J. mar. biol. Ass. India, 1981, **23** (1 & 2) : 86 - 140

DISTRIBUTION OF ZOOPLANKTON BIOMASS, FISH EGGS AND LARVAE ALONG THE WEST COAST OF INDIA

I. DAVID RAJ AND C. P. RAMAMIRTHAM

Central Marine Fisheries Research Institute, Cochin - 682 031

ABSTRACT

An atlas showing the correlation of oceanographic features with zooplankton biomass, fish eggs and larvae along the west coast of India during 1963-1969 from Cape Comorin to Bombay is presented with essential discussions on the inter-relationship between the hydrographic features and the biological aspects. The continental shelf region is found to be conspicuously richer in zooplankton biomass than the offshore regions. The peak of zooplankton biomass is observed during monsoon and postmonsoon periods. The low concentration occurring during summer and premonsoon periods are in good agreement with the similar work done elsewhere. During the summer months fish eggs and larvae show generally an increasing trend, but exceptions have also been observed when there was a higher abundance during the peak monsoon.

INTRODUCTION

THE WATERS along the west coast of India are wellknown for their high productivity (Prasad, 1966; Prasad *et al.*, 1970; Nair *et al.*, 1973; Currie *et al.*, 1973) and fishery yield (Silas, 1969; Jones *et al.*, 1973; Silas *et al.*, 1976) for a long time. A vast amount of oceanographical and biological data have been collected in these waters by the Central Marine Fisheries Research Institute ever-since the year 1957 on board the vessels R. V. KALAVA and R. V. VARUNA. Most of the hydrographic data has been published, but a detailed correlation between the oceanographic features and the zooplankton biomass has not been done yet. In the present account, quantitative abundance of zooplankton biomass, fish eggs and fish larvae in relation to oceanographic features have been processed and discussed for a period of nearly seven years (1963-1969). Although a perfect correlation is not claimed, noticeable relationships between the correlated properties have been observed. These are presented in a series of charts and a brief writeup therein. During the International Indian Ocean Expedition a good deal of hydrography and plankton data have been collected and the results have been published in IOBC Atlases (IOBC, 1968 a, b) based on average values calculated from all the stations in every 5° square (Rao, 1973). But, in the present investigations a more intensive study along the west coast of India alone has been made based on 1578 zooplankton samples collected by the IIOE Standard net during 1963-1969, which is hoped to be more useful for the study of coastal productivity and fishery.

The authors are highly indebted to Dr. E. G. Silas, Director, Central Marine Fisheries Research Institute, Cochin for suggesting this problem and his keen and continued interest and encouragement during the course of this work. They are also grateful to Dr. P. V. Ramachandran Nair and Dr. A. V. S. Murty for their help. The help rendered by Dr. K. Rengarajan in preparing the manuscript and text figures is also gratefully acknowledged. The authors are thankful to Dr. P. Parameswaran Pillai for his critical reading of this manuscript and suggestions.

MATERIAL AND METHODS

To achieve a better understanding on the distribution of the zooplankton biomass, fish eggs and fish larvae in relation to hydrographic properties such as temperature, salinity and dissolved oxygen, a total of 1578 zooplankton samples collected along the west coast of India during 1963-1969 by the IIOE Standard net (Currie, 1963) were analysed and the results are enumerated hereunder. The plankton collections were made from 200 m depth to the surface in the oceanic stations and 5 m above the bottom to the surface in the coastal waters. Wet volume (in cc) of the zooplankton collected was estimated by using a volume estimating apparatus and calculated for 1000 m^3 of water strained (cc of plankton per 1000 m^3 of water strained). The fish eggs and larvae were completely removed from the total sample, counted numerically and estimated to 1000 m^3 of water filtered (Number per 1000 m^3). These estimates are categorised in 5 grades in the accompanying charts. The hydrographic sections that were worked out during particular months can be considered as representative ones, since along the west coast of India, and especially south of 16°N, major changes in the hydrographic features within particular months have not been much.

RESULTS

The data from August 1963 has been considered for the purpose of studying, the hydrography and a possible correlation between the plankton biomass and hydrography. August being the peak monsoon month along the west coast, the coastal upwelling phenomenon was quite conspicuous. A coastal belt of 20-25 kilometres width was characterised by a high abundance of zooplankton (Fig. 1 a, d).

Data during September 1963 was scanty between Cochin and Mangalore. But north and south of this, the features could be studied. Eventhough it was the fag end of the monsoon, the incursion of offshore subsurface waters into the shelf were still prevalent (Fig. 2 d) and the plankton biomass (Fig. 2 a) was comparable to those during August.

During October 1963, the thermal features near the coast still exhibited the presence of upwelling as evidenced by steep temperature gradient towards east in the horizontal at the 10 m, 20 m and 30 m isobaric levels (Fig. 3 d). This can further be confirmed by the dissolved oxygen distribution in the coastal areas (Fig. 3 f). The salinity maximum has migrated to lower depths than the premonsoon period (Fig. 3 e). A noticeable decrease in the plankton biomass has occurred during October (Fig. 3 a).

The depth of the mixed layer (Fig. 4 d) has increased much during November 1963 and more or less isothermal features prevailed in the upper layers. Upwelling features have completely disappeared. It could be observed that the zooplankton abundance has considerably decreased in the shelf region, than the previous months (Fig. 4 a). During November all the shelf stations contained between 301 and 900 cc of zooplankton per 1000 m^3 of water strained. The downward migration of the thermocline during November is also quite conspicuous. The mixed layer appeared to be rich in dissolved oxygen content also (Fig. 4 f) and the waters are 70-80% saturated with respect to dissolved oxygen content. It could be observed that the width of the plankton rich belt has increased than that in October.

The above mentioned belt has decreased in width during December 1963 (Fig. 5 a) when more stable conditions exist as far as the hydrography was concerned (Fig. 5 d). The meridional drifts were very weak and the fishery along the coast is maximum during this period. It is possible that the depletion of plankton during this period, may possibly be due to the consumption of plankton by fishes and other animals.

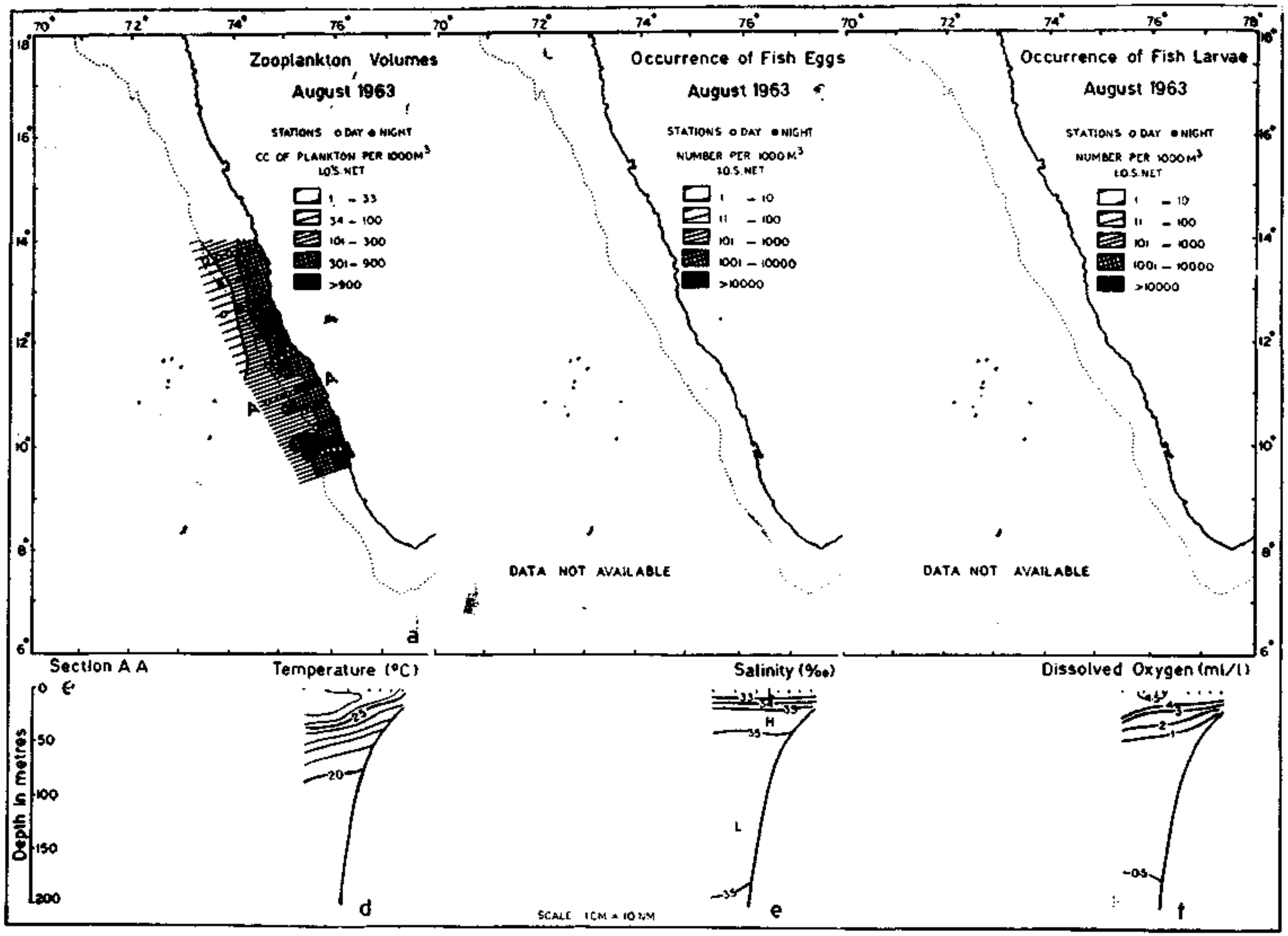

Fig. 1. Distribution of zooplankton biomass in relation to hydrography in August 1963.

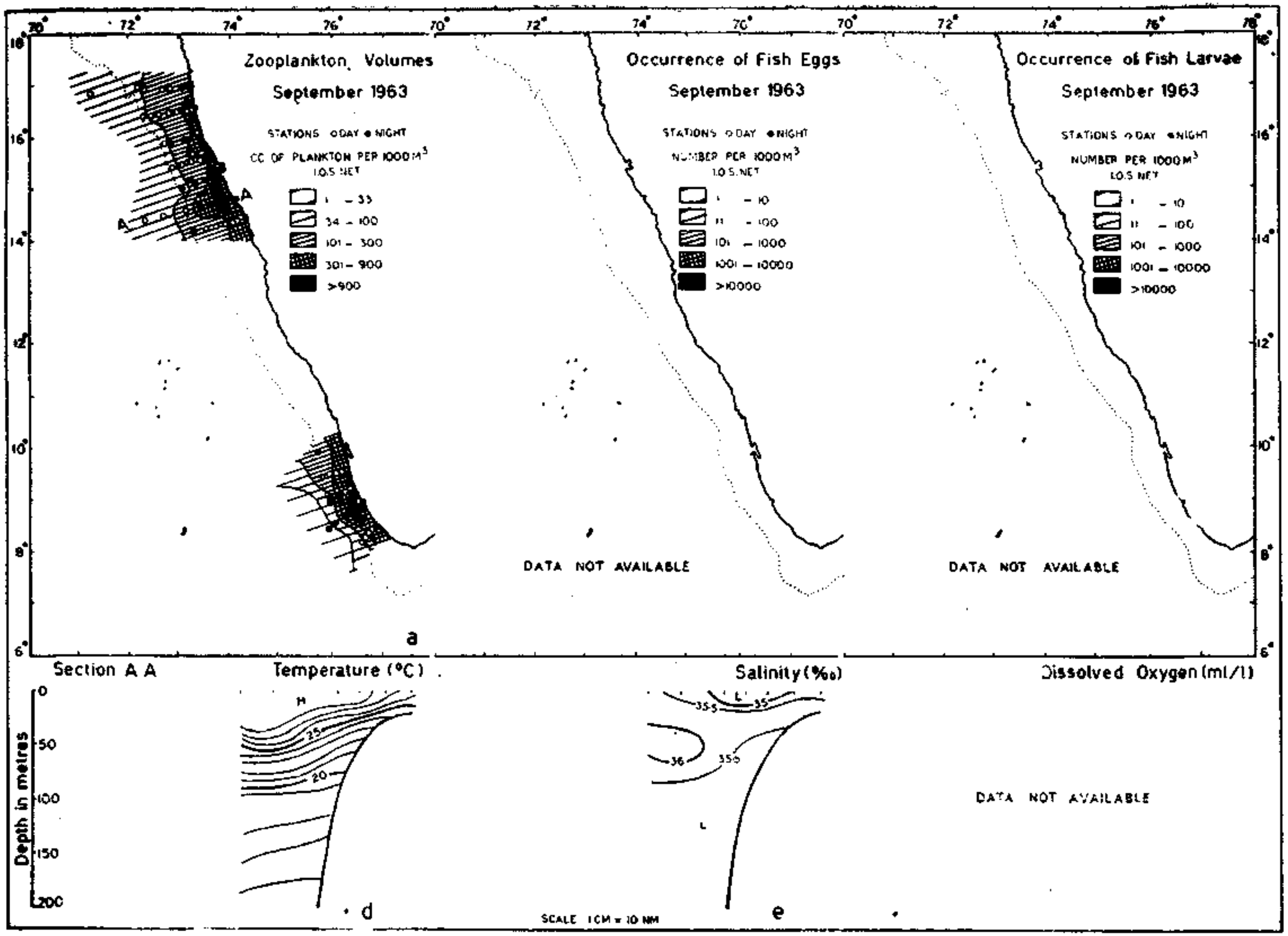

Fig. 2. Distribution of zooplankton biomass in relation to hydrography in September 1963.

