BULLETIN
ZOOLOGISCH MUSEUM

UNIVERSITEIT VAN AMSTERDAM

Vol. 3 No. 20 28-III-1974

FURTHER OBSERVATIONS ON THE MIGRATION OF *GAMMARUS ZADDACHI* SEXTON (CRUSTACEA, AMPHIPODA) IN A FRENCH STREAM

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ABSTRACT

The migration of *G. zaddachi* in La Slack, a small stream on the French Channel coast, and some physico-chemical properties of the river are discussed.
In laboratory experiments, the influence of the Cl- and Ca++ concentration on the survival-rate and reproduction of *G. zaddachi* was investigated. A raise in the Cl- concentration of the medium caused a significant improvement of the survival-rate. A raise in the Ca++ concentration also gives, although not significant, a higher survival-rate.

I. INTRODUCTION

The migration of *G. zaddachi* in the river Slack, a small stream on the French Channel coast (Pas-de-Calais), was studied by Dennert et al. (1969). It was shown, that the pattern of activity of *G. zaddachi* has a diurnal rhythm, with the activity peak at night.

All year long a downstream migration ("drift") could be noticed, whereas during the spring and autumn equinoctial spring tides a migration in upstream direction took place. Evidence was found, that the animals, although using the current for their migration, were not carried away passively. Migration therefore, was assumed to be an active process, depending on the physiological state of the animals concerned. Finally a correlation was found between the migration cycle and the reproductive cycle of *G. zaddachi*.

In the present study, the migration of *G. zaddachi* in La Slack is investigated more closely. During field observations, we tried to find a confirmation of the results obtained earlier. Some of the environmental factors, such as temperature, salinity and pH were examined more thoroughly. Special attention was payed to the distribution pattern of the species in La Slack during the observation period. Similar investigations on the migration of *G. zaddachi* and *G. chevreuxi* in a small river in Brittany, have been carried out by Girisch et al. (unpubl.).

In addition to the fieldwork, some experiments were carried out in which the survival rate and the reproduction of *G. zaddachi* in several experimental media with varying Cl- and Ca++ concentrations were determined.

II. STUDY AREA, MATERIAL AND METHODS

For a detailed description of the study area and of the sampling methods we refer to Stock et al. (1966) and Dennert et al. (1969). The map (fig. 1) shows the localities in which regularly each month samples of gammarids were collected with a dip-net. These localities are numbered 1 to 12. The stations A and B were visited in October 1969 only. Fig. 1 shows also the stations (denoted in Roman numerals) where the migration of *G. zaddachi* was investigated with the aid of the combination-net (see Dennert et al., 1969, fig. 1).
At station I the tidal influence is still strong, and this is reflected by sharp and strong variations in salinity, and a reversal of the current direction at high tide.
At station II the current still reverses at high tide, but only occasionally a slight rise in salinity occurs at high tide.
At station III the current also reverses at high tide, but the water remains fresh all the time.

The laboratory experiments were carried out with down-stream migrating animals caught in October 1969 with the combination-net at the stations I, II, and III. Animals from each of these stations were used to test the effect of experimental media on the reproduction and survival. The animals were kept in plastic basins of 25 x 25 x 10 cm, each filled with 2 liters of one of the experimental solutions.

In the experiments, animals from one station, and in the same experimental medium, were kept in three basins, so the experiments have been carried out in triplicate. The experimental media were:

I. water with 40 (± 10) mg/l Cl- and 10 (± 4) mg/l Ca++
II. water with 40 (± 10) mg/l Cl- and 100 (± 10) mg/l Ca++
III. water with 160 (± 20) mg/l Cl- and 10 (± 4) mg/l Ca++
IV. water with 160 (± 20) mg/l Cl- and 100 (± 10) mg/l Ca++

The chlorinity values of the water used here are the mean values in the river Slack in the limnic part of the river (40 mg/l) and in the upper reaches of the mixohaline part of the river (160 mg/l).

The values for the Ca++ content of the water were the average values found in the river Slack at all stations (100 mg/l), and 10 times less (10 mg/l).

The experimental media were made by mixing estuarine Slack water with limnic Slack water and destilled water.

Every 14 days the solutions in the basins were renewed.

Temperatures varied with the outside temperatures, but never dropped below 5°C.

