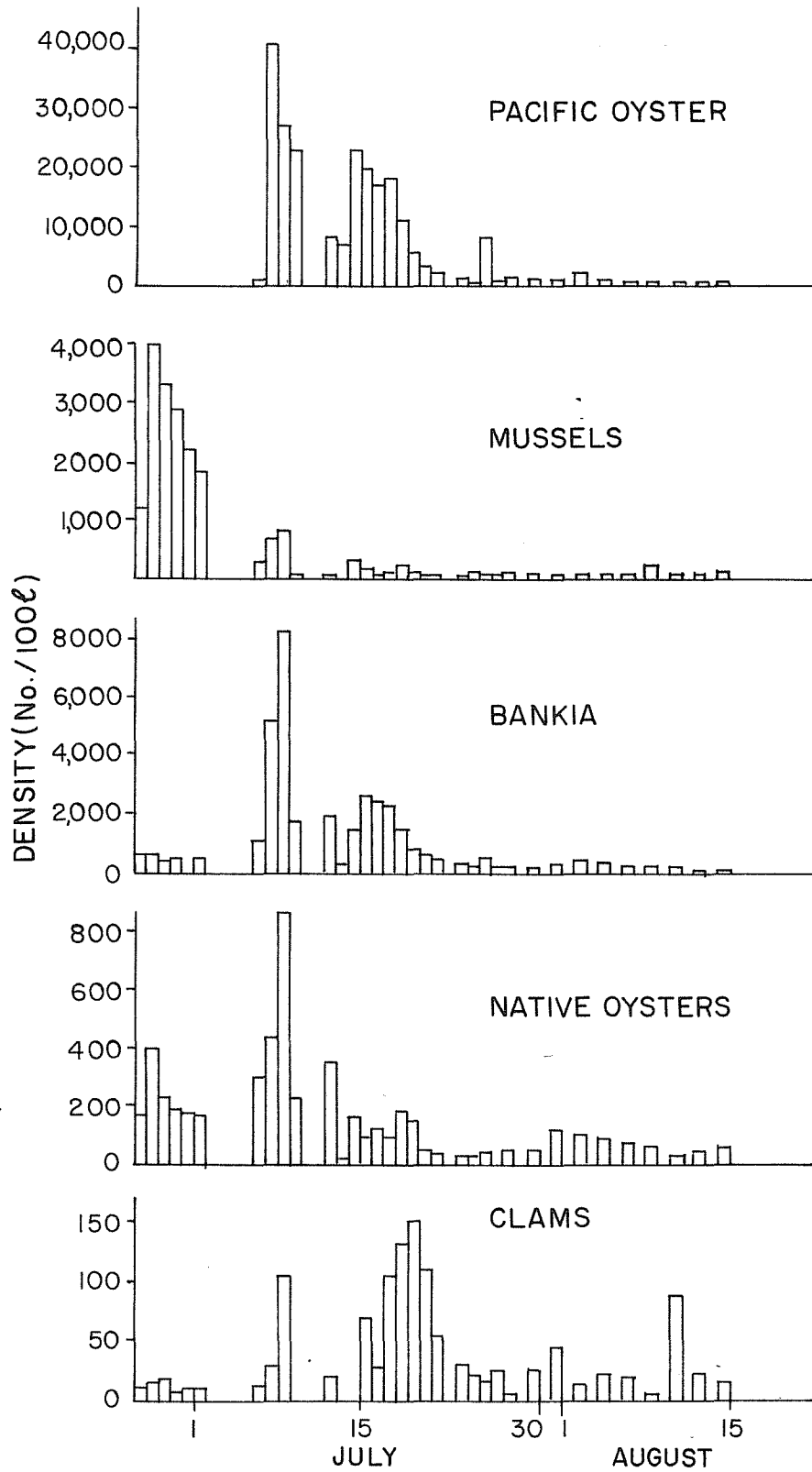
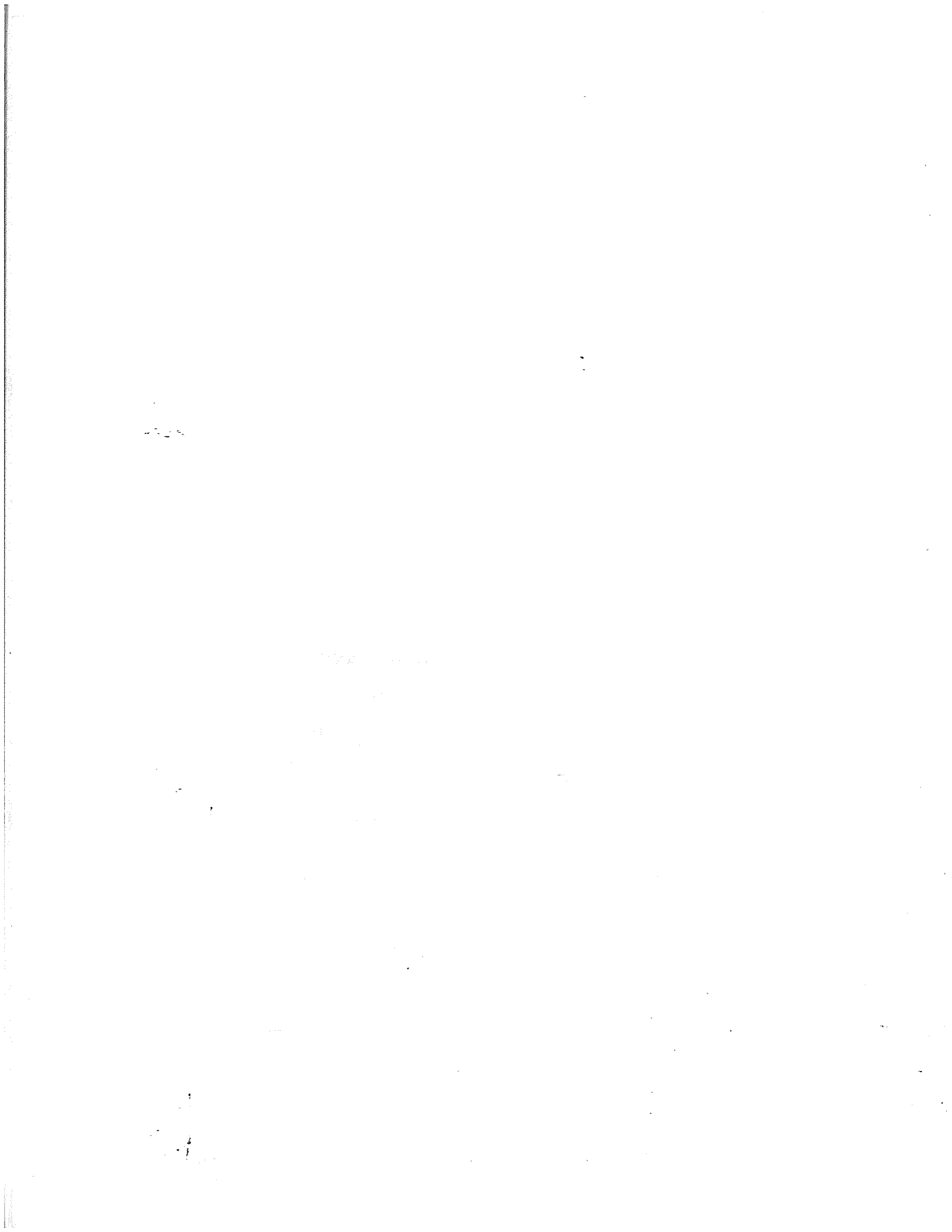


Fig. 20. Average density of all species of larvae observed in pipe samples. Note changes in scale.