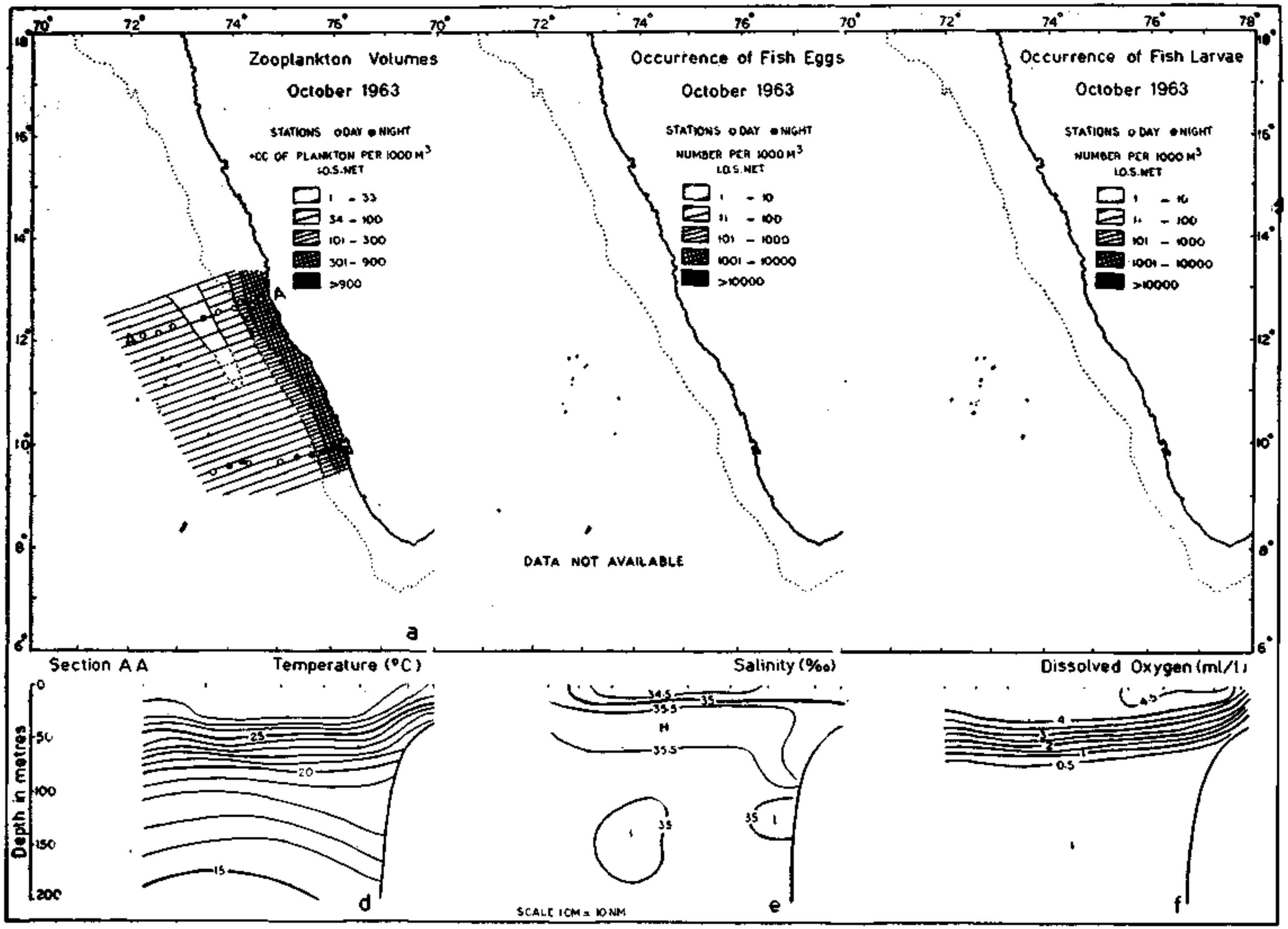

Fig. 3. Distribution of zooplankton biomass in relation to hydrography in October 1963.

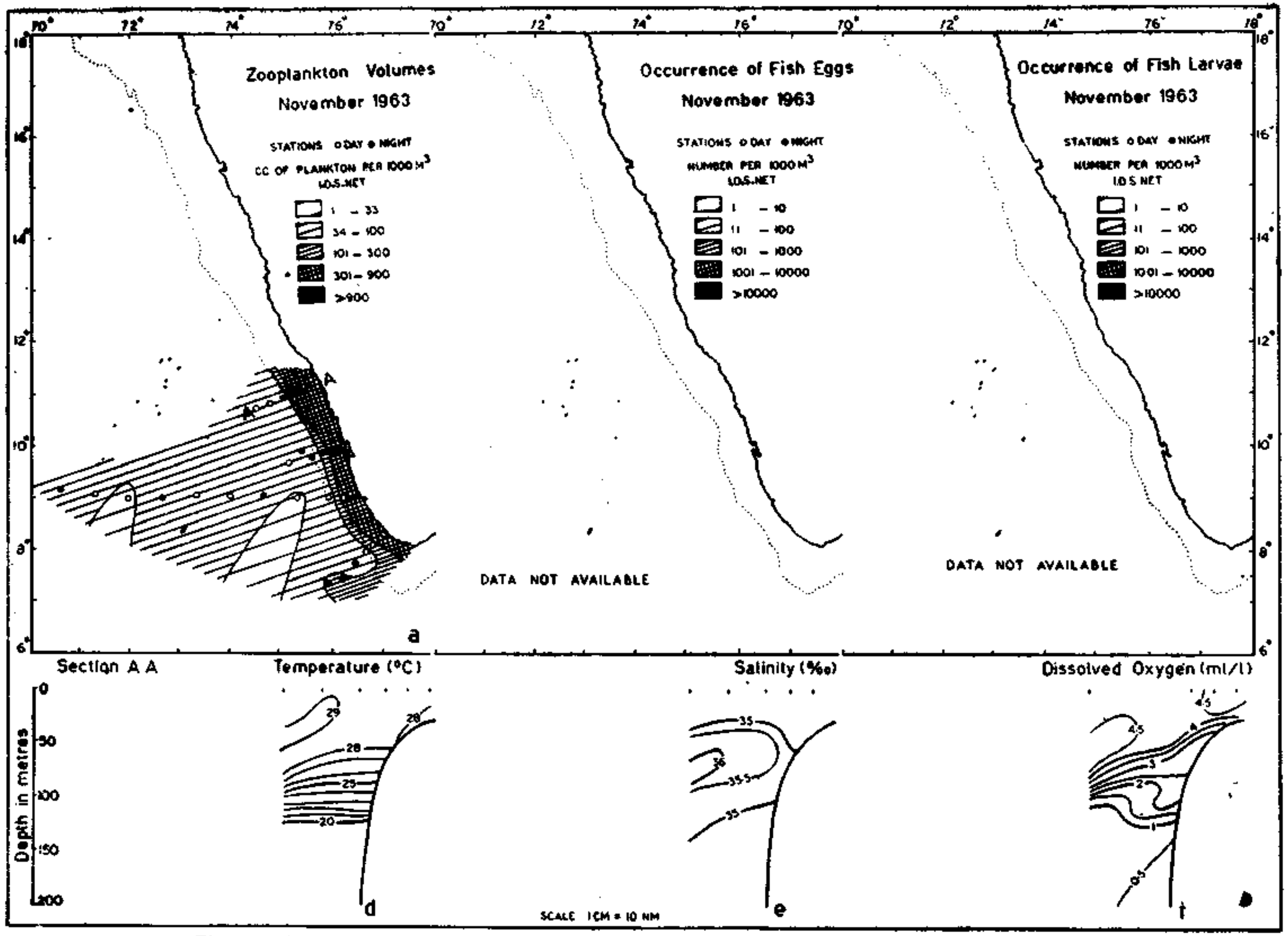

Fig. 4. Distribution of zooplankton biomass in relation to hydrography in November 1963.

The mixed layer appears to be truly homogeneous during February 1964 (Fig. 6 d) and there was a noticeable increase in the plankton biomass over the continental shelf (Fig. 6 a). From this month onwards data on fish eggs and larvae were also available. A reasonably good abundance of fish eggs and larvae could be observed at this time and the abundance of the latter being more (F ig. 6 b, c). The meridional drifts in the mixed layer appeared to be very weak, rather absent. Probably this is an environmental support for the eggs and larvae to remain more or less stationary.

A representative section during March 1964, covered the Quilon Bank area where a plankton abundant strip was observed and another one along the coast with a gap of depletion (Fig. 7 a). Presence of internal waves was observed in this area and in the western most region, a sort of divergence was also noticeable from the temperature structure (Fig. 7 d). Wavy nature of the isohalines at the top of the thermocline was also conspicuous. Dissolved oxygen values (Fig. 7 f) were comparable to those in February. The zooplankton abundance in the Quilon Bank area was comparable to those existing in the midcontinental shelf region. Considerable increase in the abundance of fish eggs and larvae was observed during March 1964 (Fig. 7 b, c). One noticeable feature in the larval distribution during March 1964 was the very high abundance in the near coastal region between 11° and 12° N and the total absence in the whole of the continental shelf between 9° and 11° N. In the offshore regions the larval abundance was higher.

With comparable features in the salinity and oxygen distribution patterns, during April 1964, the season progressed, but the summer increase in temperature values was observed. The internal wave patterns during March have disappeared and a much more stabilized thermal pattern existed (Fig. 8 d). The stratification of the thermocline in the vertical was more stronger than that in March 1964. A noticeable feature of this month was the very high abundance of zooplankton in the region off Cochin and the whole of the continental shelf was rich so to say in plankton biomass. A depletion was observed in the Quilon Bank area and as a matter of fact the waters were much poorer in plankton abundance beyond the continental shelf (Fig. 8 a). By the progress of the season (summer) the fish eggs and larval abundance was also found to be increasing gradually. The high values of larval counts were still existent in the 12° N area during April also, with another abundant region between Alleppey and Cochin. However the whole of the west coast between 8° and 13° N latitudes was rich in larval abundance whereas the abundance of eggs were less in the Cochin-Calicut area (Fig. 8 b, c).

During May 1964, monsoon features began to set in. Thus there was a noticeable decrease in temperature values in the shelf region and the trend of upward migration of the thermocline was also visible (Fig. 9 d). Coastward up-slope of the isotherms although present could not be considered clearly indicative of the approaching monsoon. A decreasing trend in the plankton abundance was noticeable and that too within the continental shelf (Fig. 9 a). The zone where high abundance of eggs and larvae was observed during April, has migrated further south (Fig. 9 b, c). It is probable that the southward coastal drift might have its influence in shifting this abundance zone southwards.