III. PHYSICO-CHEMICAL DATA OF THE WATER IN THE RIVER SLACK

III.1. Cl- content of the water

Table I gives the Cl- content of the water at high tide at the five stations located most seaward. It shows, that at station 8 (located nearly at the same point as combination-net station II) the water remains limnic in spite of the reversal of the current.

Except for November 1969, the same can be said for the stations 9 and 10.

Only at the stations 11 and 12 a considerable increase of the chlorinity occurs at high tide. At all the stations the Cl- values at low tide are less than 50 mg/l. At the stations 1 to 7 all year long a chlorinity of 40 mg/l or less was recorded.

III.2. Ca++ content of the water

Ca++ content of the water remained nearly constant during the whole year, with fluctuations between 95 and 110 mg/l at all stations except the most seaward stations 9, 10, 11, and 12. There, at times when at spring tide the chlorinity sharply increased, the Ca++ content of the water increased to values up to 280 mg/l.

III.3. Na+ content of the water

The Na+ content of the water varied at the different stations from 10 to 90 mg/l. Here again the stations 11 and 12 showed an extreme raise in the Na+ content of the water at spring tide, even values of 6000 mg/l being reached. On the whole the fluctuations of the Na+ of the water were very similar to the fluctuations in Cl- content.

III.4. pH

The pH of the Slack water fluctuated very little, both during the year and between the stations. All pH values measured during the observation period vary between 7 and 8.

III.5. Temperature

Fig. 2 shows the bottom temperature at the stations investigated, at low tide and high tide each month.

It is clear, that at all stations winter temperature drops below 6°C. This justifies the conclusion brought forward earlier (Dennert et al., 1969, in accordance with Kinne, 1952), that temperature cannot be a factor with negative influence upon the reproduction of *G. zaddachi* in limnic parts of the river in winter.

III.6. Conclusion

From the physico-chemical data presented here two things become clear, viz. (1) the Cl- and Ca++ contents of the water in the river Slack, in combination with the low winter temperature, form no hindrance for *G. zaddachi* to reproduce in the limnic parts of the river (see also V.2.), and (2) the variation in the Cl-, Ca++, and Na+ contents of the water and the variations in pH are so small and incoherent, especially in the limnic part of the river, that definitely none of these can be a trigger-factor for the migration of *G. zaddachi*.

IV. FIELD OBSERVATIONS

IV.1. Combination-net catches

Fig. 3 shows the accumulated catches with the combination-net at the stations I, II, and III from October 1969 to April 1970.

At the equinoctial spring tide in October a great number of individuals were migrating in catadromous direction at station I. A less pronounced catadromous migration was also recorded in February. At station II the upstream migration of the animals was still considerable in October, but relatively small in January and February. At station III the catadromous migration is almost zero at each sampling period.

Not directly related with the catadromous migration is the anadromous migration. The fact that in periods with a great number of upstream migrating animals also a raised number of downstream migrating animals was caught, is the result of the increased population density at the stations located upriver at those times.

IV.2. Dip-net catches

Dennert et al., (1969) mentioned the depopulation of the upriver area of the river Slack and the Rivière de Bazinghen in the summer months. For a more detailed survey of this phenomenon, a number of dip-net samples were taken every month at the stations shown in fig. 1.

The results of these dip-net catches, as far as the limnic part of the river is concerned, are summarized in fig. 4. The diagrams show the mutual abundance of *G. zaddachi* and *Echinogammarus berilloni* (Catta). During the winter months the upstream part of the distribution area of *G. zaddachi* is gradually depopulated, and *E. berilloni* occupies the place of *G. zaddachi*. The next autumn these regions are repopulated by *G. zaddachi*, migrating in catadromous direction from the mixohaline part of the river.

Unfortunately no exact data are known from the stations 7 and 9, although it is clear from the combination-net catches, that at the station II, located near station 9, both in March and April small numbers of *G. zaddachi* were still present in this region.

The fact that in March and April at the stations 1 to 7 no *G. zaddachi* was caught with the dip-nets, and a few *G. zaddachi* but nearly no *E. berilloni* were caught with the combination-net at station III, supports the conclusion that on the one hand the *G. zaddachi* population is almost absent, and on the other hand *E. berilloni* shows no migratory rhythm comparable with that of *G. zaddachi*.

It is to be noted that in our dip-net catches *G. pulex* (L.), recorded earlier from these parts of the river-system (Stock et al., 1966, Dennert et al., 1969) has disappeared completely. This species was found during this study in the most inland parts of the river only.