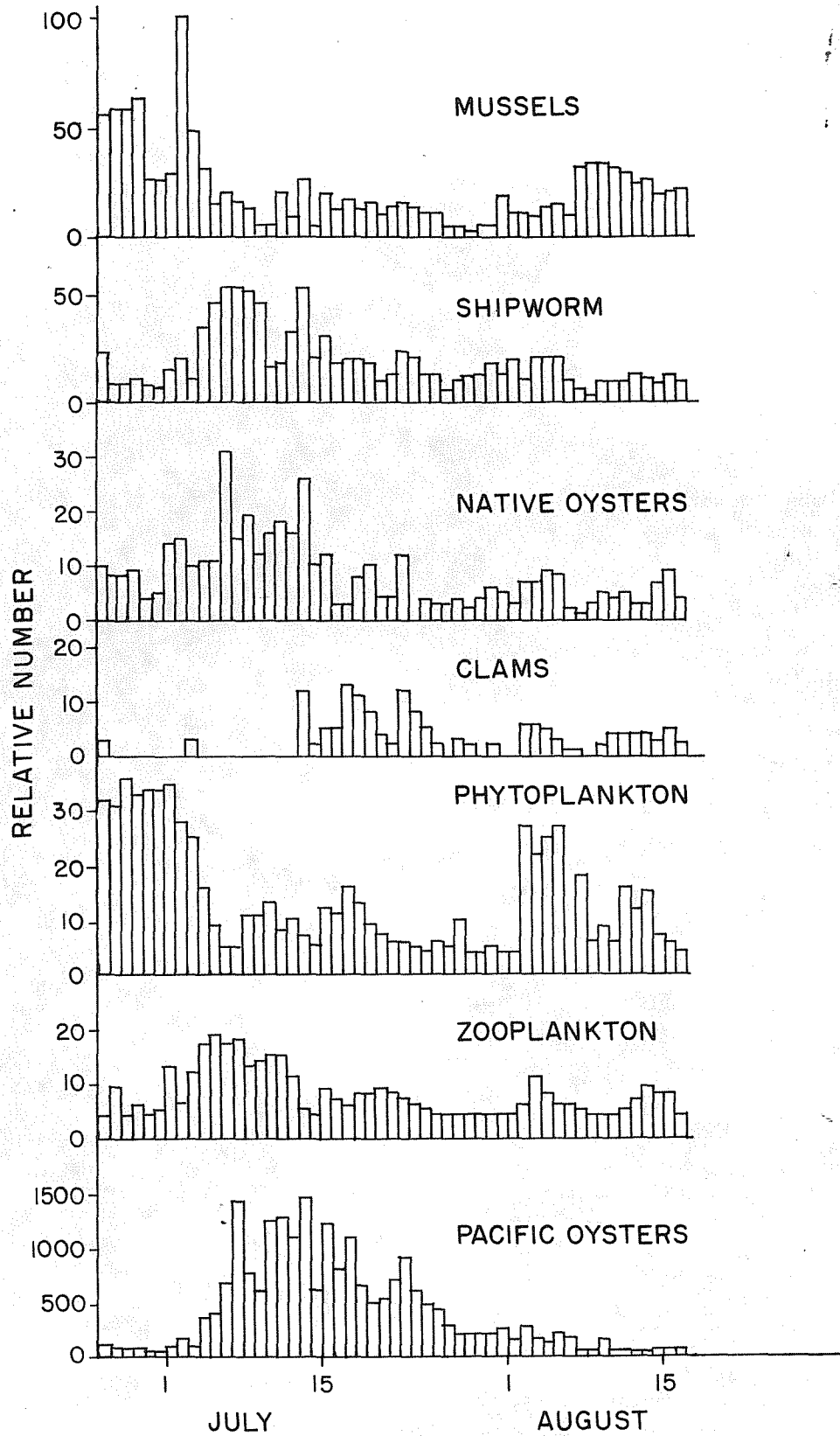
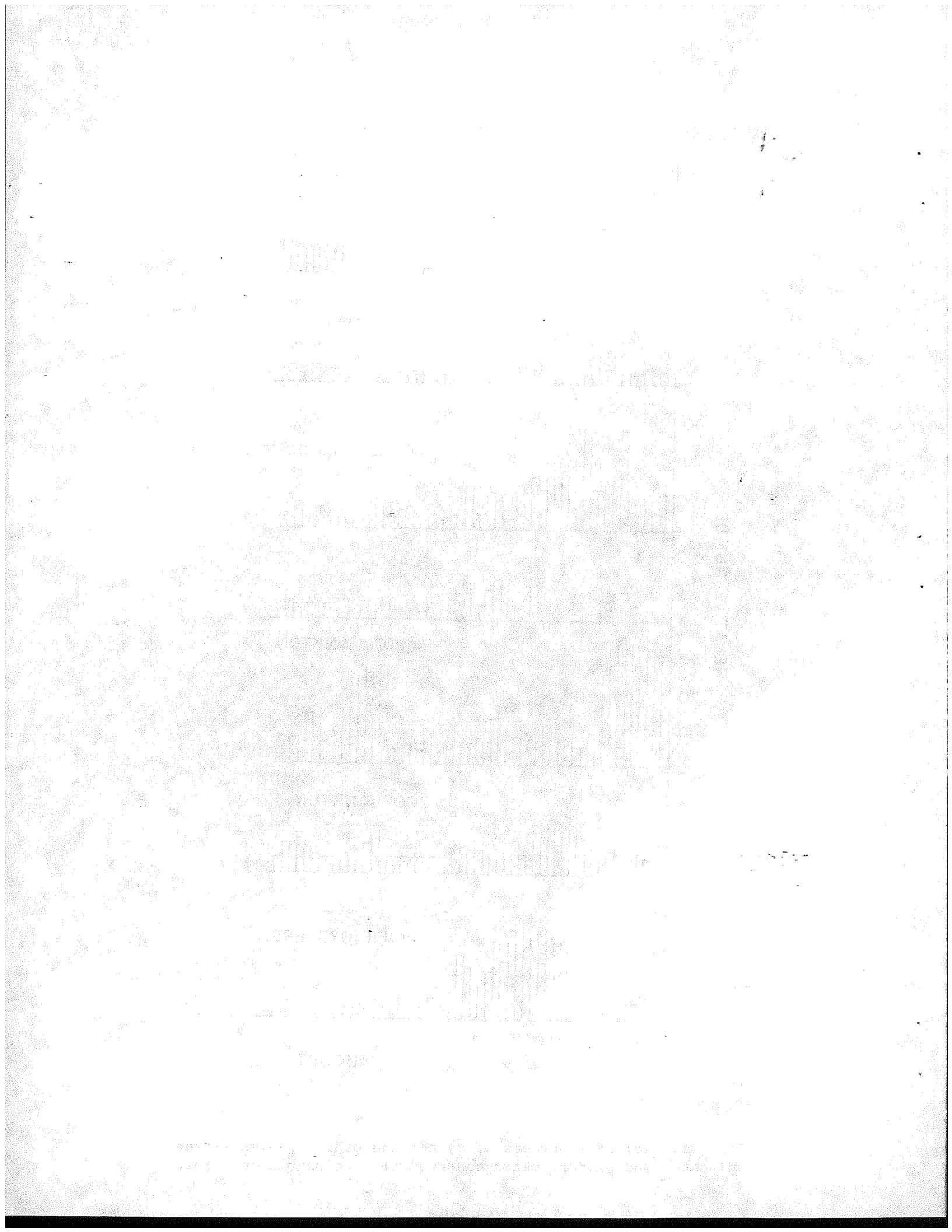


Fig. 21. Relative numbers of oyster and other bivalve larvae, zooplankton and phytoplankton observed in evening plankton tows.



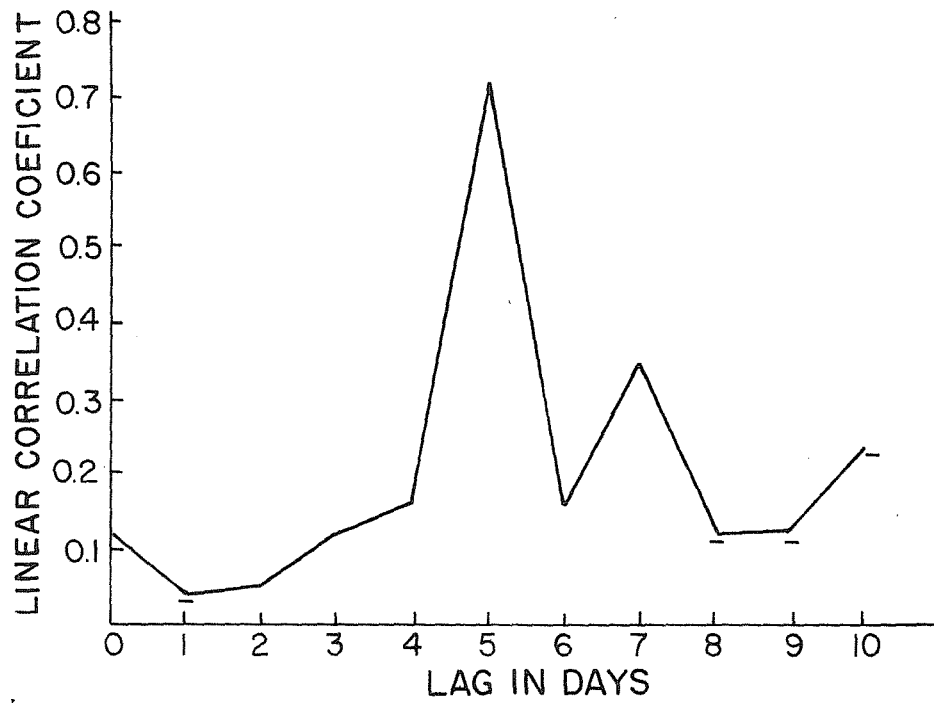
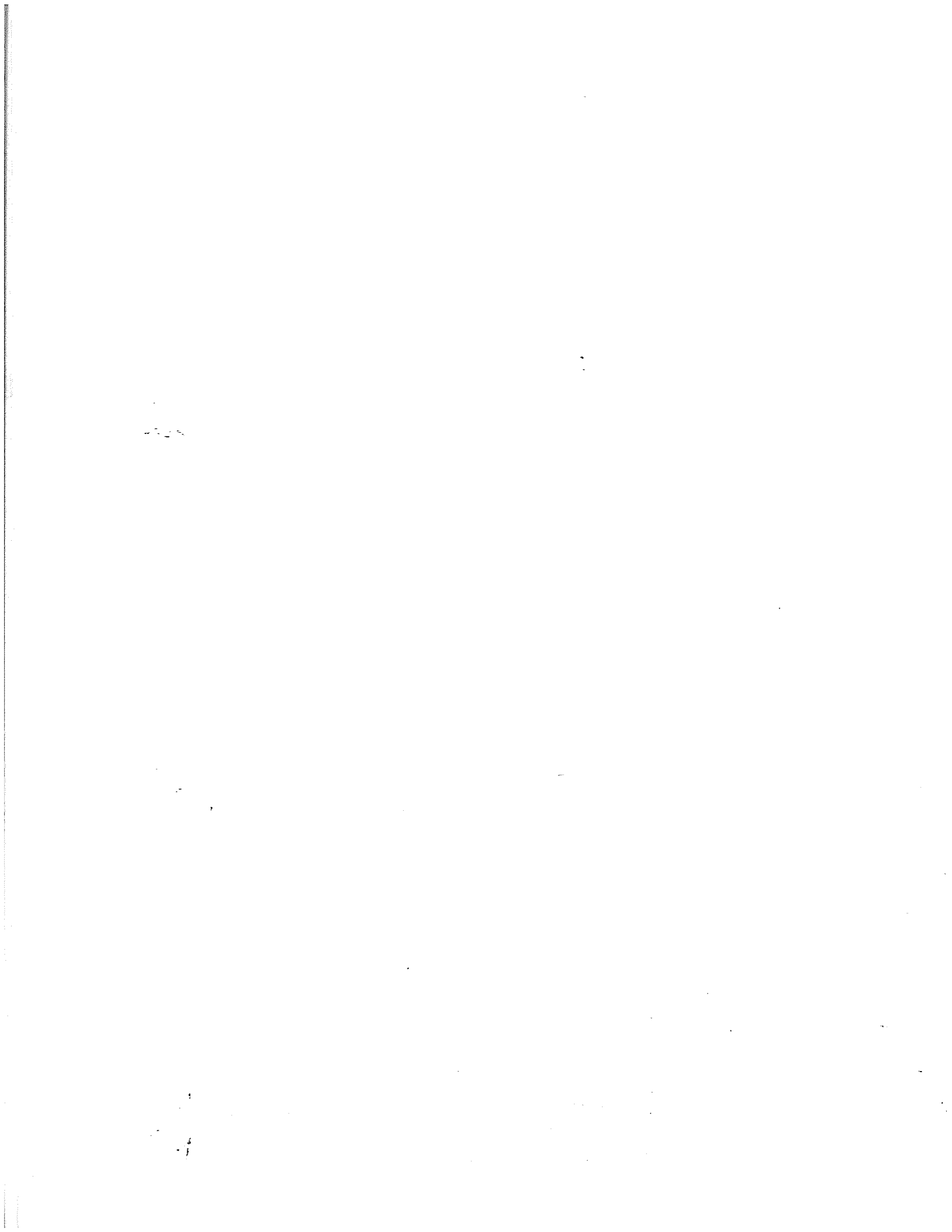


Fig. 22. Correlation coefficients for the relation between late larval density in pipe samples and daily spatfall at VELELLA with various lags.