But during June 1964, the monsoon features have remarkably developed. The plankton abundance has increased as can be seen from the increase in width of the plankton abundance belt along the

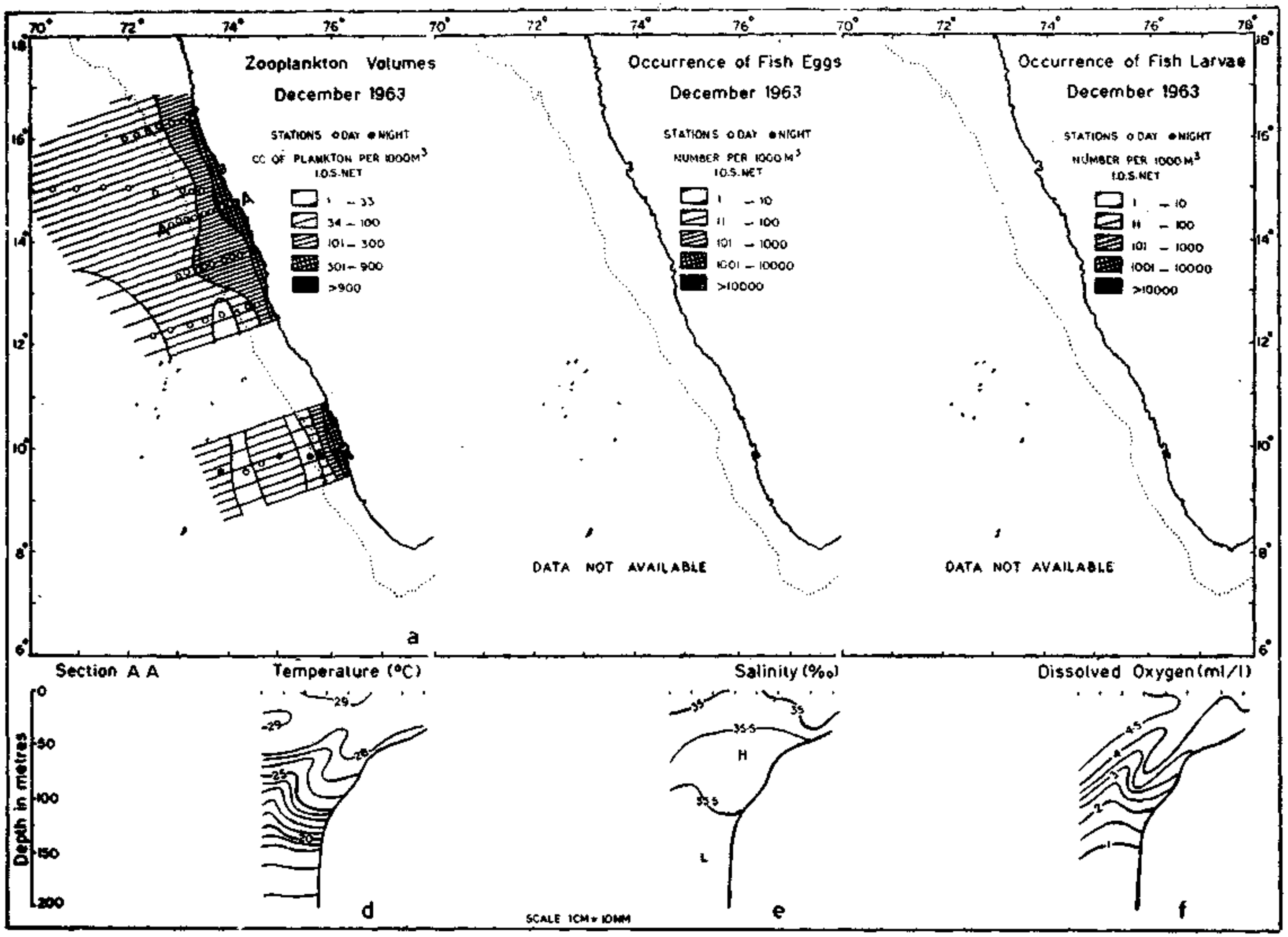

Fig. 5. Distribution of zooplankton biomass in relation to hydrography in December 1963.

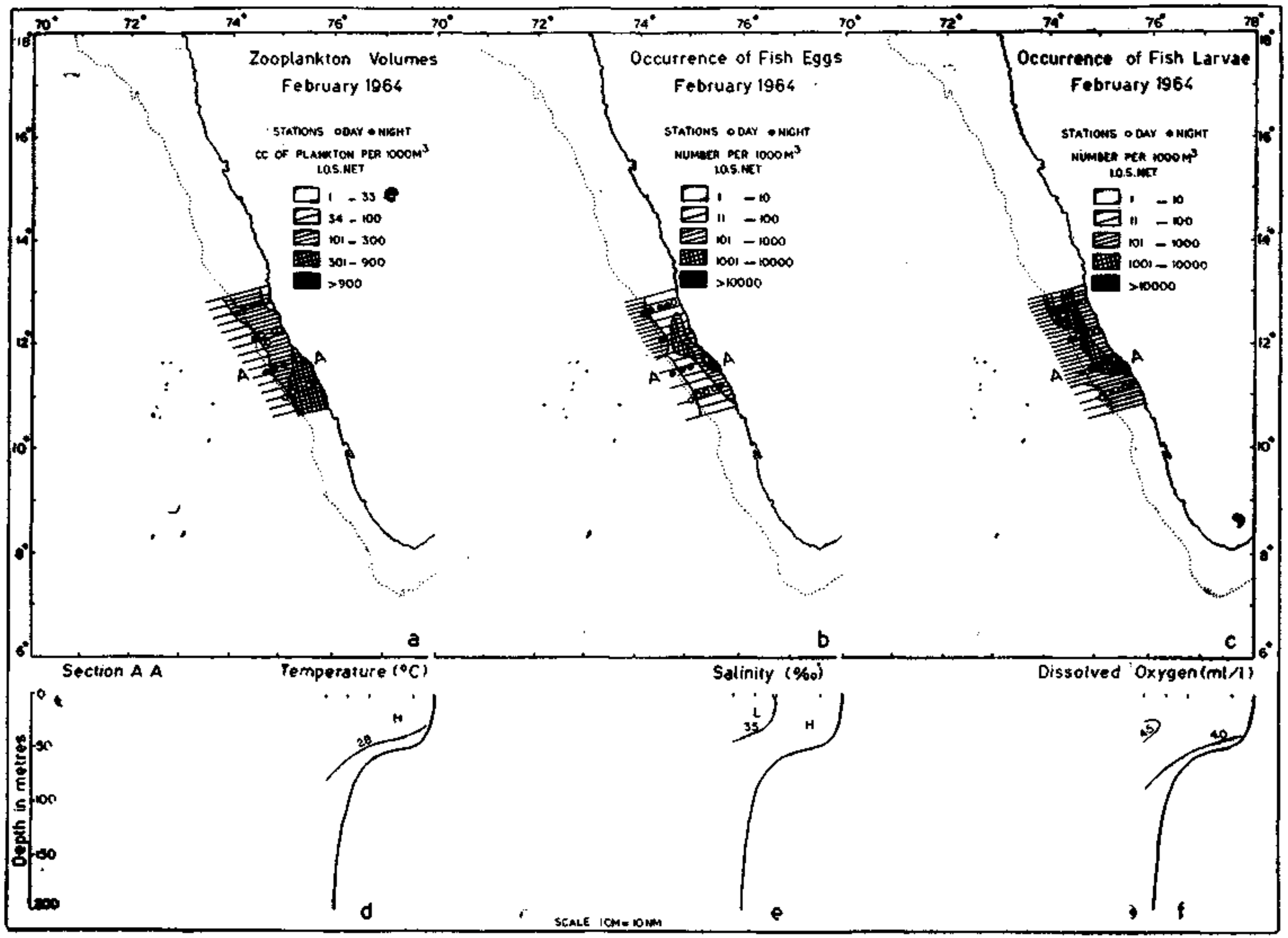

Fig. 6. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in February 1964.

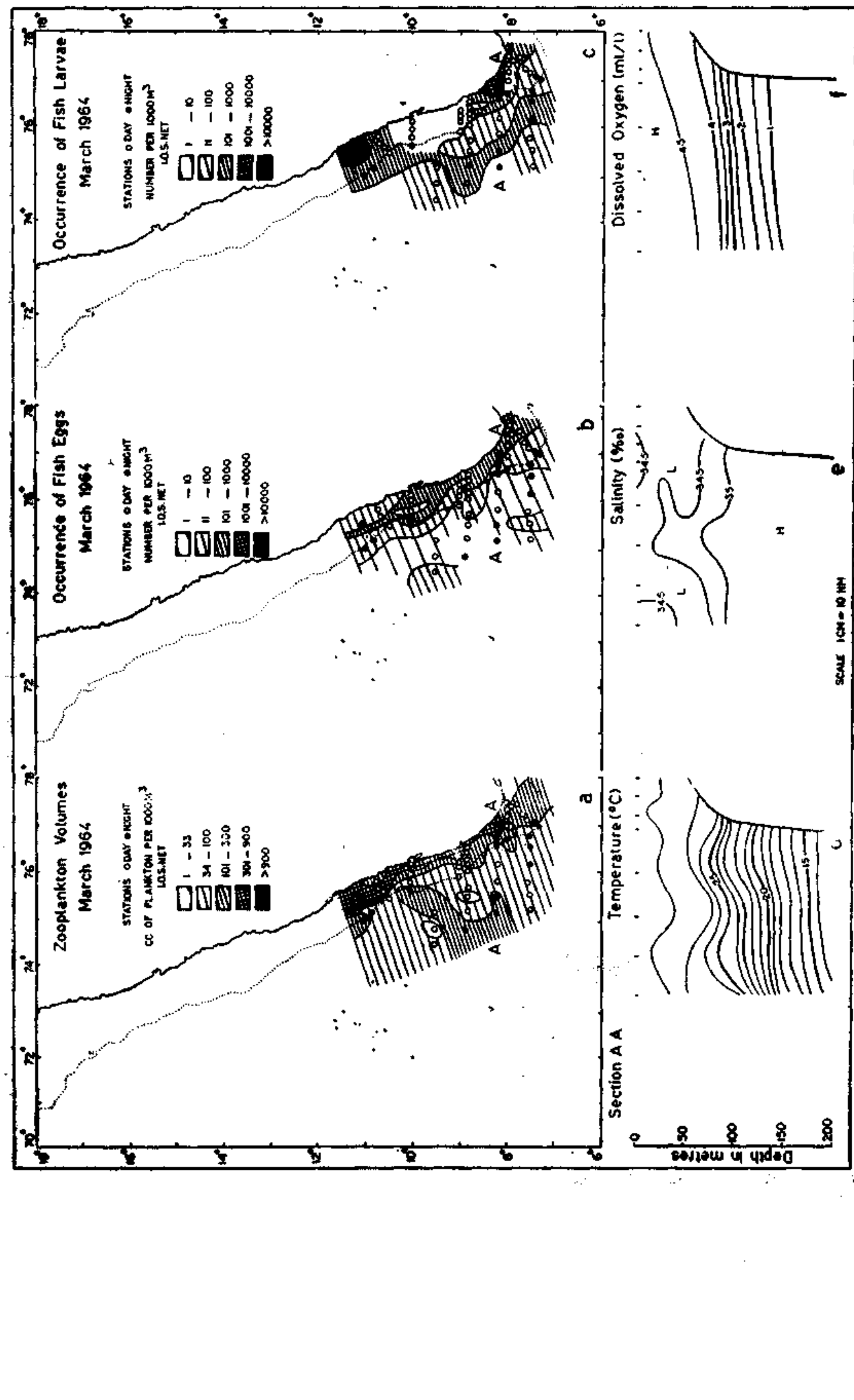

Fig. 7. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in March 1964.