IV.3. Conclusion

The catadromous and anadromous migrations of *G. zaddachi* as observed in this paper, are very similar to the migration recorded by Dennert et al. (1969). During the winter months upriver regions get depopulated by *G. zaddachi*, while the relative abundance of *E. berilloni* increases.

V. INFLUENCE OF Cl- AND Ca++ ON THE SURVIVAL AND REPRODUCTION OF *G. ZADDACHI*

V.1. Introduction

Sutcliffe (1968, 1971b) studied the influence of the external NaCl concentration on several aspects of the physiology of *G. zaddachi*. He concluded that *G. zaddachi* was able to maintain sodium balance for short periods at very low external sodium concentrations (comparable with 12 mg/l Cl-), but that the sodium transporting system at the body surface was saturated at an external concentration of about 350 mg/l Cl-. Hence between these two values the conditions for *G. zaddachi* are suboptimal.

Ca++ seems to have a considerable effect on the sodium uptake system of *G. zaddachi* as was shown by Sutcliffe (1971a). Up to concentrations of 400 mg/l Ca++ raised the sodium influx in *G. zaddachi*. Similar results were obtained by Schmitz et al. (1967) for *G. tigrinus*.

In view of these facts, it seemed worthwhile to determine the influence of the Cl- and Ca++ concentration on the reproduction and survival-rate of *G. zaddachi*.

The conditions, under which the experiments took place, are described in section II.2. Since Goedmakers (1972) found, that in experimental populations of *Gammarus* species an offspring was rarely obtained in large numbers, due to lack of shelter and cannibalism, in the breeding experiments the precopulae were kept apart in small basins. The temperature in these small basins was kept at 5.5 ± 0.5° C.

V.2. Influence of Cl- and Ca++ on the survival-rate

The results of the experiments are given in table II. A very sharp increase in the survival percentage of the animals is demonstrated when the Ca++ content, but especially when the Cl- content of the water is raised. At the same time it is clear, that especially the animals from the middle and upper reaches of the river show an acute decrease in the mortality-rate after a raise in the ion content of the medium.

Tested with the chi square test a highly significant ($P < 0.001$) difference exists between the mean survival percentages in the four tested media. No statistical differences ($P > 0.05$) were found between the survival percentages in the media with low and high Ca++ concentration and the same Cl- concentration. So, statistically neither the results from the media I and II, nor the results from the media III and IV differ, although it is clear, that a not significant positive influence is attained by a raise in the Ca++ concentration. The differences between the media with a low (I and II) and a high (III and IV) Cl- concentration are highly significant ($P < 0.001$).

Table II also records the number of days (to the nearest quintuple) in which half of the population died. The longevity increases with increasing salinity, but with the chi square test no statistical significant differences ($P > 0.05$) between the populations in the four media are found.

V.3. Influence of Cl- and Ca++ on the reproduction

As the number of precopulae used in the breeding experiments was rather small (eight per medium), the results from these experiments only give an indication of the influence of the Cl- and Ca++ ions on the reproduction of *G. zaddachi*.

It showed that females, ovigerous as well as non-ovigerous at the beginning of the experiments, produced offspring in the media II, III, and IV. In these three media 50% or 62.5% of the females produced offspring. The results in medium I were rather poor, with only two females (ovigerous at the beginning of the experiments) producing offspring.

V.4. Conclusion

From the experiments in which the influence of the Cl- and Ca++ content of the water on the survival-rate and reproduction of *G. zaddachi* were studied, the following conclusions can be drawn:

a) a positive influence of the Ca++ ion on the survival-rate is shown. In water with a raised Ca++ content, the survival is greater, and more females produce offspring .

b) The influence of the Cl- ion is far greater than the influence of the Ca++ ion. When the chlorinity is raised, the survival percentage more than doubles.

c) The combination of a raised Ca++ and Cl- content of the water gives the highest survival-rate.

d) Populations from the limnic parts of the river Slack seem to be more susceptible to an increasing ion content of the water, than populations from the upper reaches of the mixohaline part of the river.

VI. DISCUSSION

The data, presented in this paper, constitute a confirmation of the earlier report of Dennert et al. (1969) on the migration of *G. zaddachi*.

From the detailed chemical analysis of the Slack water in winter, it became apparent, that the conditions in the limnic part of the river do not prevent reproductive activity in *G. zaddachi*.