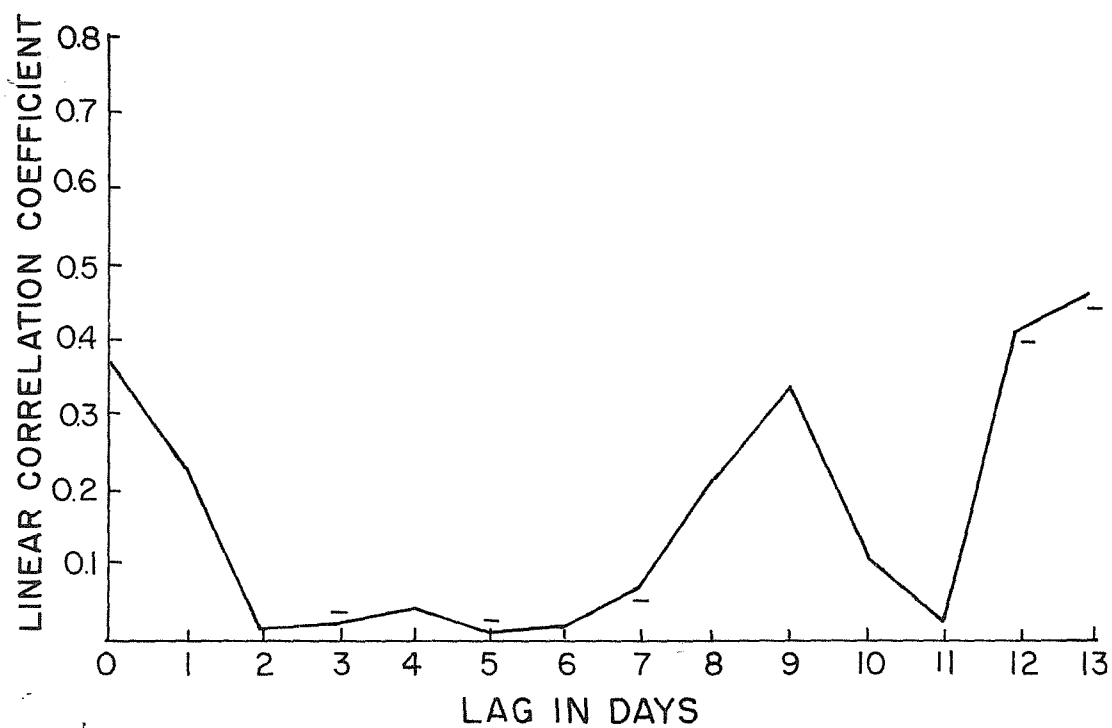
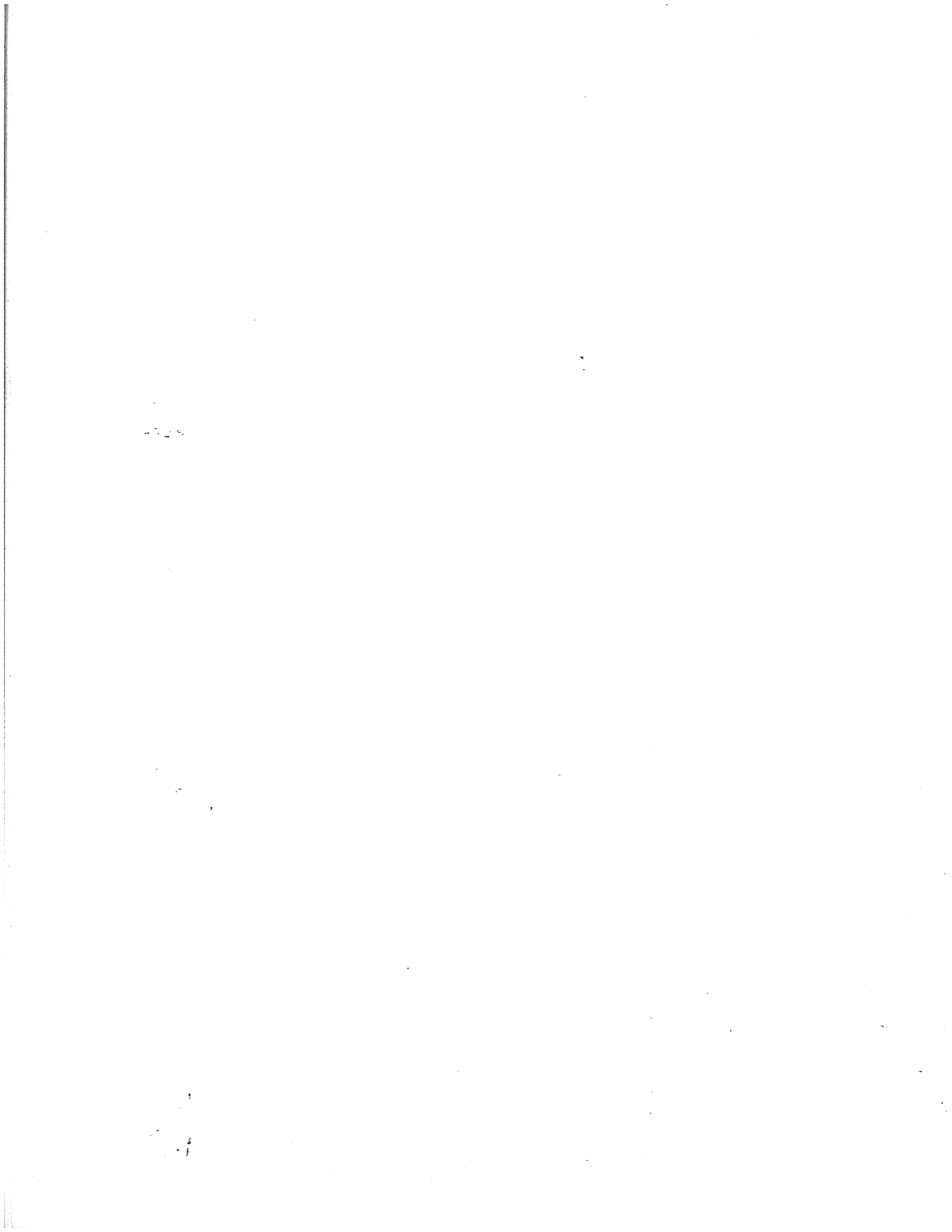


Fig. 23. Correlation coefficients for the relation between late larval abundance observed in evening plankton tows and daily spatfall observed at the VELELLA with various lags.