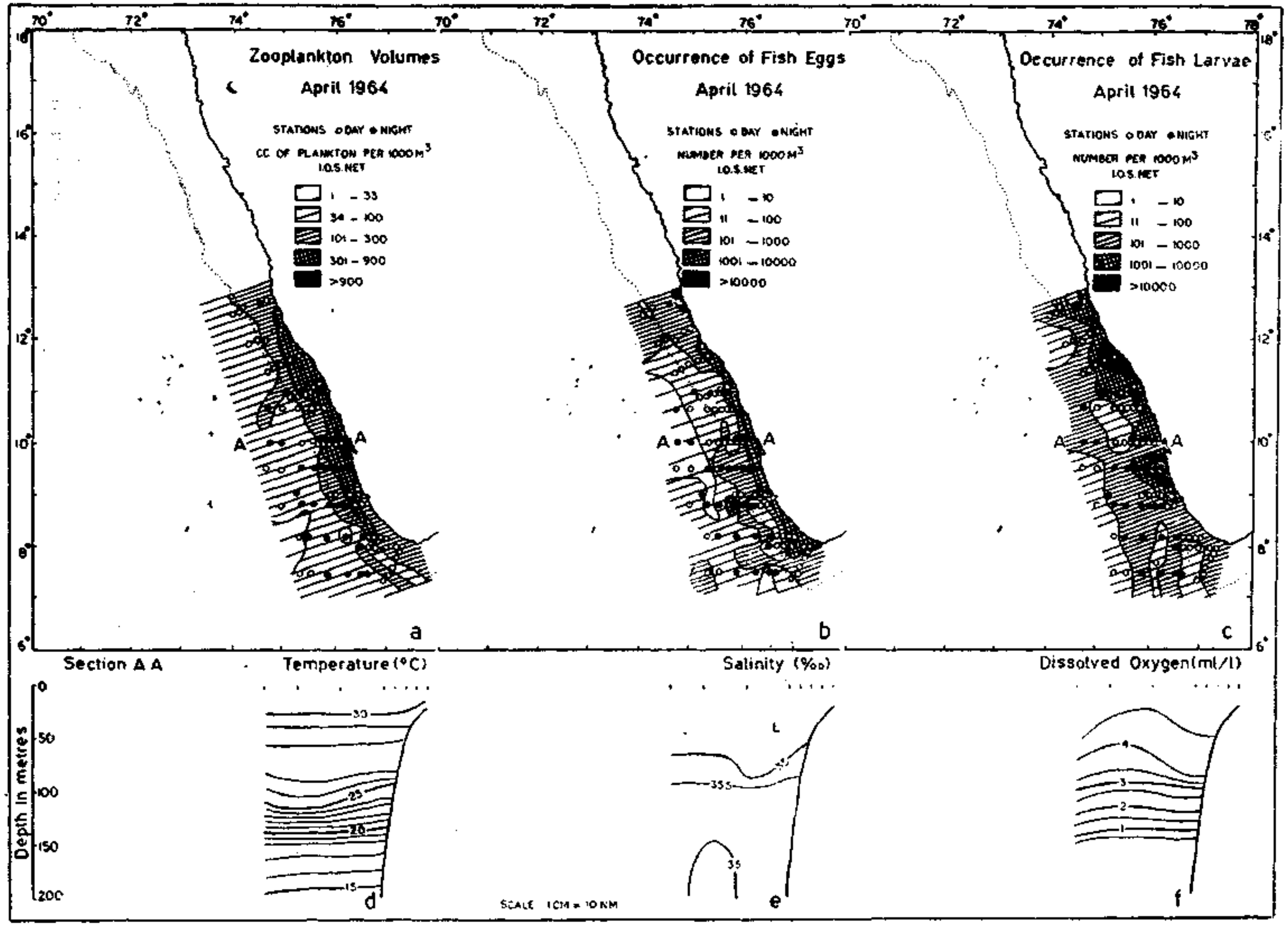

Fig. 8. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in April 1964.

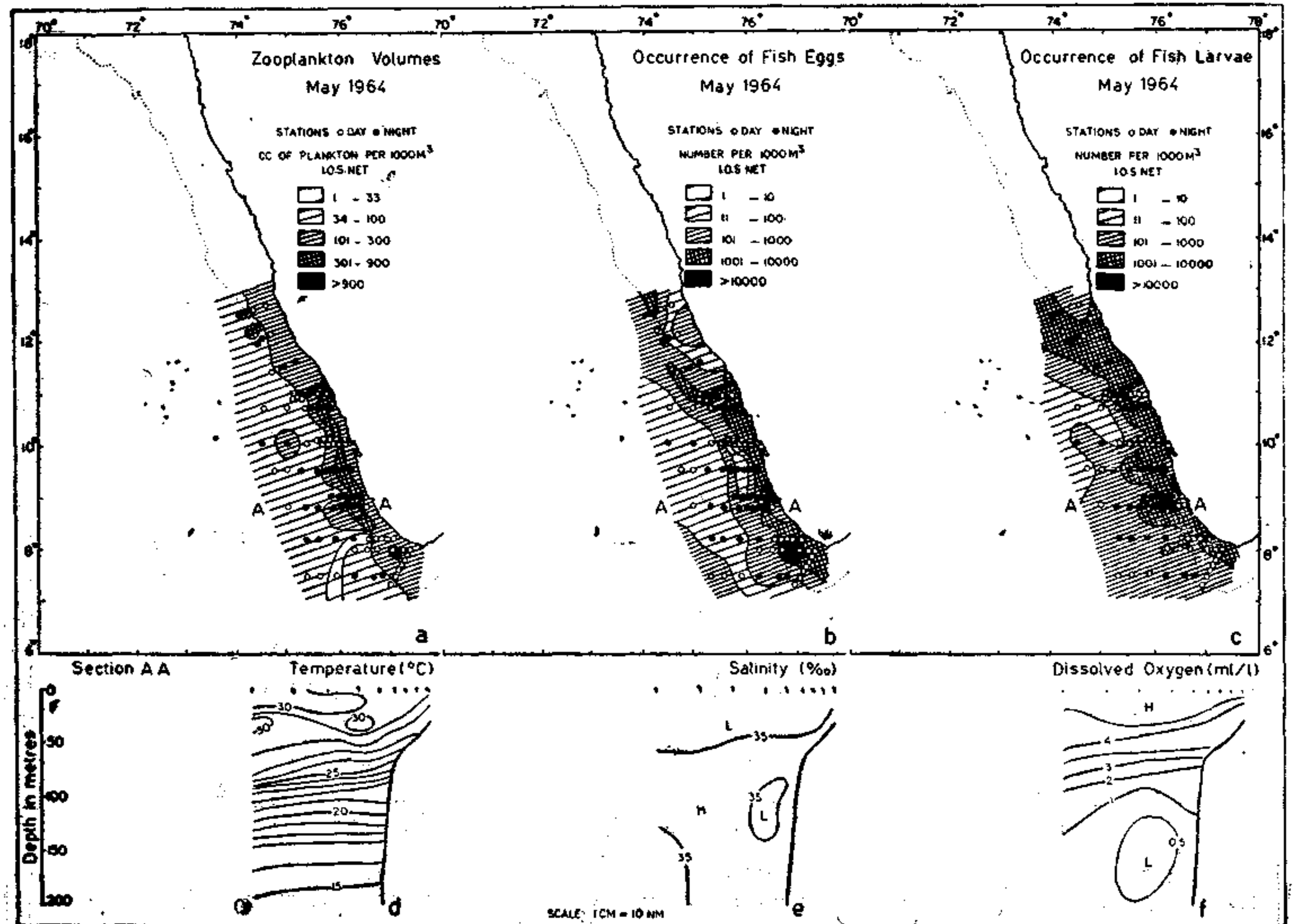

Fig. 9. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in May 1964.

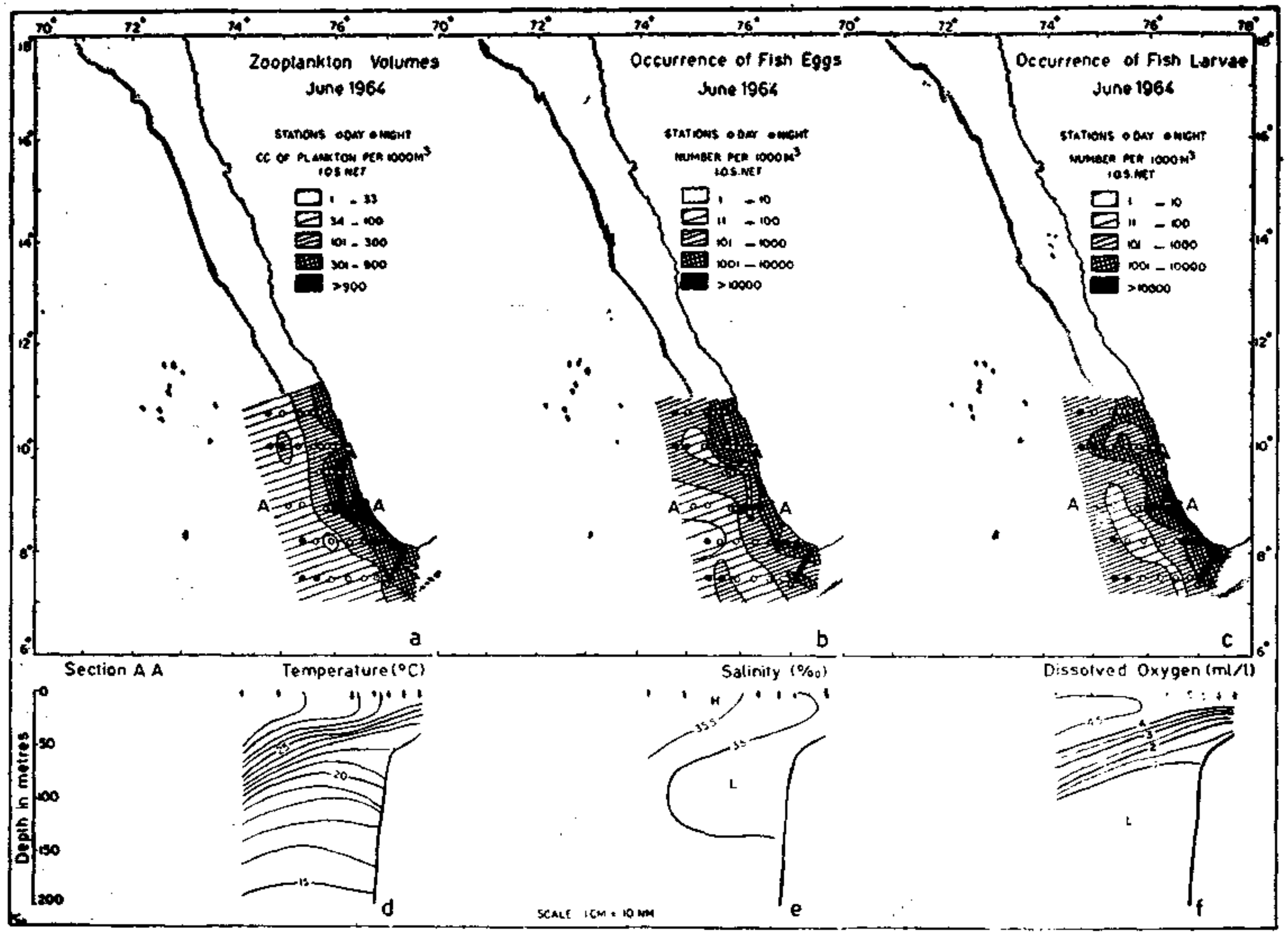

Fig. 10. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in June 1964.

coast (Fig. 10 a). Clear cut indications of upwelling are obvious during June (Fig. 10 d, f). The remarkable coastward upslope of the isotherms and the isolines of dissolved oxygen content are considered as good indications of the incursion of the subsurface waters into the continental shelf. The incursion of these nutrient rich waters into the shelf resulted in a very high abundance of zooplankton in the region especially in the region off Quilon as can be seen from the figure. The larval abundance was maximum in the near coastal area (Fig. 10 c) and this incidentally coincided with the region where maximum zooplankton volumes were observed. However the occurrence of fish eggs have a decreasing trend by the progressing monsoon (Fig. 10 b).

A zone of sinking, rather convergence was observed during July 1964 in the offshore regions and the intensity of the coastal upwelling was more than in June (Fig. 11 d). The thermocline has migrated to the very surface in the coastal areas, and a steep gradient in dissolved oxygen content was observed from surface downwards (Fig. 11 f). All these amount to a much higher plankton abundance during July than in June, especially in the southern region (Fig. 11 a). Curiously enough a remarkable decrease in the quantum of eggs and larvae was observed during July. Probably the migration of adult fish from the upwelling zones during monsoon can be cited as a causative factor (Fig. 11 b, c).

Data was deficient during August and September 1964 and during the end of the postmonsoon period in October, indications of upwelling were still perceptible along the west coast (Fig. 12 d). The thermocline was still very near to the surface and the downward gradient of dissolved oxygen values were also noticed (Fig. 12 f). This further appeared to support a good abundance of zooplankton especially in the region off Calicut to Quilon and by December there was a drastic decrease in the plankton abundance (Fig. 13 a). An examination of the hydrographic features revealed that upwelling had more or less completely subsided and the downward migration of the thermocline was also observed. The mixed layer was again observed to be mostly isothermal (Fig. 13 d). The weakening of the monsoon by October has resulted in an increasing trend in the eggs and larvae distribution (Fig. 12 b, c). But during winter (December) the abundance of fish eggs and larvae in the northern regions was much poor (Fig. 13 b, c).

Sinking of isohalines from the offshore region was observed in the region off Cochin during January 1965 with the salinity maximum at the top of the thermocline with a core value of 36.3‰ at a depth of 60-70 m (Fig. 14 d). The sinking was perceptible in the thermal distribution pattern also although at a deeper depth. Again a noticeable decrease in the abundance of zooplankton (Fig. 14 a) was conspicuous which feature was observed during December 1963 and January 1964 also. It is worthwhile to recollect the probable reason for this depletion which has already been discussed. High depletion in the fish eggs was observed from Cape Comorin to Cochin although the larval abundance was adequate (Fig. 14 b, c). Again the latter can be referred side by side with zooplankton abundance.