In our laboratory experiments, this observation was confirmed, although it was clear, that a significant difference in survival-rate exists between *G. zaddachi* specimens kept in water with a low ion content (with values as found in the limnic part of the river Slack) and specimens kept in water with a raised ion content (with values as found in the upper reaches of the mixohaline part of the river).
This supports expectations based on the results of Sutcliffe (1968, 1971 a & b).

The conclusion of Dennert et al. (1969) that due to a high population density in autumn, the new generation of *G. zaddachi* migrates from the mixohaline to the limnic part of the river, and that during the rest of the year part of the population, especially ovigerous females, migrates back to the estuary, seems to be confirmed entirely by our new observations.

ACKNOWLEDGEMENTS

The authors are indebted to Prof. Dr. H. Boulangé (†) of the "Laboratoire Ch. Maurice" at Ambleteuse-sur-Mer, who has put the facilities of the laboratory at our disposal, and to Mr. J. Zaagman for his assistance in making the graphs.

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Received: 14 August 1973

Table I

Cl^- content in mg/l of the Slack at the bottom at high tide, measured at the five seawardmost stations

month	st. 8	st. 9	st. 10	st. 11	st. 12
October	40	45	45	65	17700
November	40	8700	11600	12100	16900
December	30	28	28	35	61
January	40	38	40	40	5300
February	35	37	38	11600	13000
March	40	45	46	12500	14300
April	40	36	39	36	36

Table II

Survival-rates of *G. zaddachi* from the stations I, II, and III under experimental conditions

	medium I☆			medium II☆			medium III☆			medium IV☆		
	st. I	st. II	st. III	st. I	st. II	st. III	st. I	st. II	st. III	st. I	st. II	st. III
number of animals	76	85	41	64	85	41	49	44	56	30	46	46
number of animals after 90 days	17	6	4	12	9	9	20	14	15	8	25	14
surviving percentage	22	7	10	19	11	22	41	32	27	27	54	30
mean surviving percentage per medium		13			16			33			39	
d 50★	30	35	40	20	45	50	40	50	40	40	65	40
mean d 50 per medium		35			40			45			50	

☆ for the composition of the media see section II.

★ d 50 = number of days in which the population is reduced to half of the original number of animals, round off at the nearest quintuple.