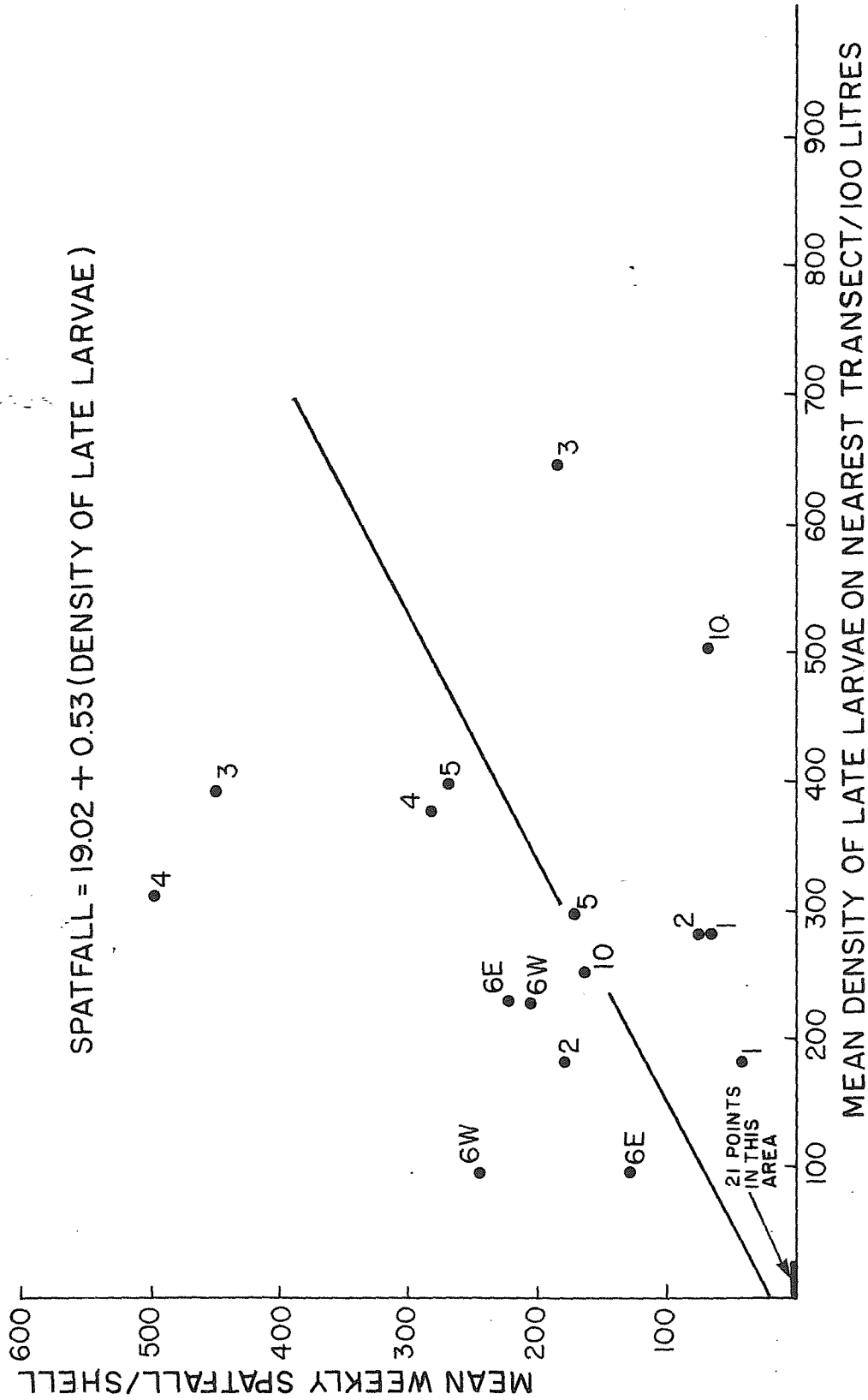
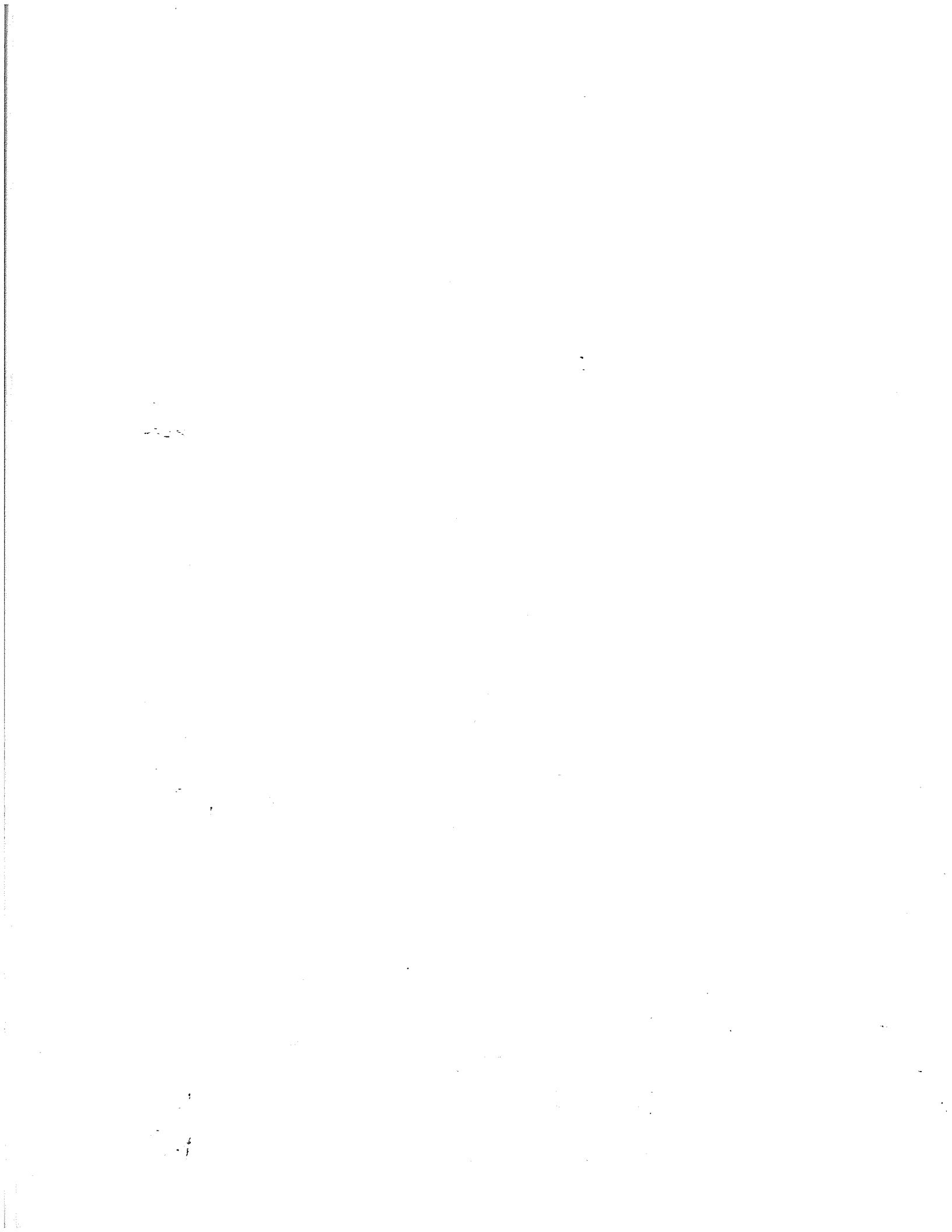


Fig. 24. The relation between density of late stage larvae observed in pipe samples and the mean weekly spatfall five days later at various stations. Larval density was measured at the pipe sample transect nearest to the spatfall station.



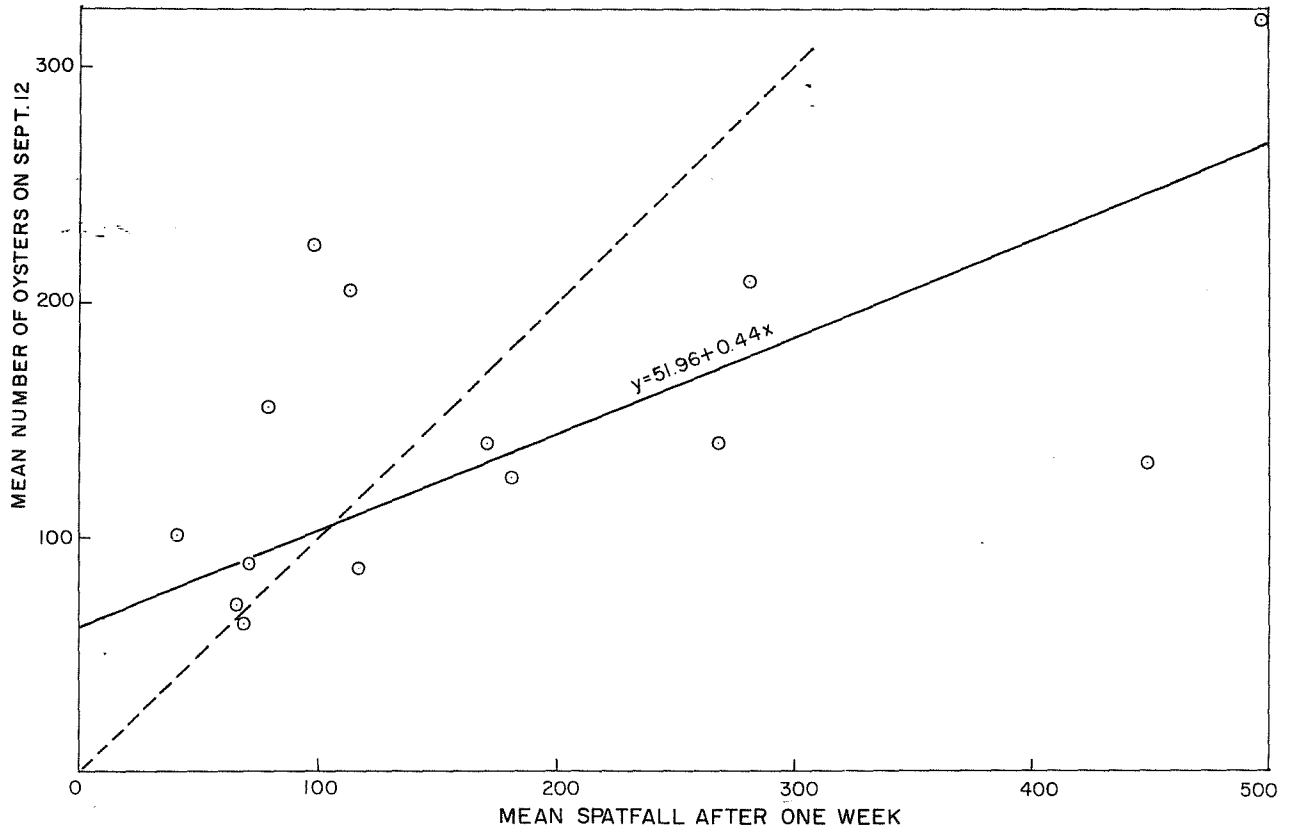
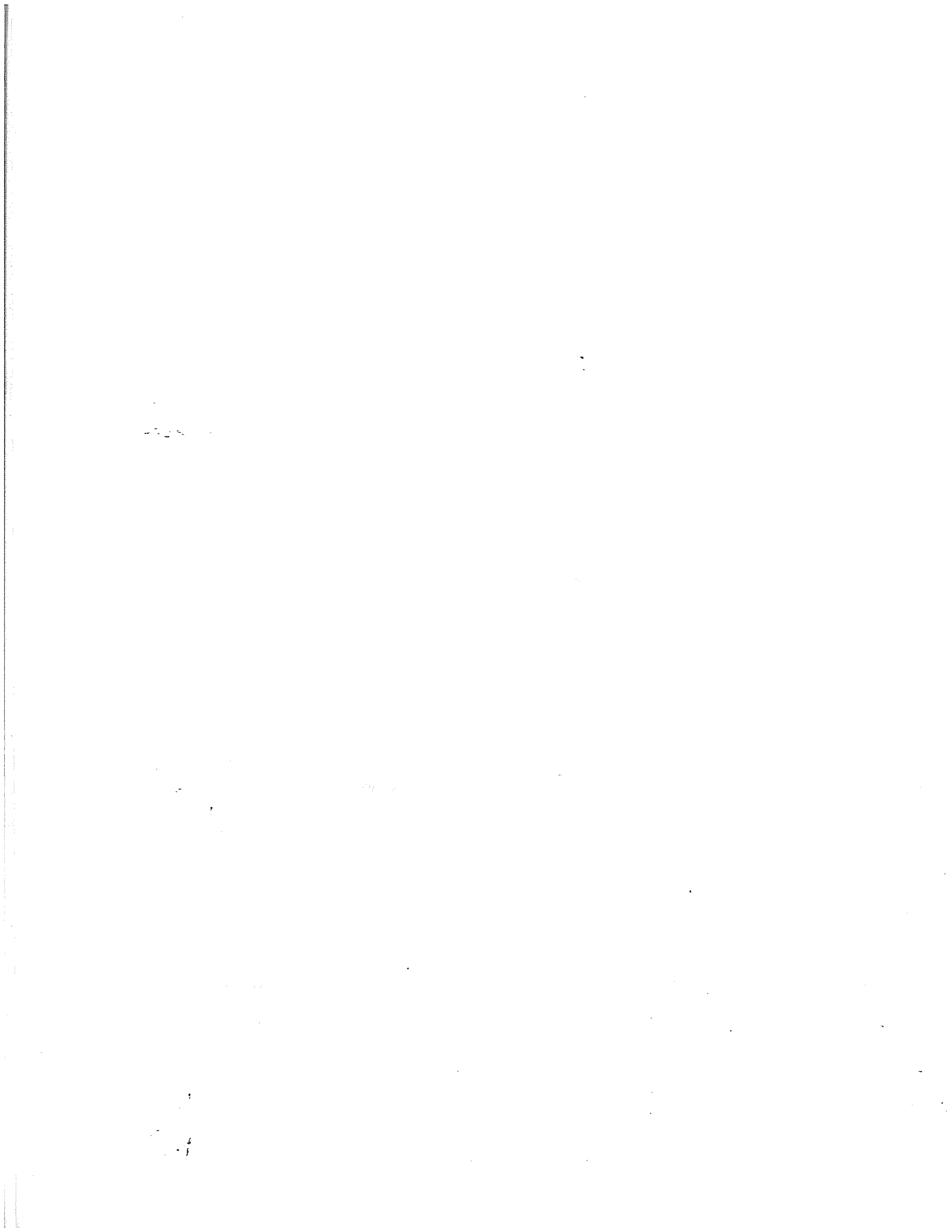