Comparable features existed in April 1965 also as in 1964, as far as plankton abundance was concerned although a region of high abundance with a very small coverage during 1964 differentiated the conditions in the region off Cochin (Fig. 15 a). Typical summer features prevailed as far as the environmental hydrography was concerned (Fig. 15 d, e, f). As in 1964, a noticeable increase in the larval quantum was observed during April 1965 (Fig. 15 c) although the abundance of fish eggs was not much (Fig. 15 b).

The prolongation of summer hydrographic features during May 1965 (Fig. 16 d, e, f) resulted in a decrease in zooplankton during this month (Fig. 16 a) than in May 1964. A glance of the thermal distribution pattern for May 1964 would reveal that the incursion of offshore subsurface waters into the shelf region has already started whereas in May 1965 the thermal pattern reveals the presence of internal waves. The difference in hydrography may contribute to the higher abundance during 1964 than in 1965. During May 1965 the eggs and larval abundance was much less compared to 1964 (Fig. 16 b, c) coinciding with the decrease in zooplankton. The delay in the onset of monsoon and in the attainment of the environmental monsoon features of the waters probably contributed to the variation in the zooplankton biomass between 1964 and 1965.

The higher intensity of upwelling along the west coast during June 1965 than the previous year can be said to be a causative factor for the higher abundance of zooplankton along the coast during June 1965 (Fig. 17 a). Although there was a maximum region in 1964, the spatial extent and the coastal congregation of the zooplankton was more during 1965. The horizontal eastward temperature gradient was much more intense during 1965 (Fig. 17 d) in the continental shelf region than in 1964. Such a trend in the distribution pattern was reflected in the case of dissolved oxygen also (Fig. 17 f). The meridional extent of the zone of larval abundance has increased markedly during June 1965 and likewise that of fish eggs also (Fig. 17 c). But a narrow coastal belt was still in a depleted condition as far as the distribution of fish eggs was concerned (Fig. 17 b, c).

Due to heavy monsoon, collection of data was interrupted during the later half of the monsoon season in 1965 and when the collections could be resumed in October, all the monsoon characteristics have mostly disappeared and so to say a very drastic decrease in the plankton abundance was observed (Fig. 18 a). Most of the investigational areas supported an abundance of only below 100 cc/1000 m^3 and in the offshore regions, abundance was very low. Thus it can be seen that the thermocline has migrated further down to about 50 m depth from about 15 m during monsoon (Fig. 18 d). The stratification in the vertical column was much more stable than that in monsoon and southward drifts in the mixed layer observed during June were mostly absent during October. These depleted conditions were reflected in the distribution pattern of fish eggs and larvae also (Fig. 18 b, c).

Comparable conditions existed during November 1965 (Fig. 19 a, b, c) and in December 1965 (Fig. 20 a, b, c). Paucity of data did not permit a true comparison with 1964 and a representative hydrographic section could not be worked out during December 1965. However the region between 11° and 14° N latitudes offered a primary comparison in the sense that over the continental shelf and slope, plankton abundance was very low in both years (Fig. 19 a, 20 a). Data for fish eggs and larvae was also scanty and in general the abundance was lesser than that in 1964.

The mostly isothermal features in the mixed layer during January 1966 and the well stratified thermocline from 100-200 m were typical indications of the approaching summer (Fig. 21 d). The mixed layer again contained good amount of oxygen (Fig. 21 f) and the plankton abundance (Fig. 21 a) was a little bit more than in December 1965. However the larval abundance from 12° - 14° N along the coast over the continental shelf edge was higher than in

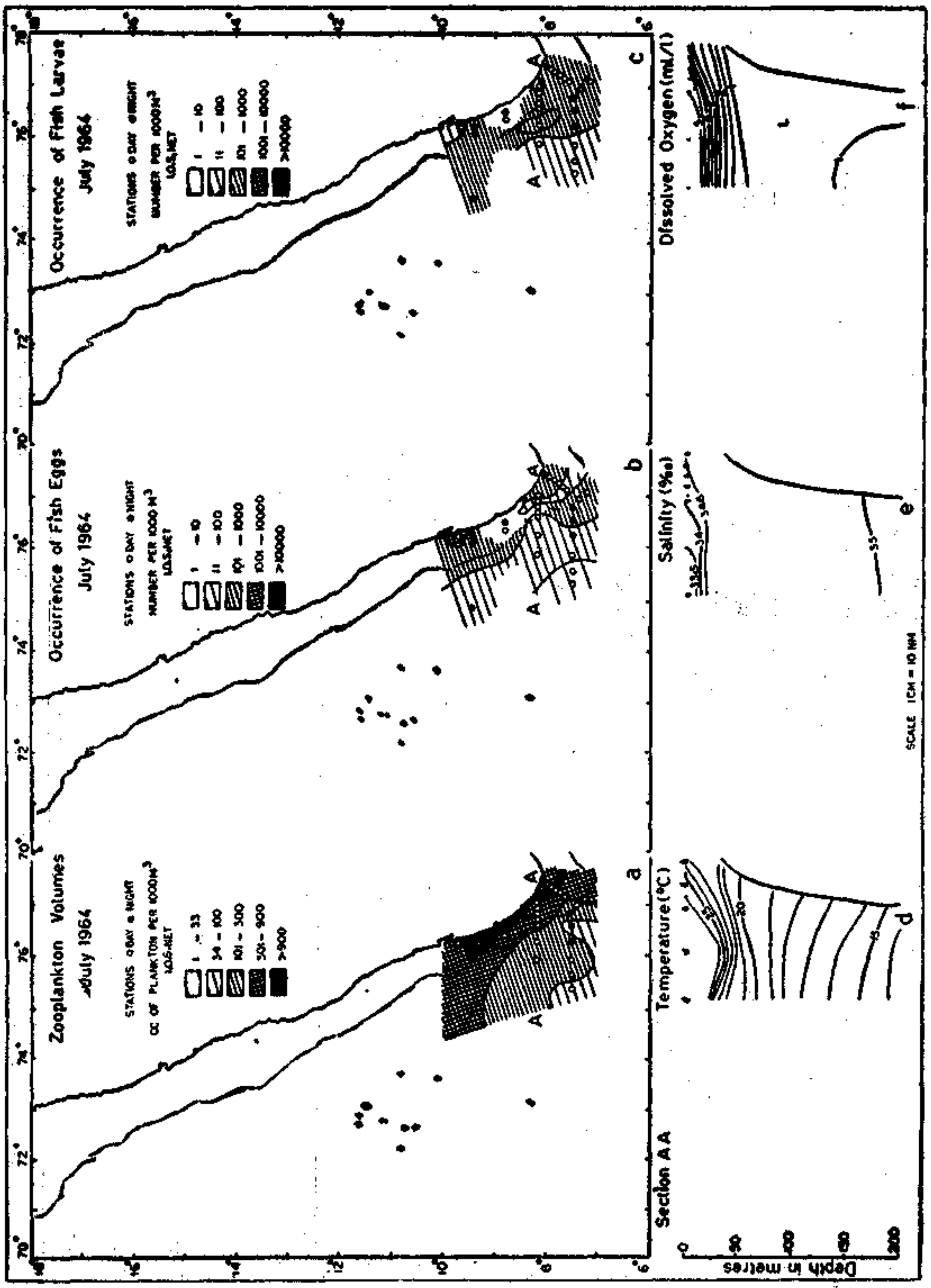

Fig. 11. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in July 1964.

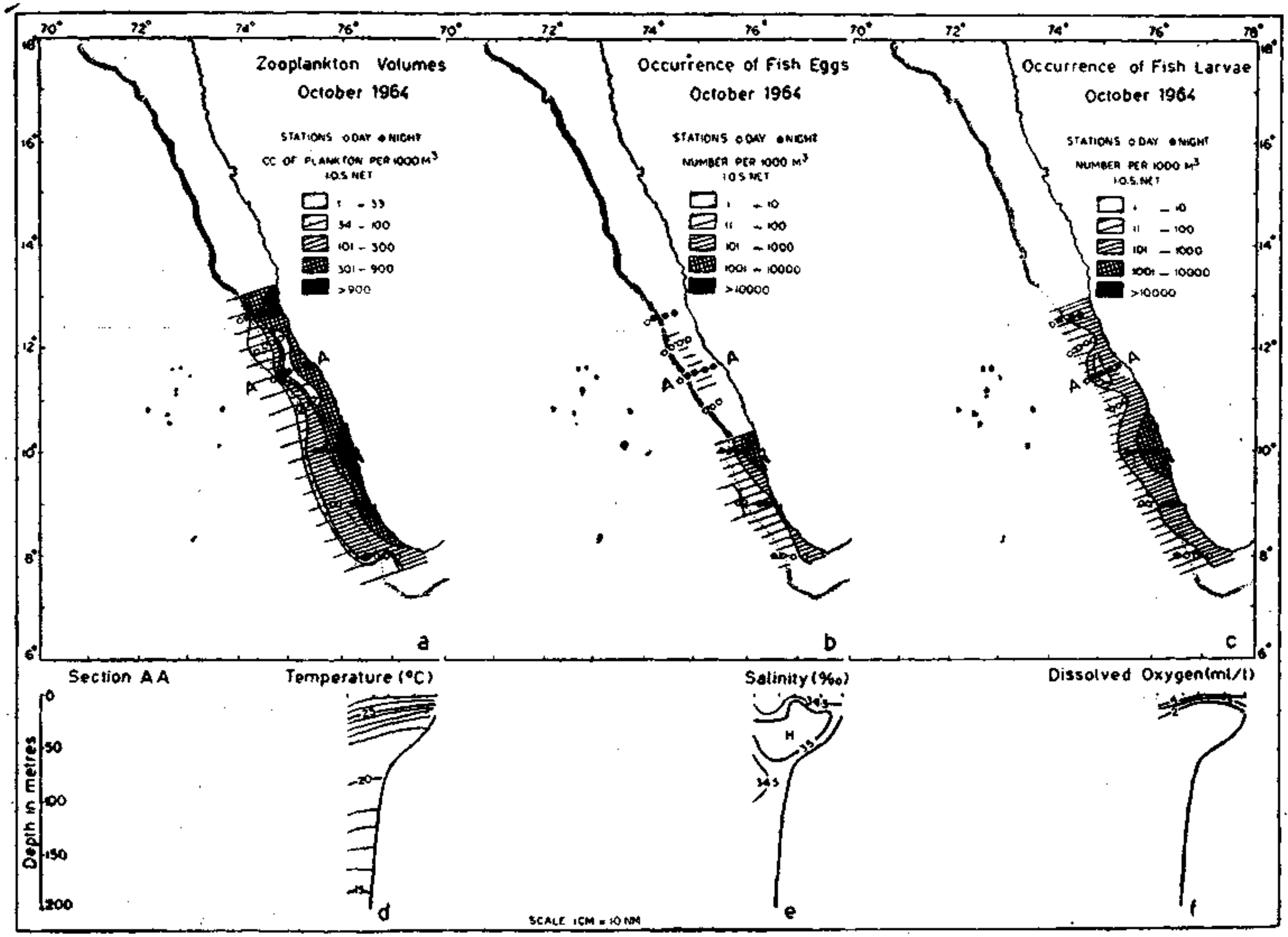

Fig. 12. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in October 1964.