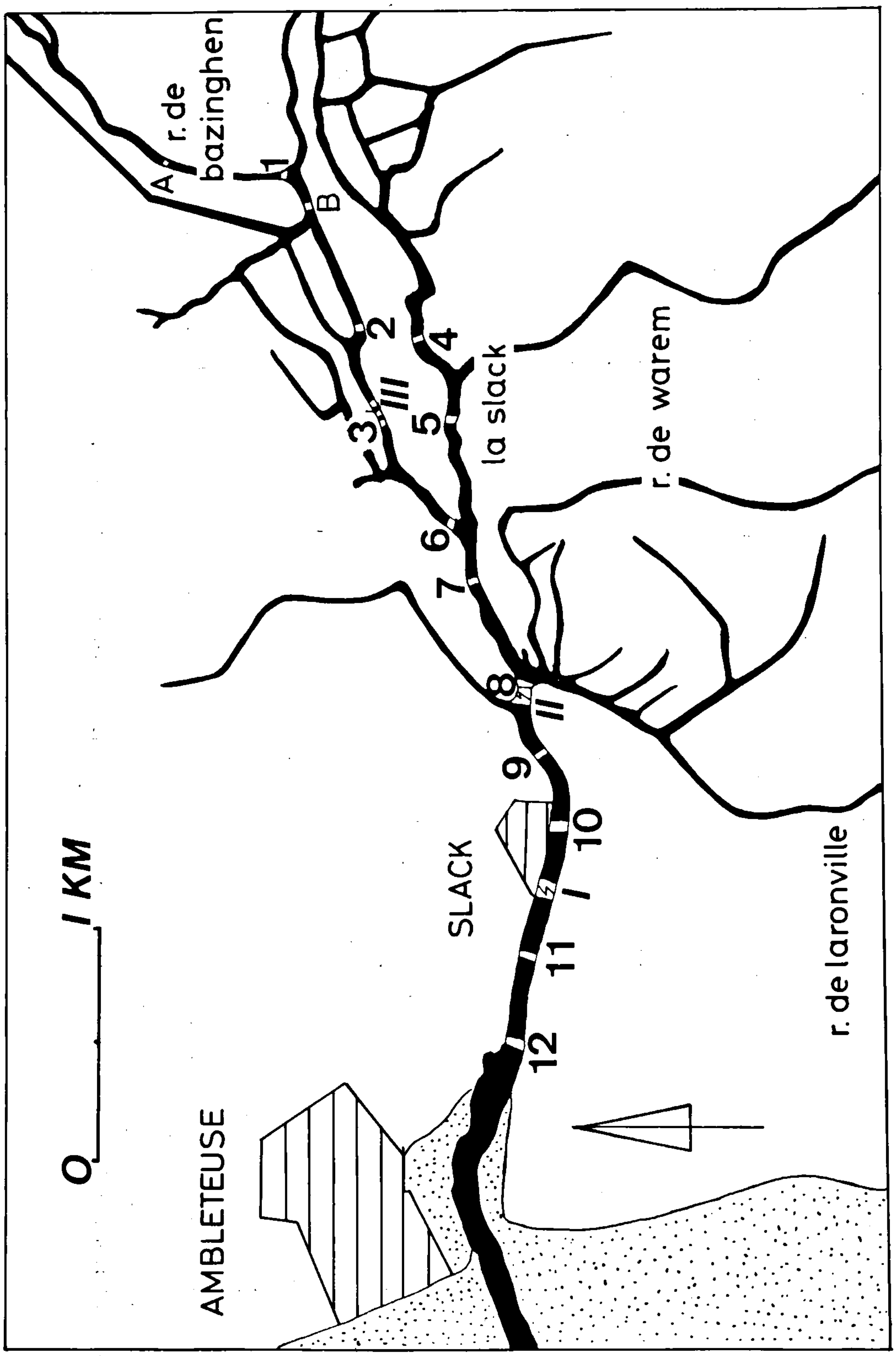

Fig. 1. The seaward part of the stream system of the river Slack. (salt marshes and tidal areas dotted; names of villages in capitals, names of streams in lower case).