Fig. 25. The relation between mean weekly spatfall observed in a sample taken after one week and the mean number of oysters per piece at the end of the season. The dotted line connects equal x and y points.



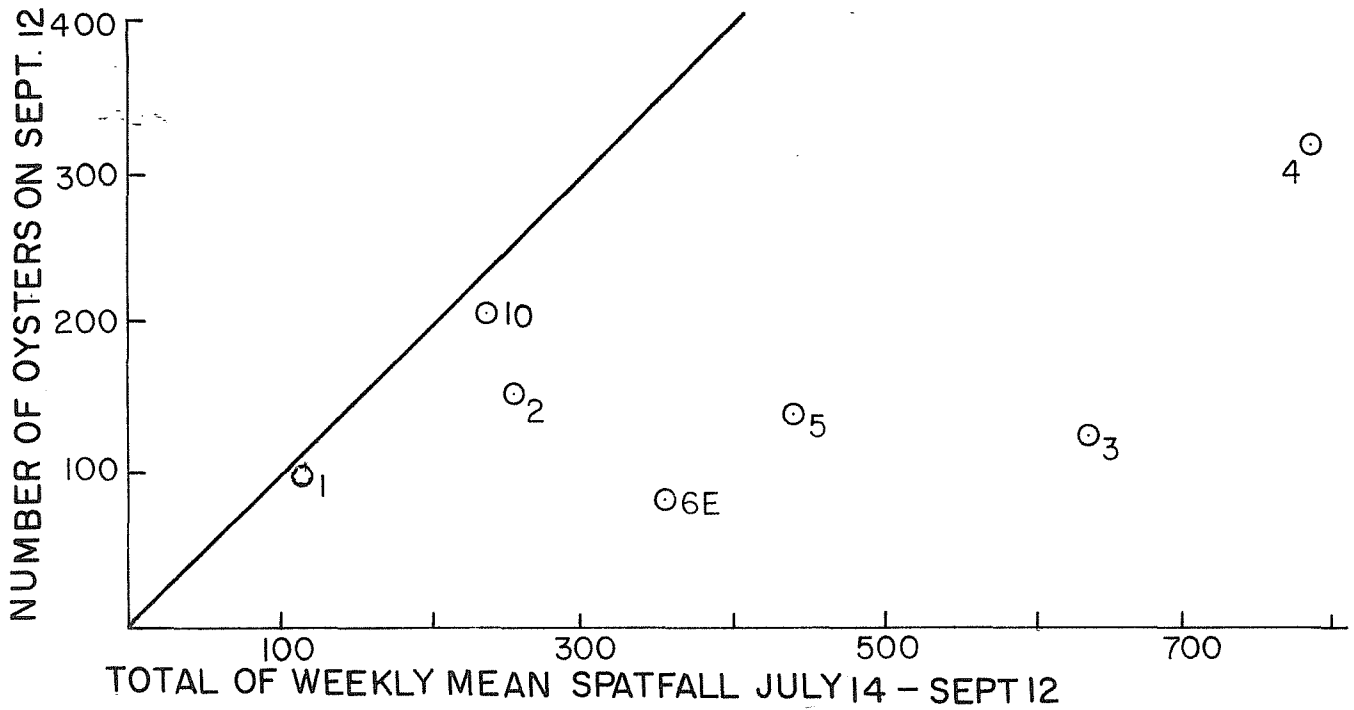
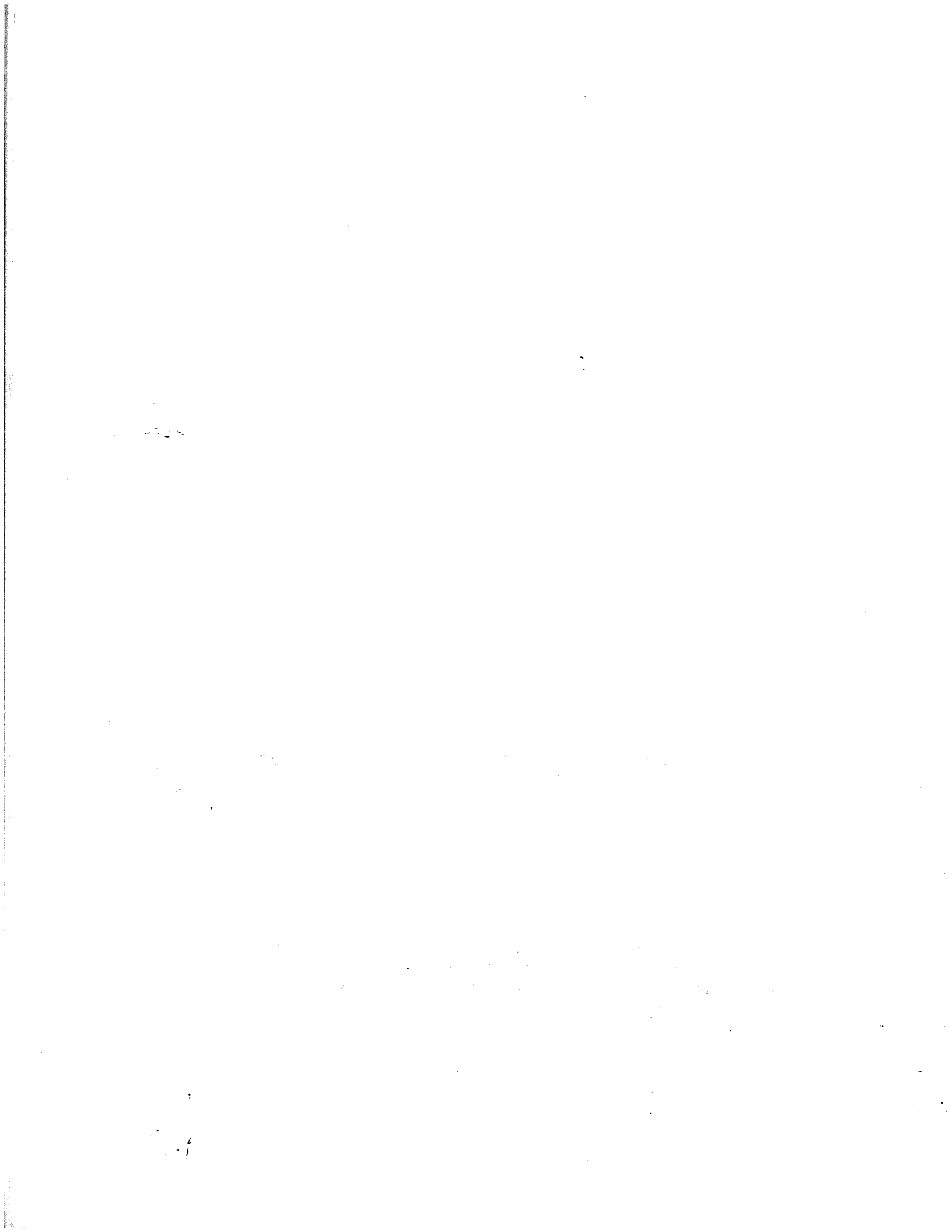


Fig. 26. The relation between the total of observed mean weekly spatfall over the summer and the number of oysters observed on cultch at the end of the season. The line connects x and y points of equal value. Numbers indicate the station.