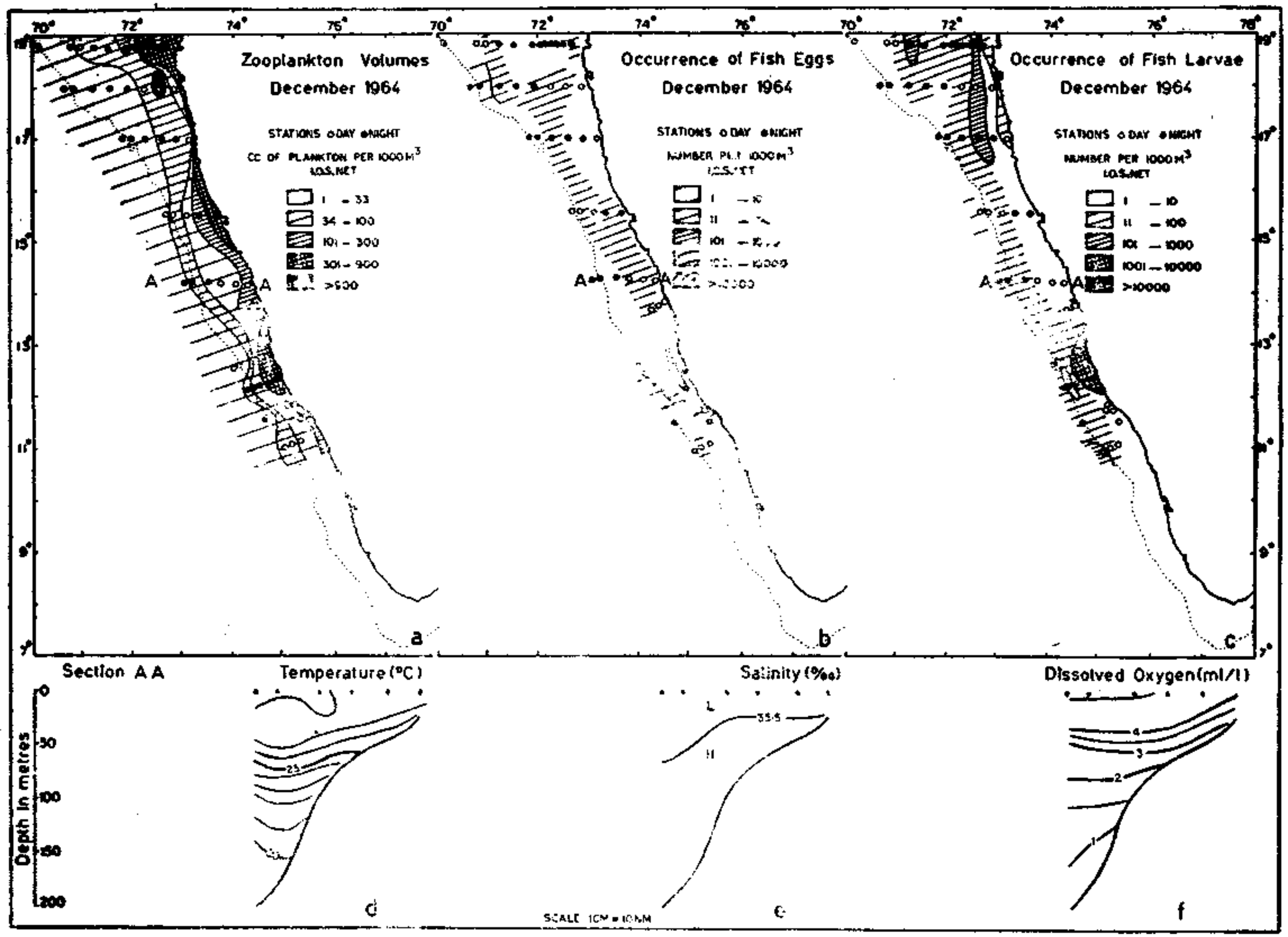

Fig. 13. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in December 1964.

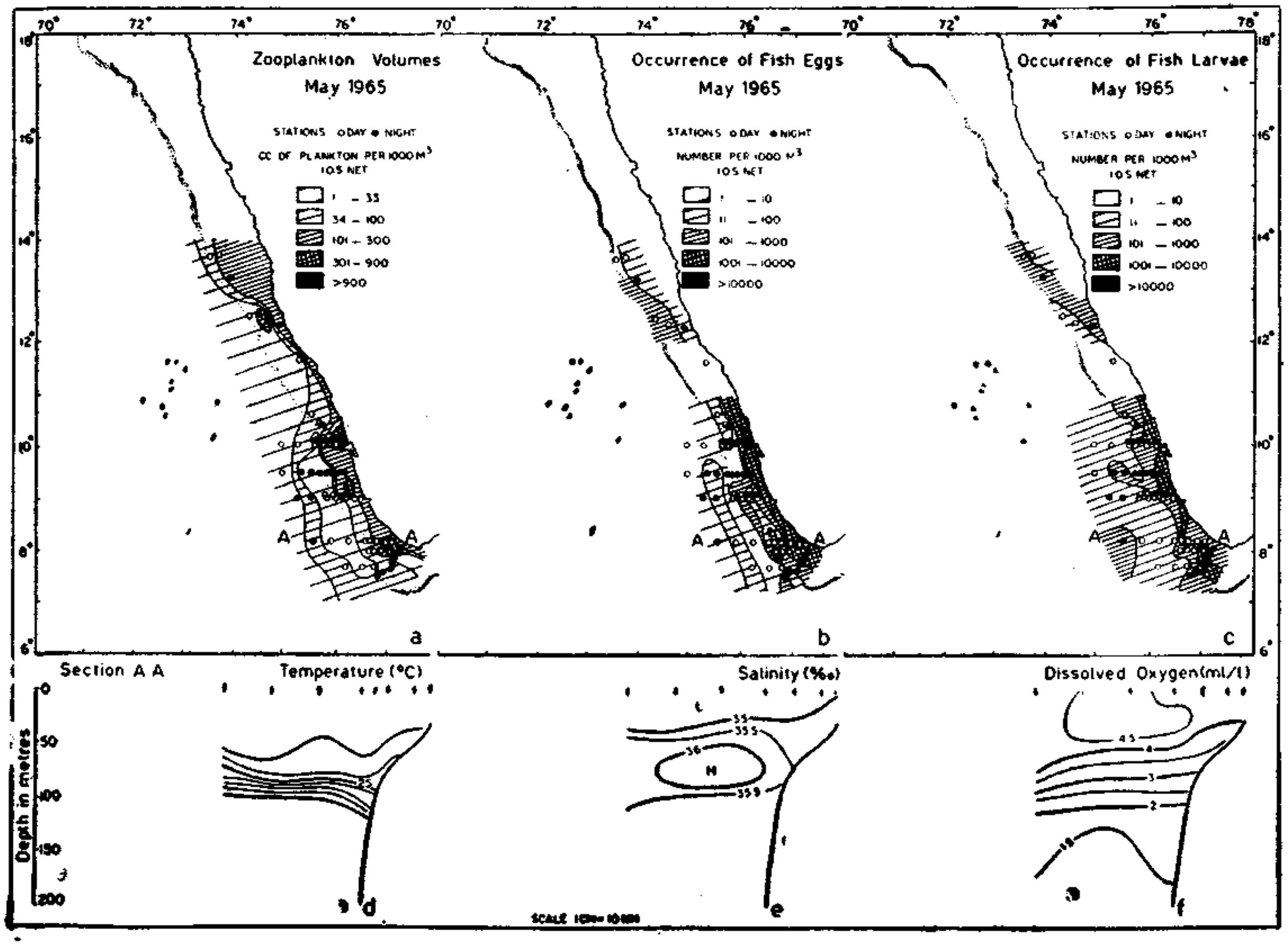

Fig. 16. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in May 1965.

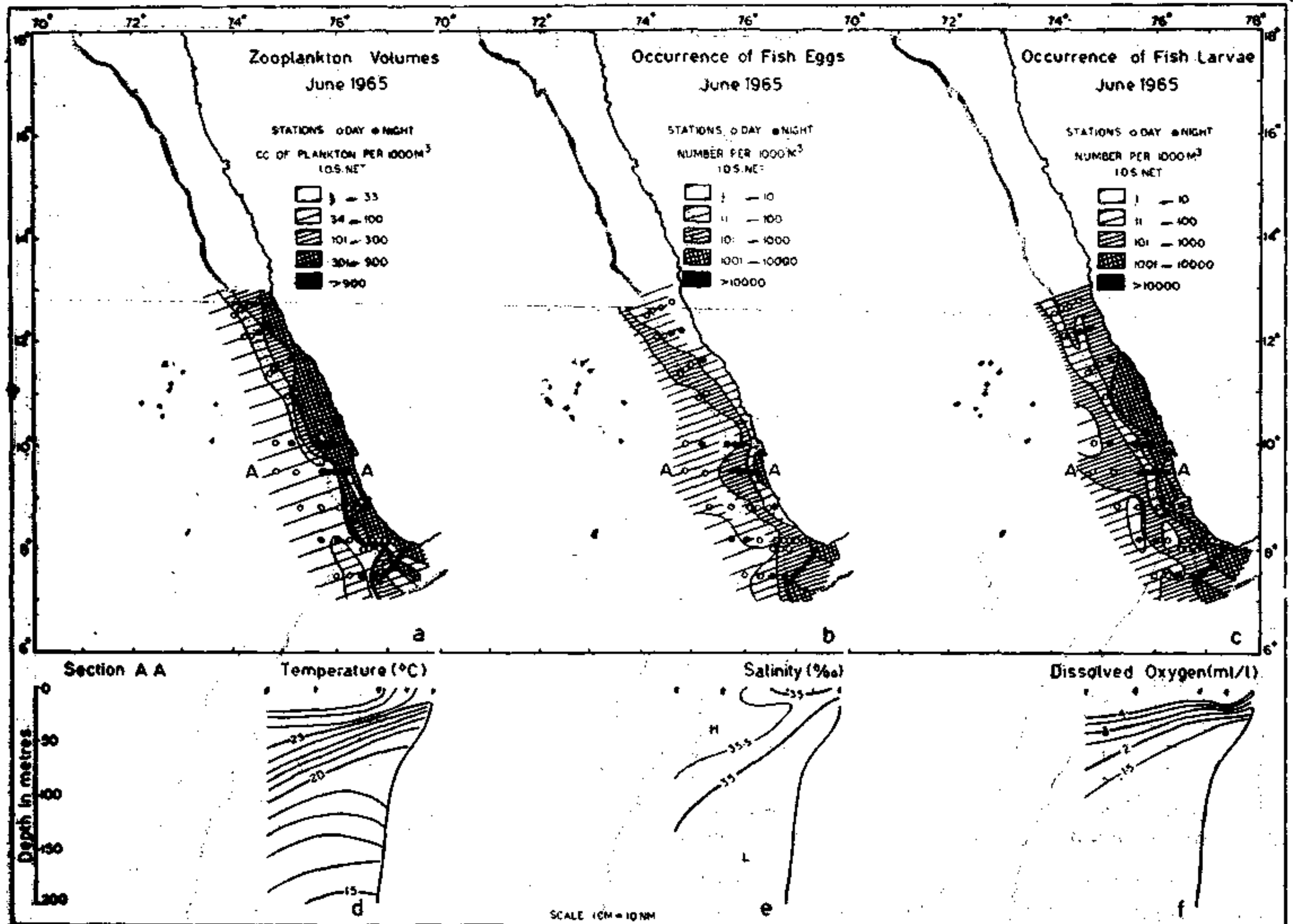

Fig. 17. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in June 1965.

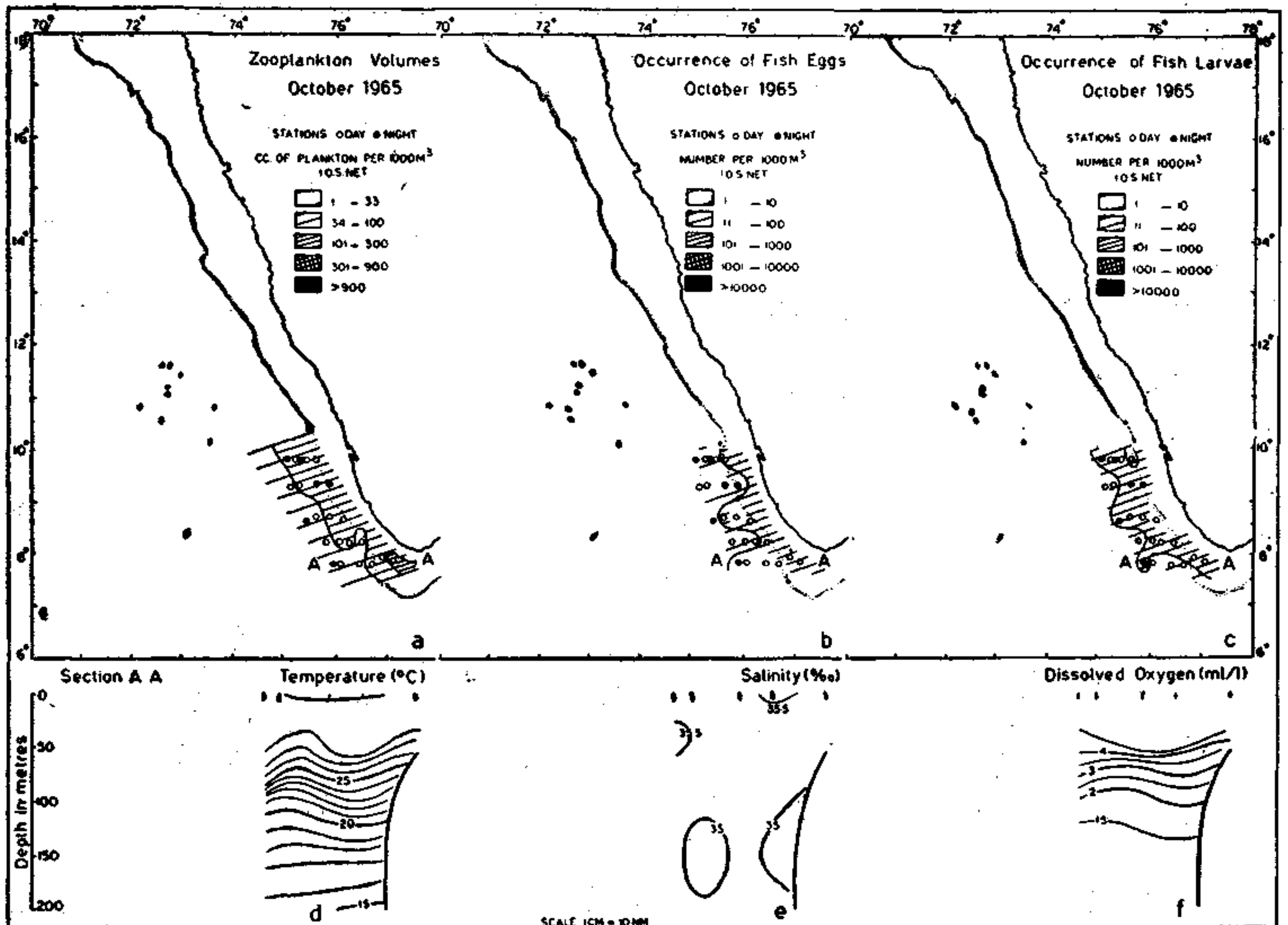

Fig. 18. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in October 1965.