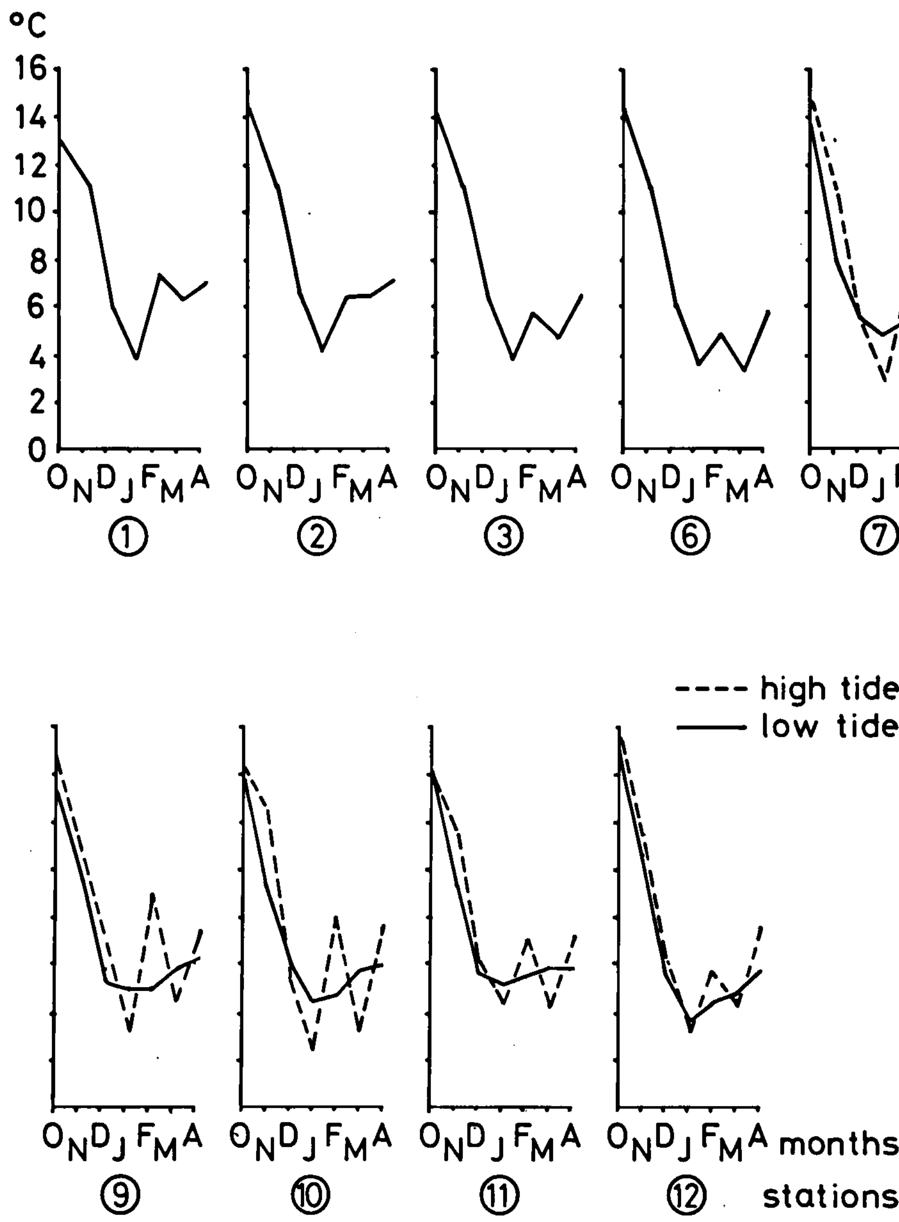

Fig. 2. Bottom temperatures (at daytime) at the stations 1 to 12 from October 1969 to April 1970.

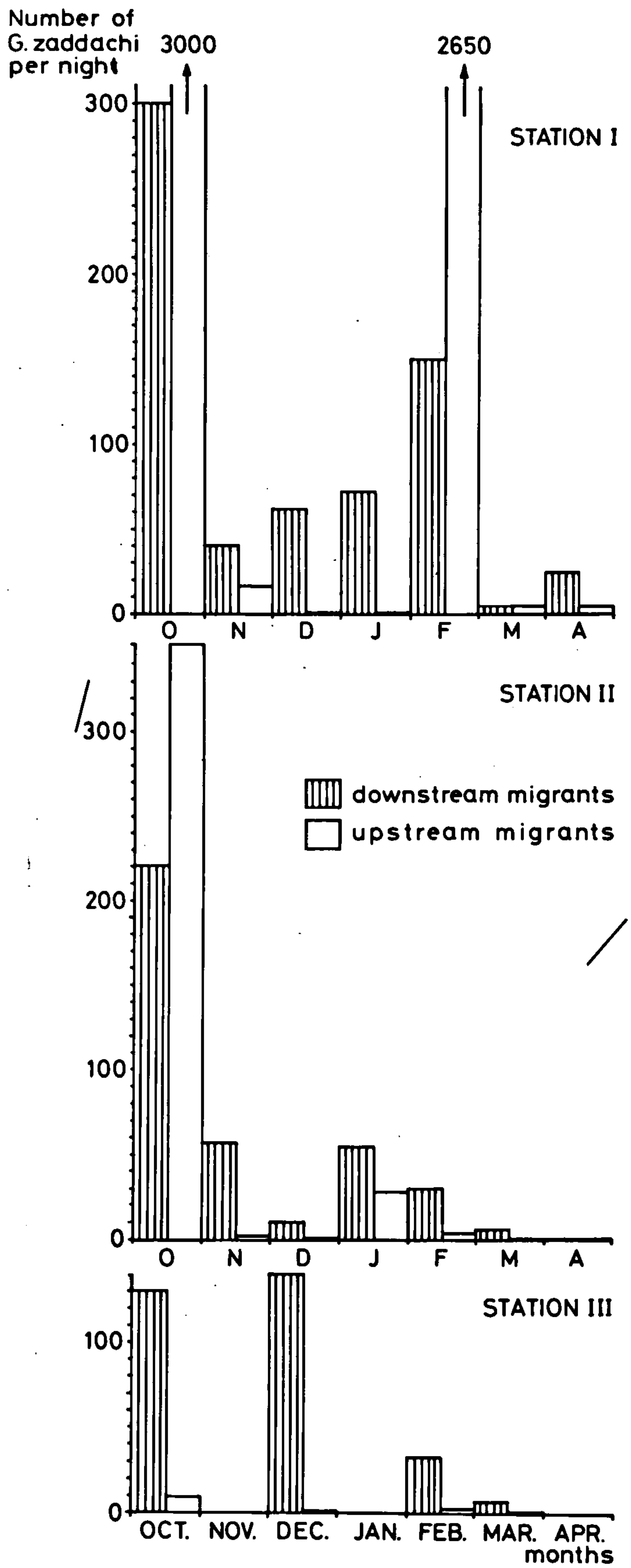

Fig. 3. Number of upstream and downstream gammarids caught with the combination-net at the stations I, II, and III per night, in the period October 1969 to April 1970.