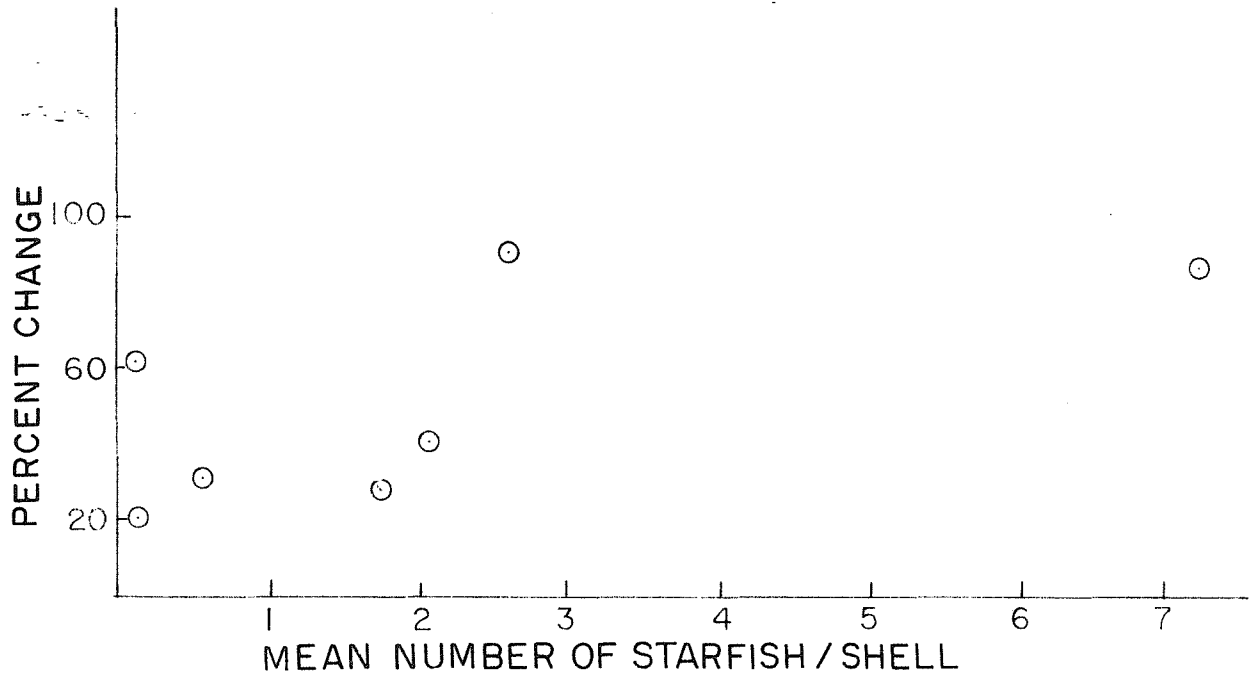
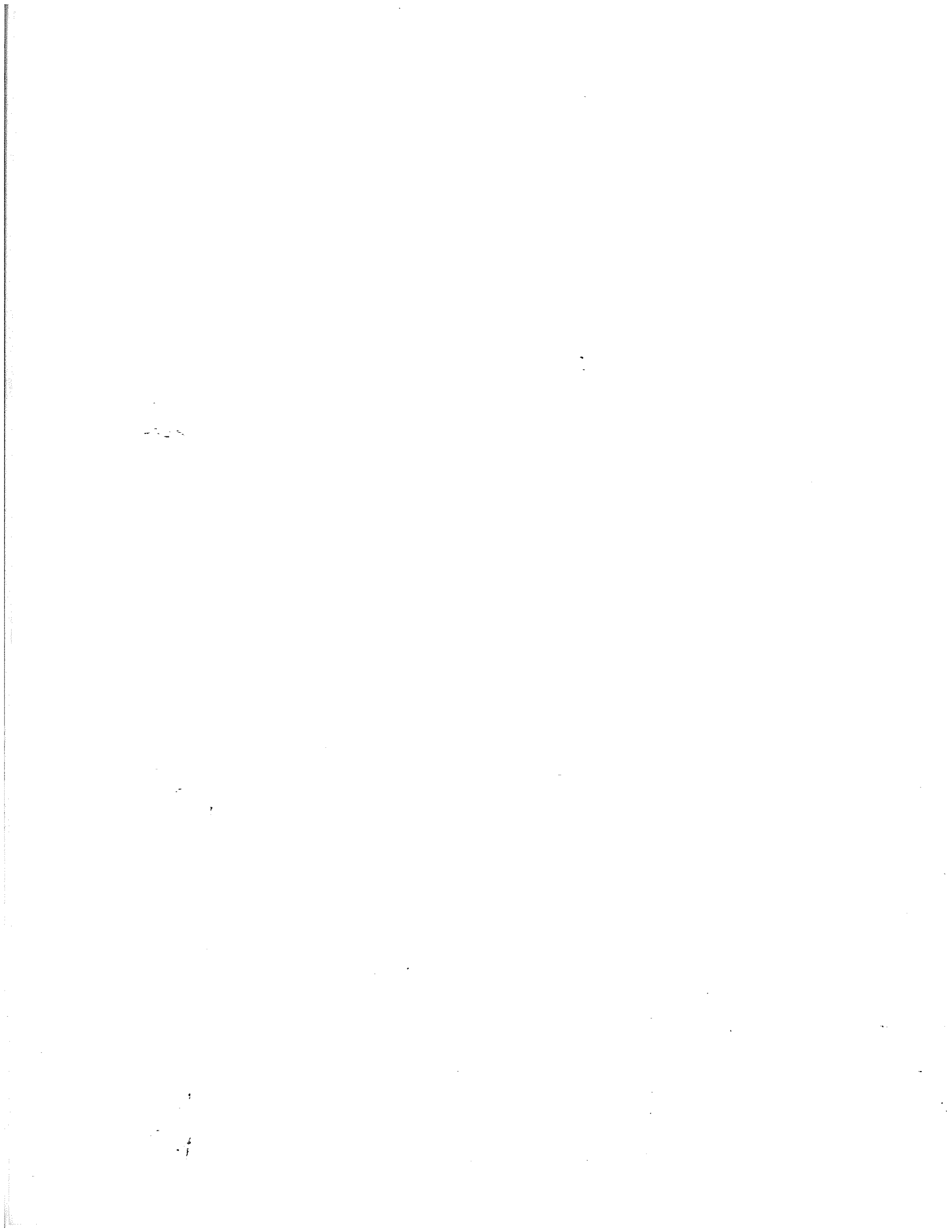


Fig. 27. Mean numbers of starfish observed on cultch at the end of the season compared with the percentage change in oyster numbers between July 21 and September 12 (Fig. 26).



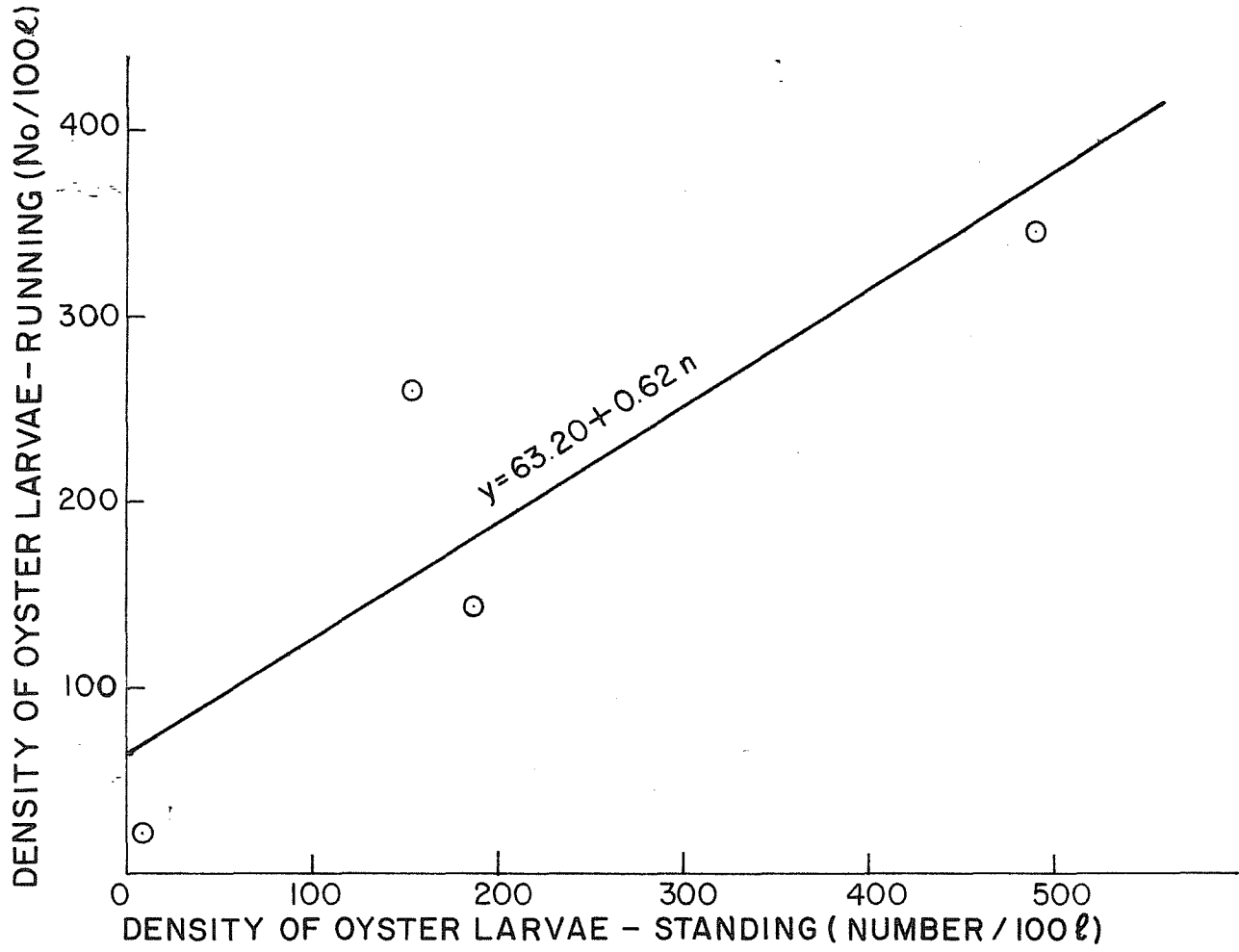


Fig. 28. A comparison of running and standing pipe samples.