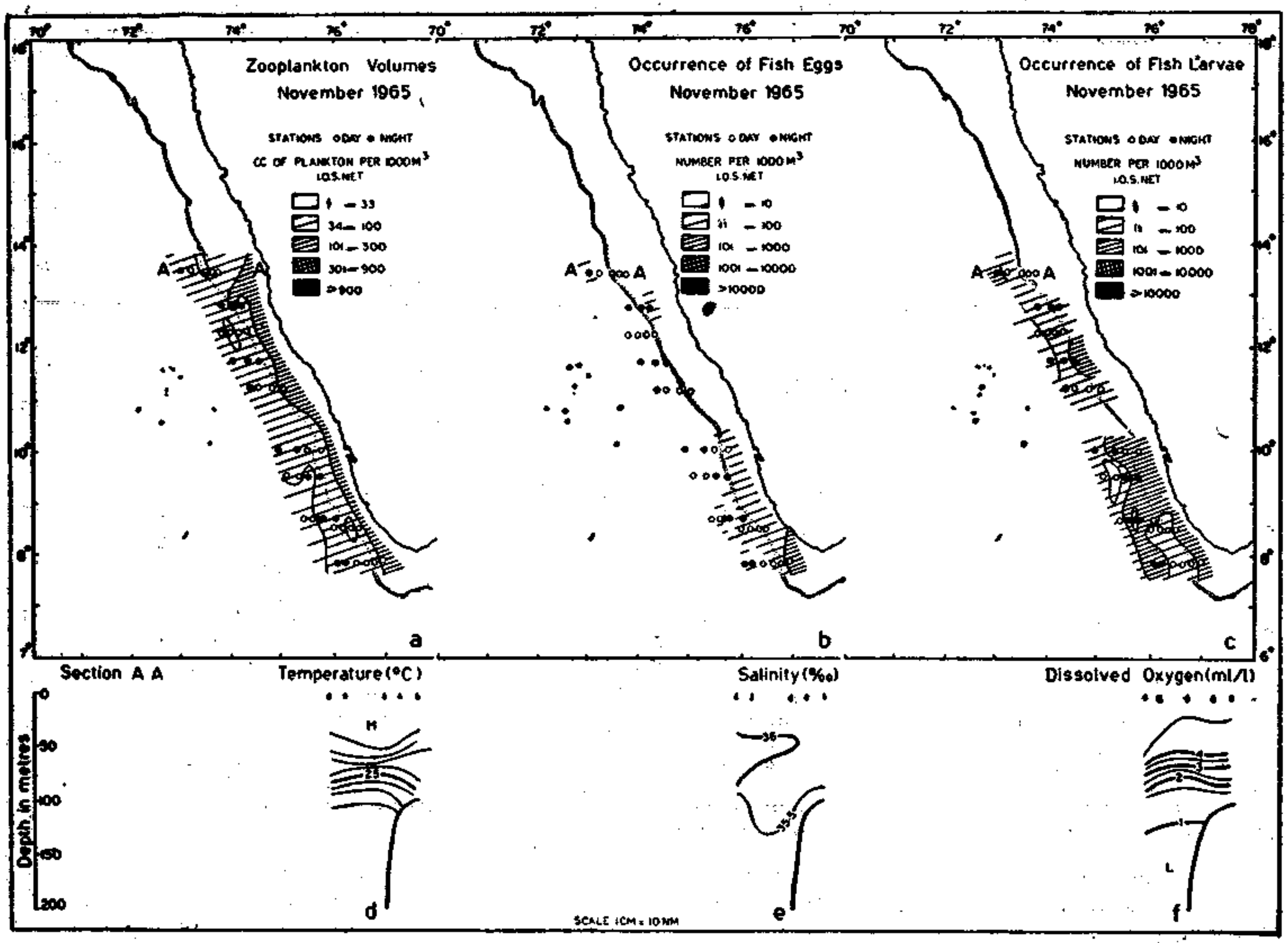

Fig. 19. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in November 1965.

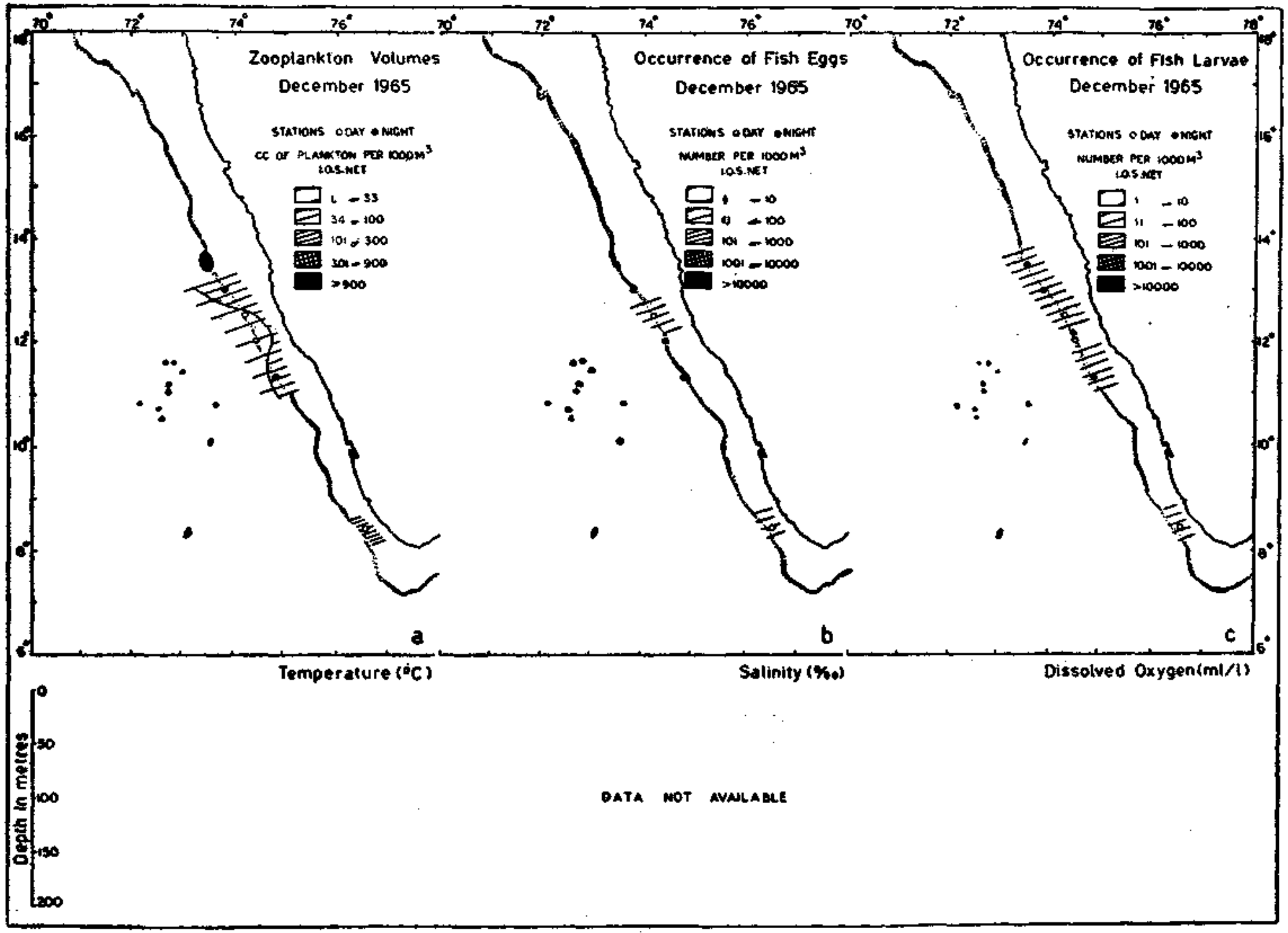

Fig. 20. Distribution of zooplankton biomass, fish eggs and larvae in December 1965.

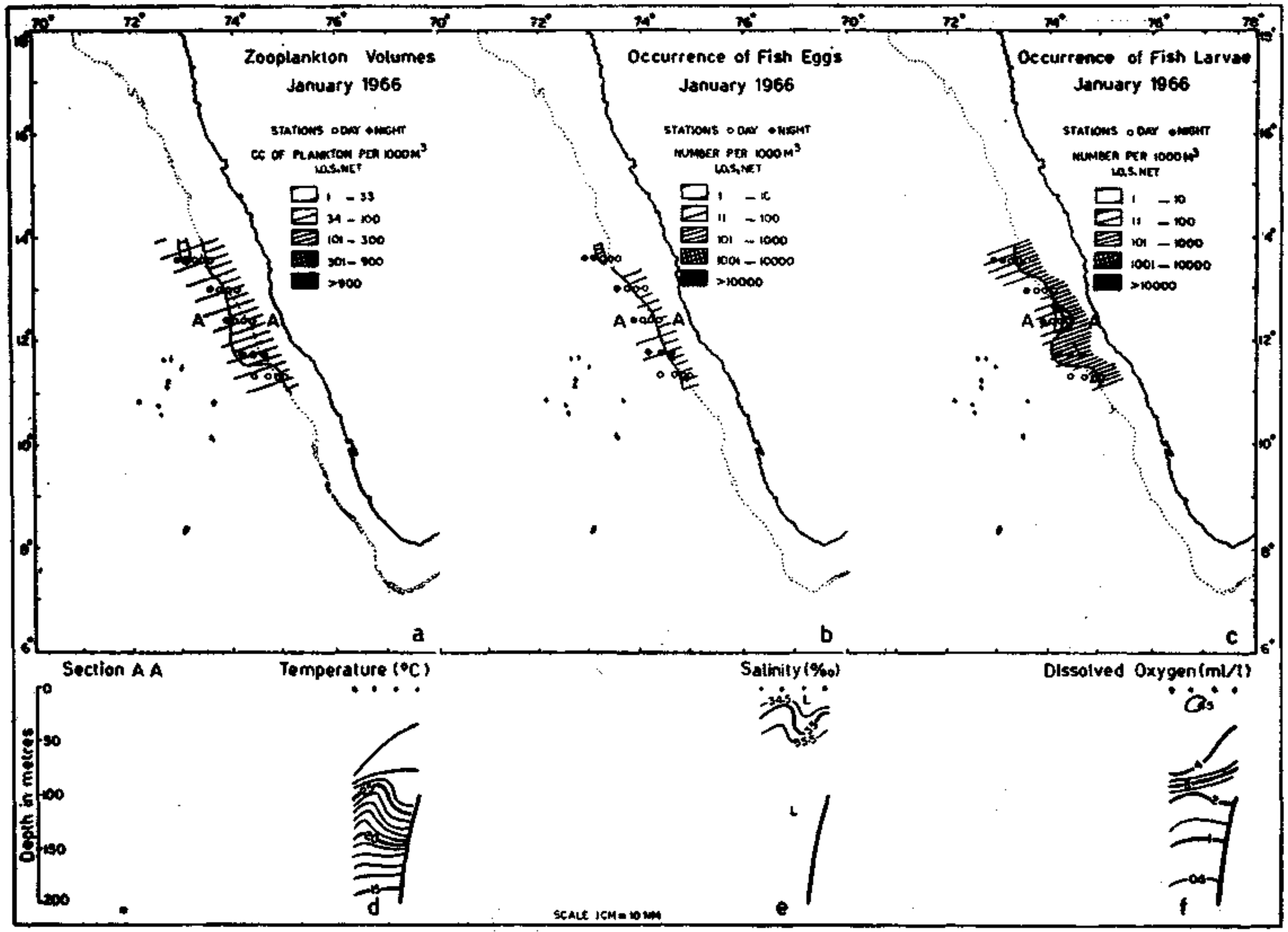

Fig. 21. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in January 1966.