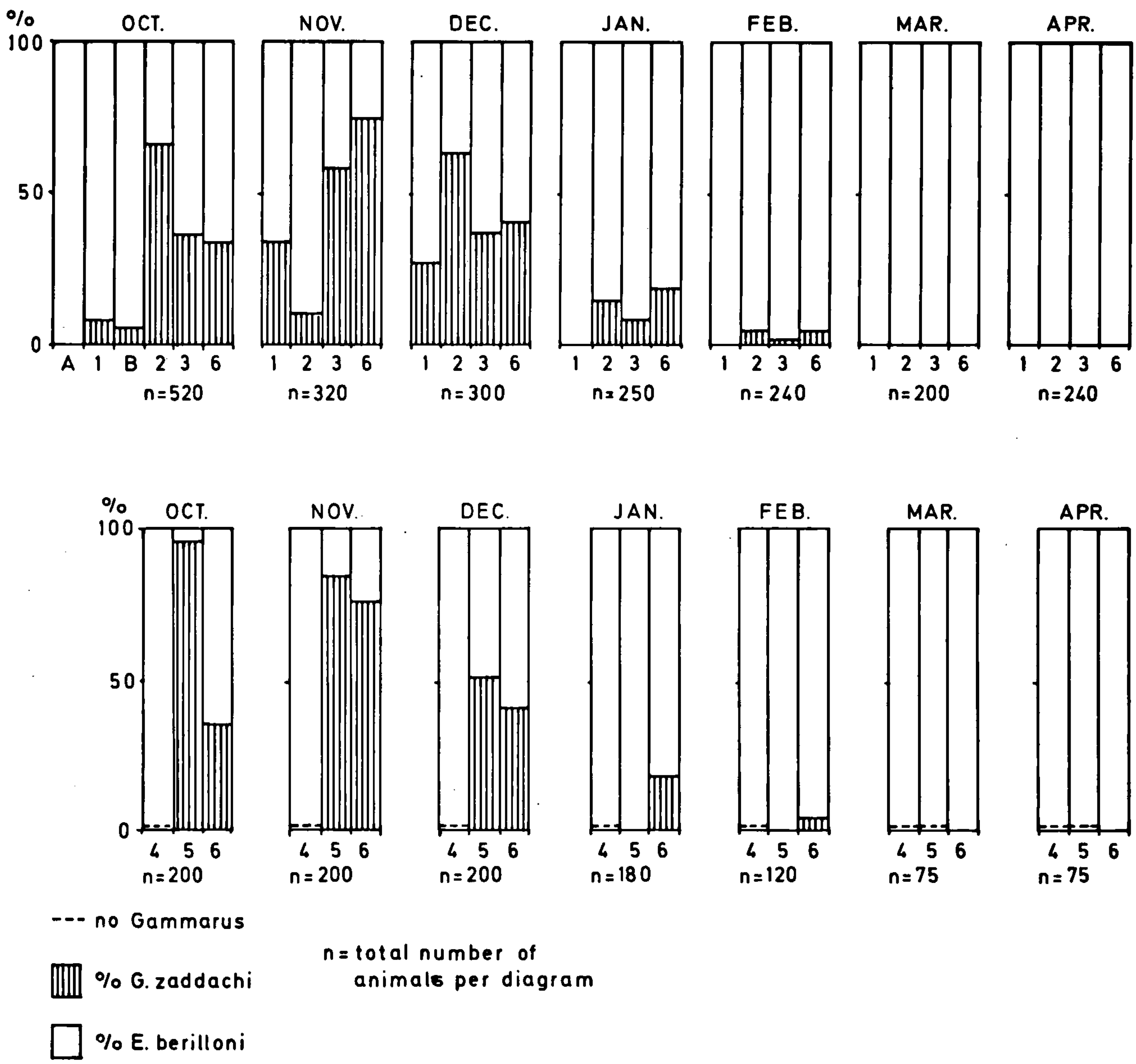

Fig. 4. Mutual abundance of *Gammarus zaddachi* and *Echinogammarus berilloni* in dip-net catches at the stations 1 to 6 in the period October 1969 to April 1970.