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10 - [unclear]

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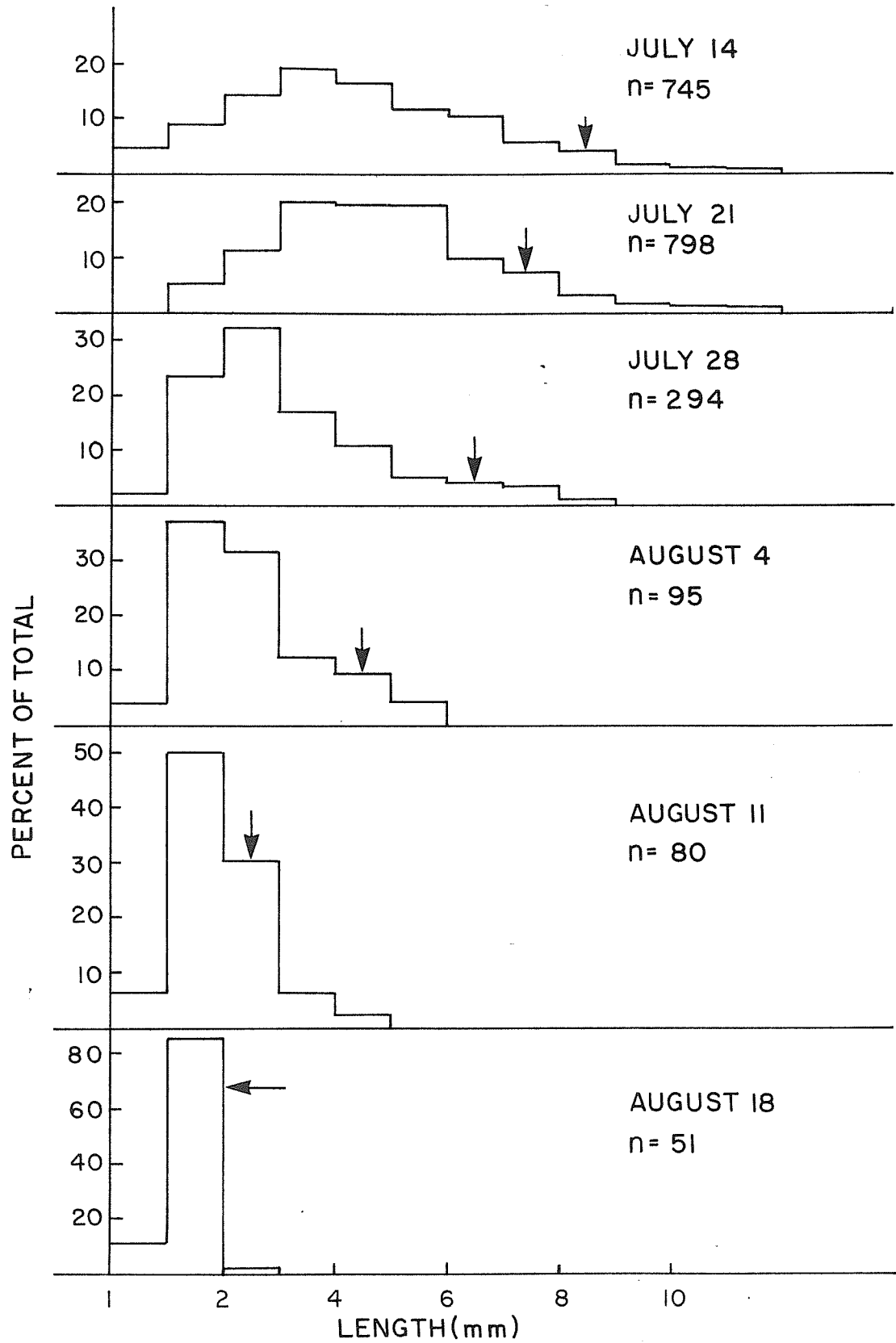
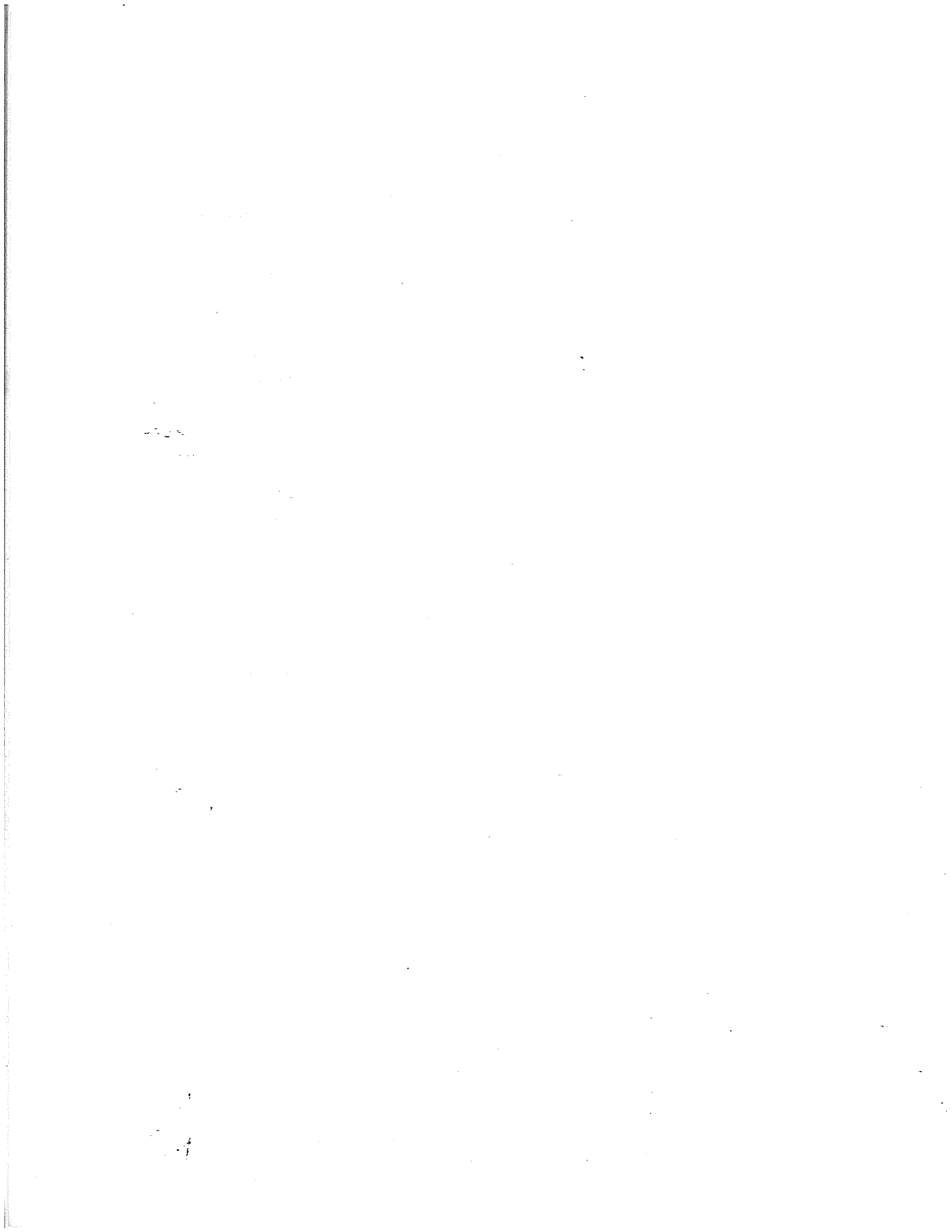


Fig. 29. Length frequencies of oysters on the tops of shells placed in the water on the dates indicated and removed from the water on September 12. Arrows indicate supposed modal size groups.



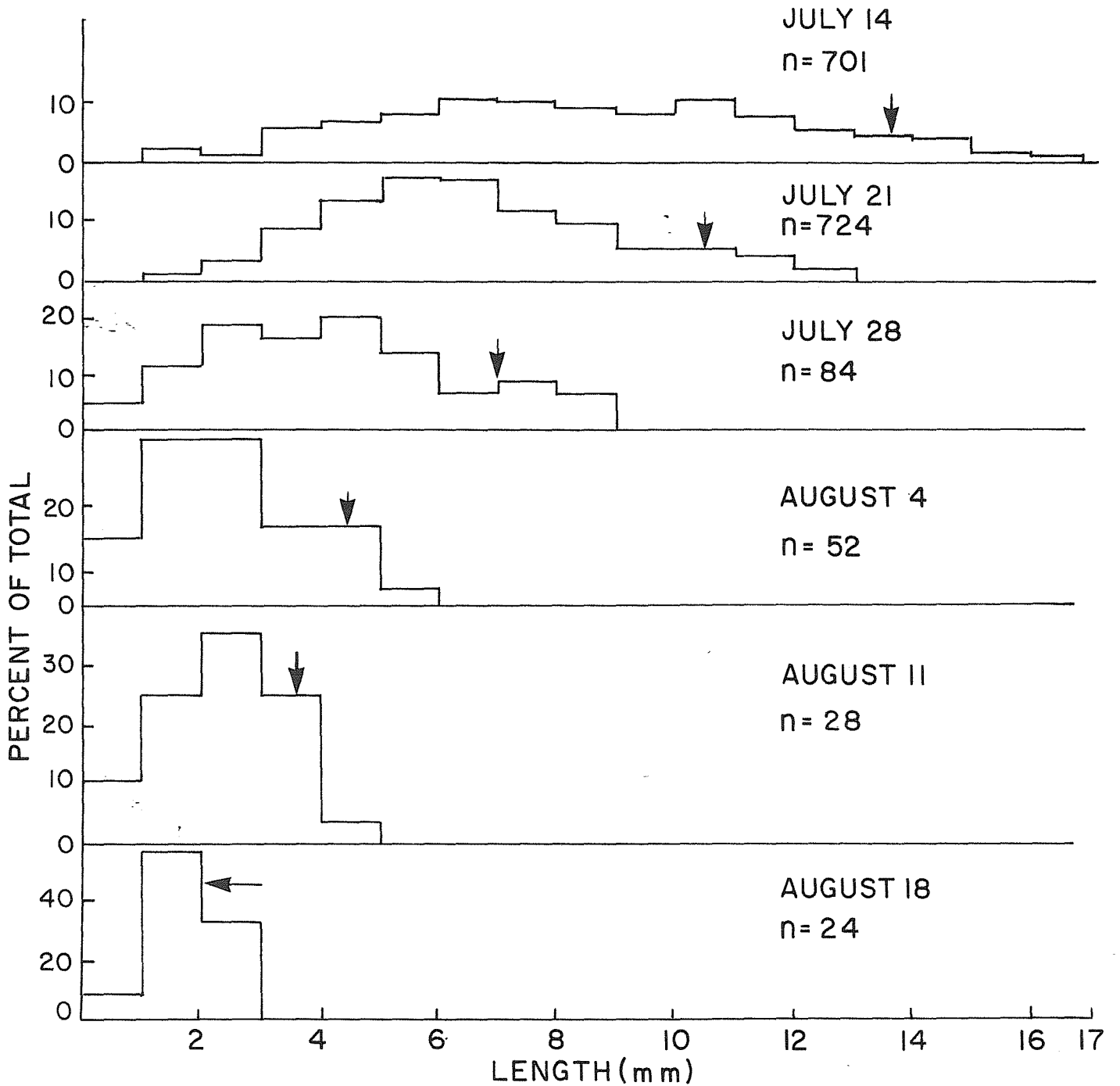


Fig. 30. Length frequencies of oysters growing on the bottoms of shells placed in the water on the days indicated and removed on September 12.

Arrows indicate supposed modal size groups.

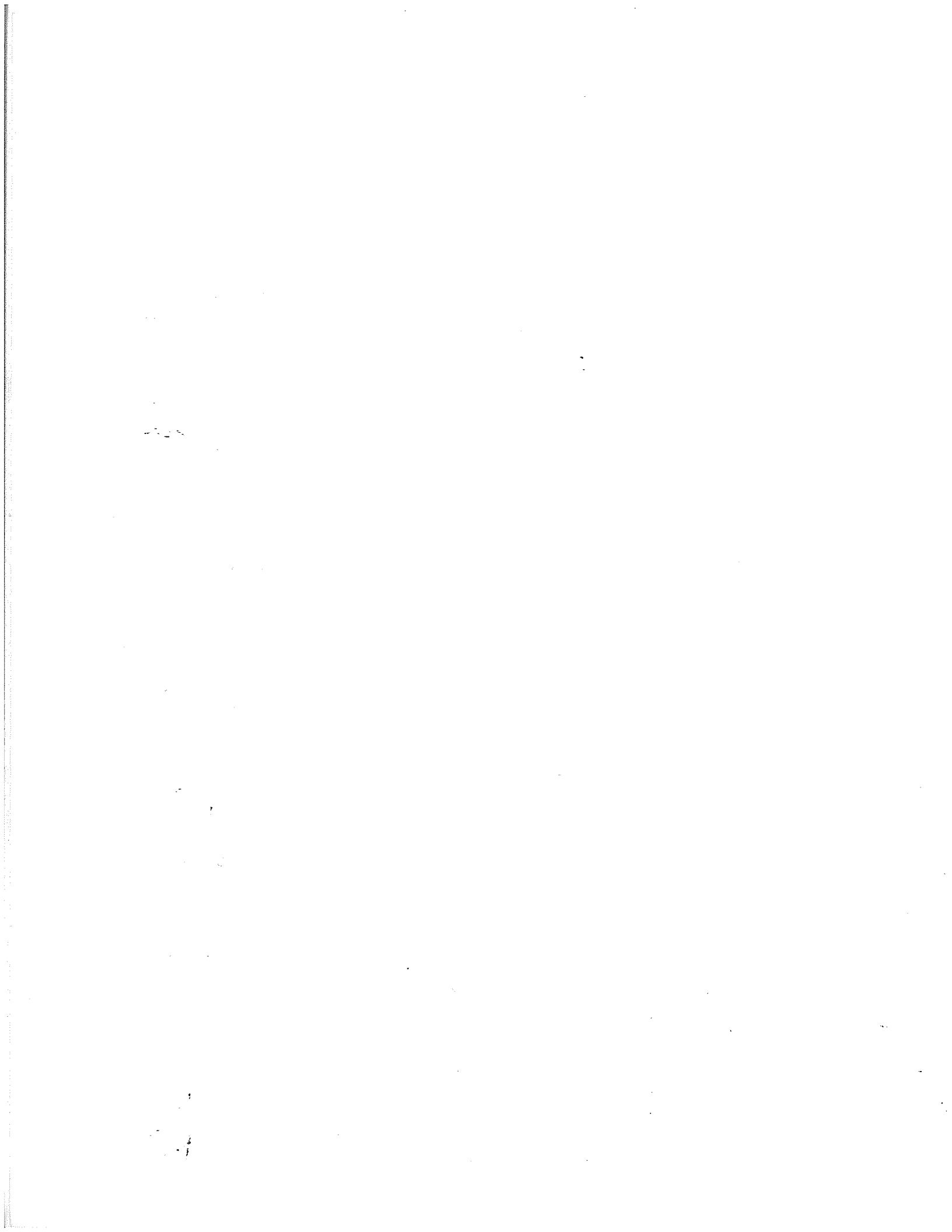
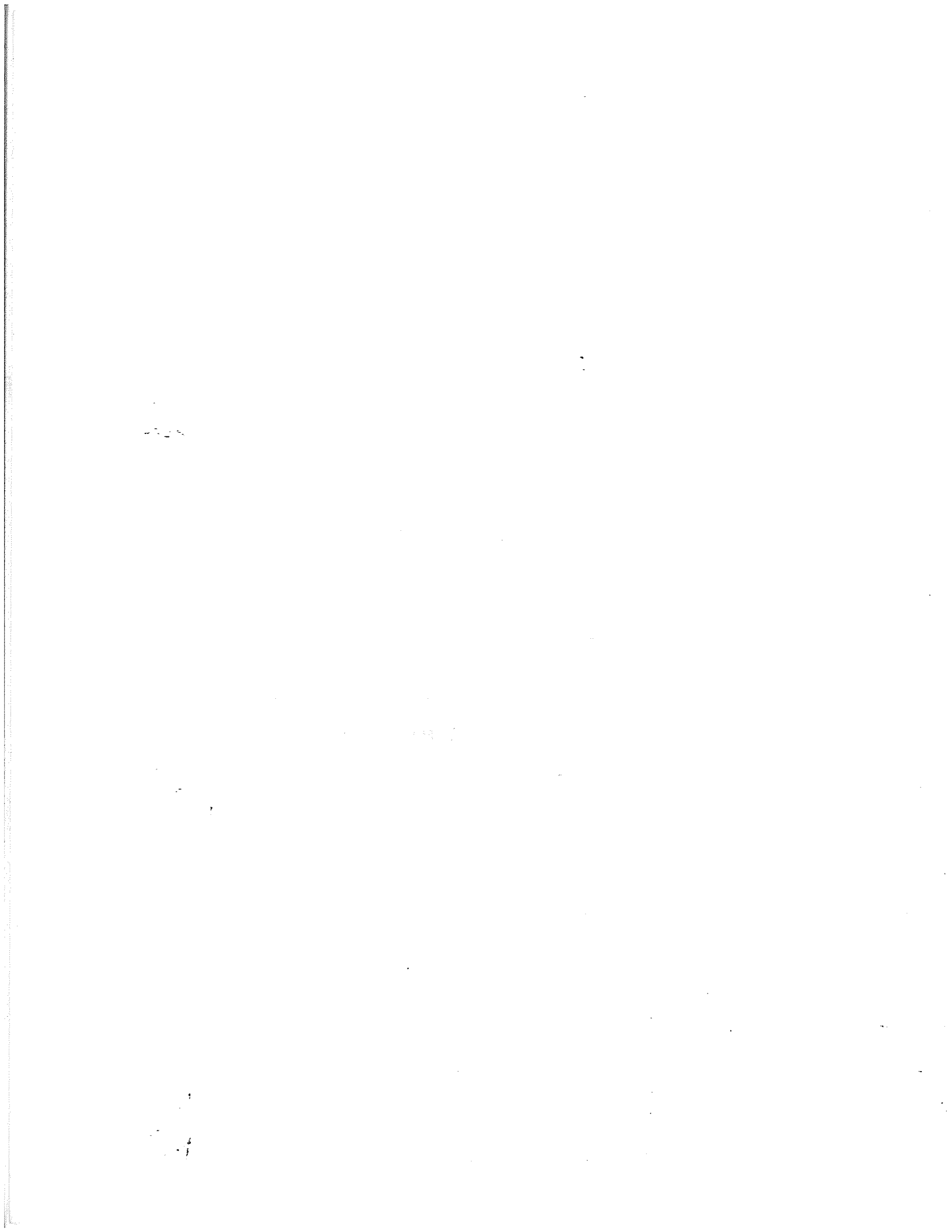




Fig. 31. Spat growth on the tops of shells. Vertical lines show the maximum sizes observed.



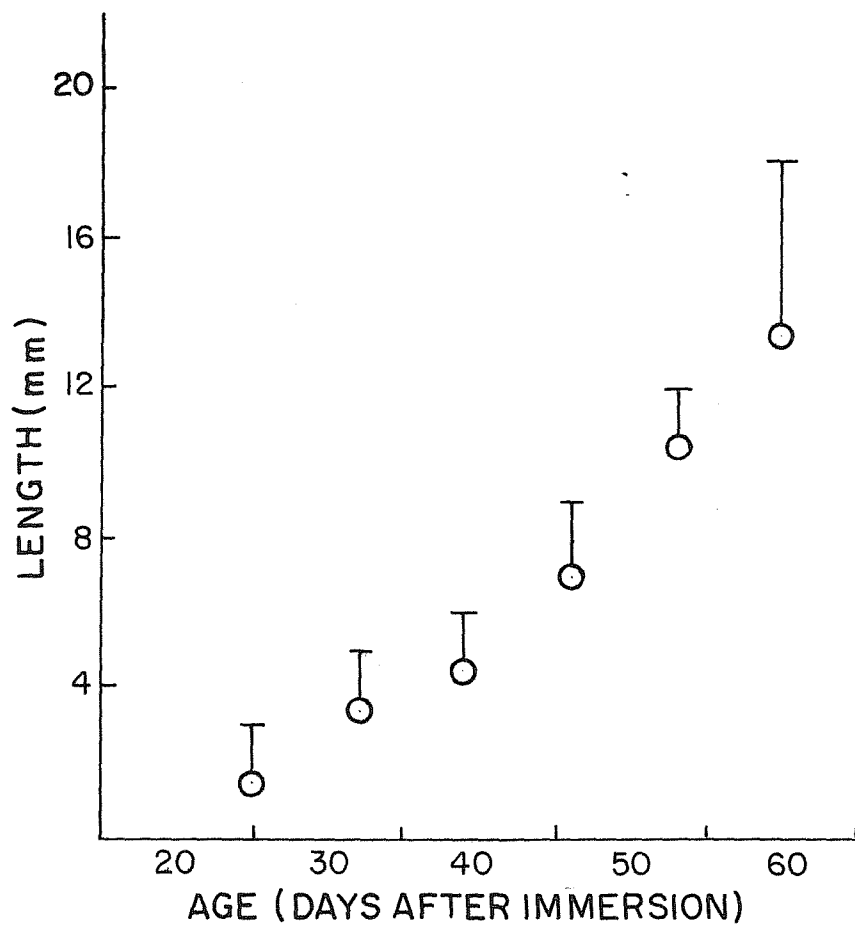


Fig. 32. Spat growth on the bottoms of shells. Vertical bars show the maximum sizes observed.