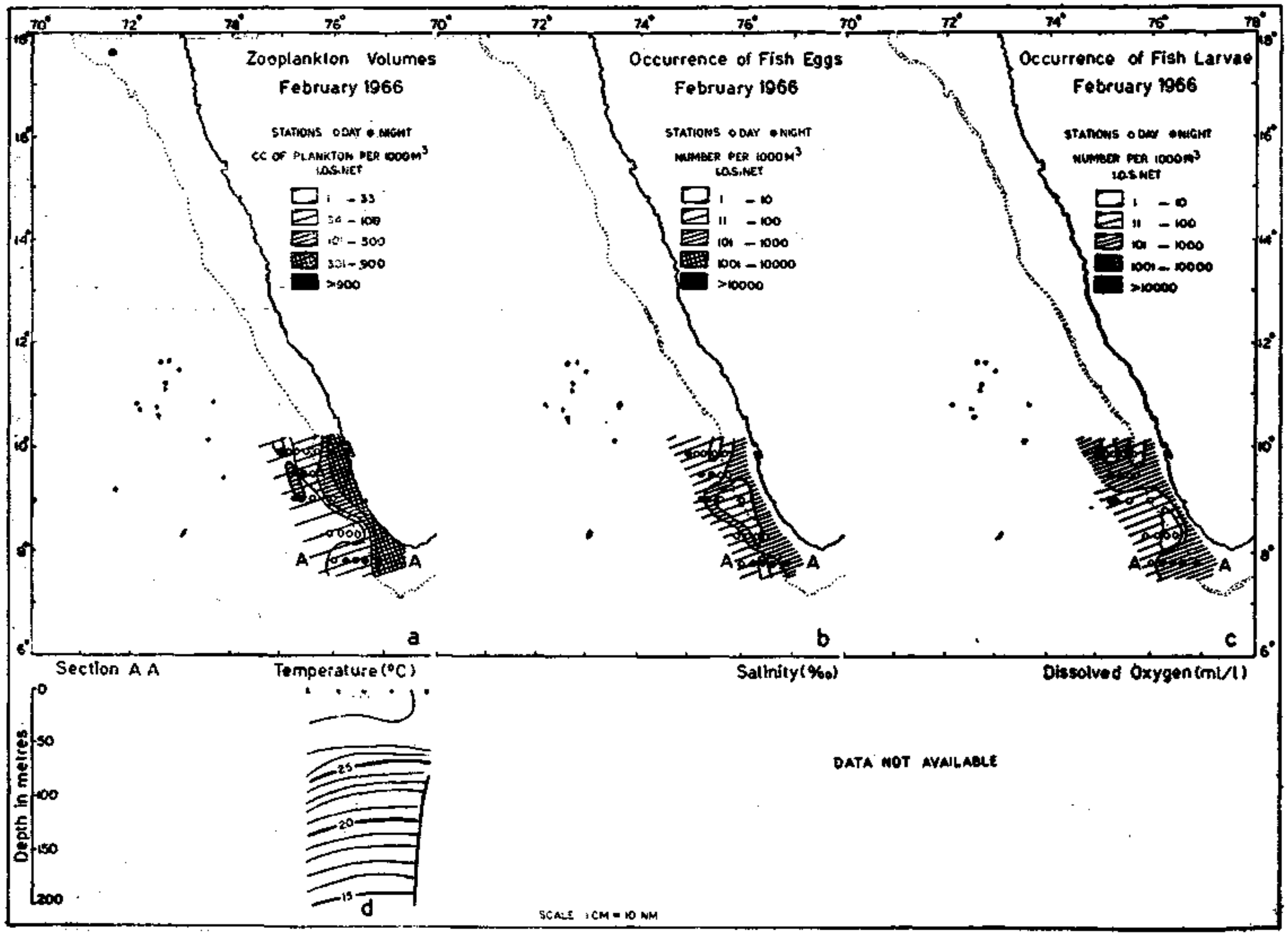

Fig. 22. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in February 1966.

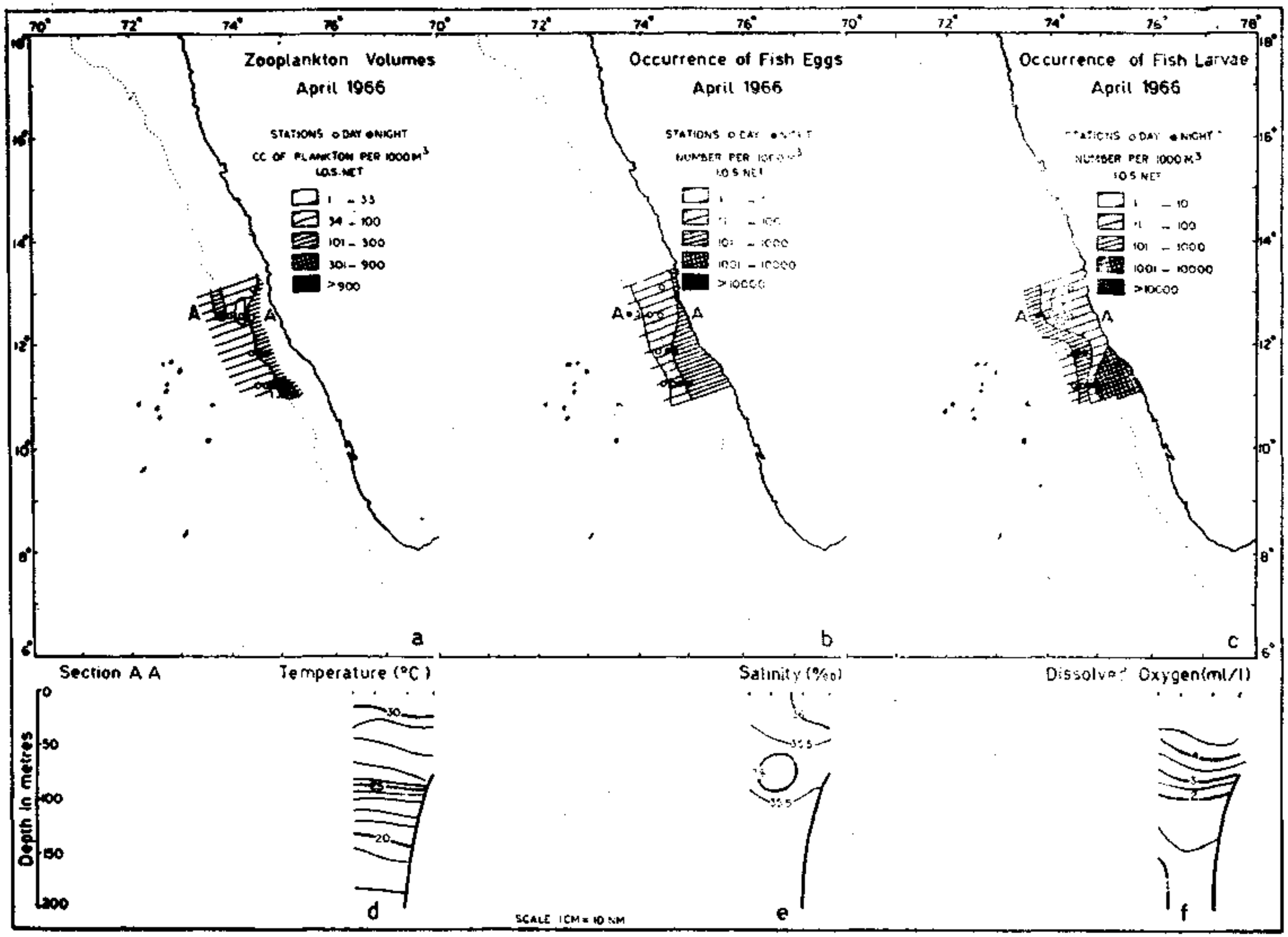

Fig. 23. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in April 1966.

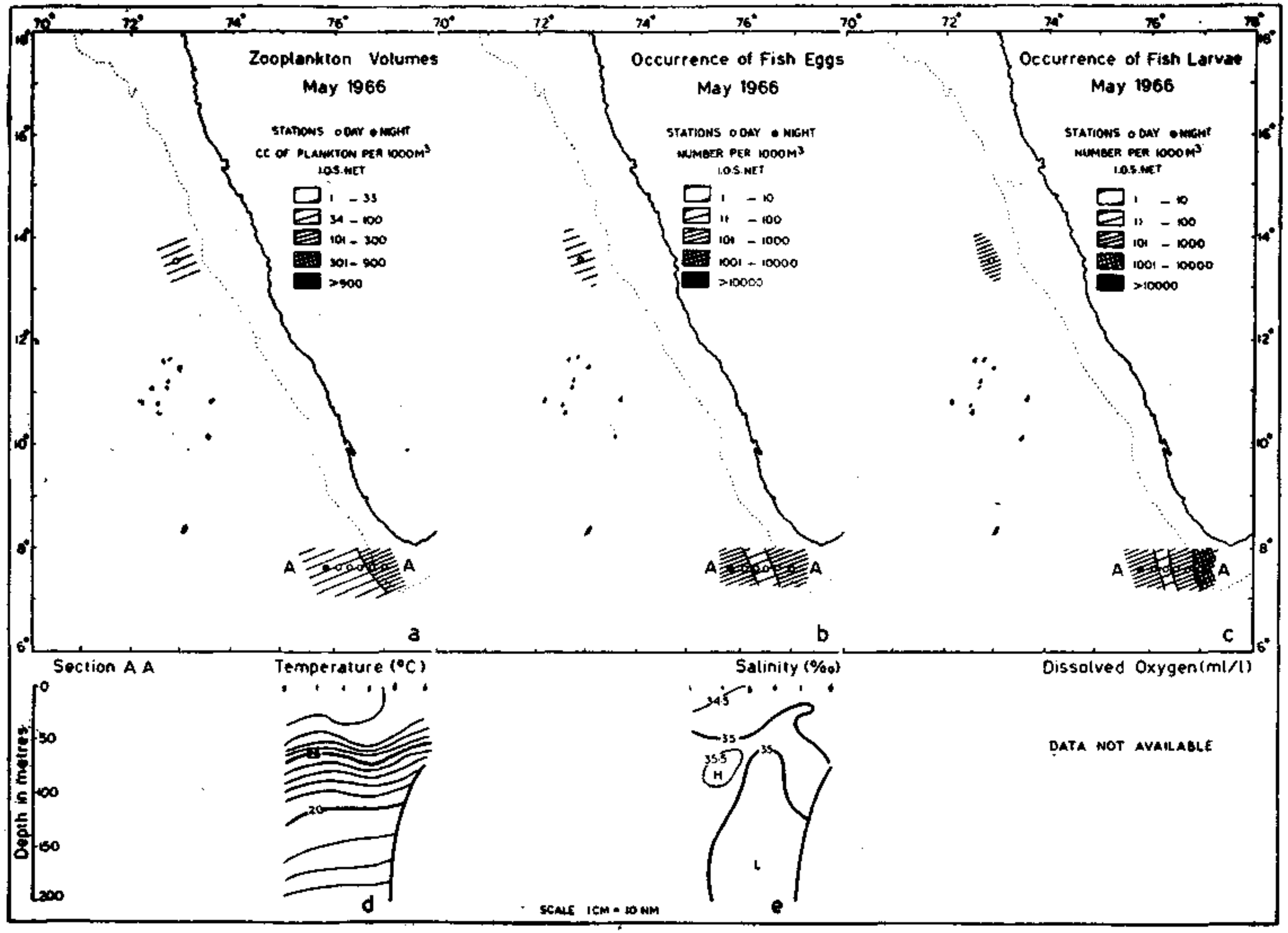

Fig. 24. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in May 1966.

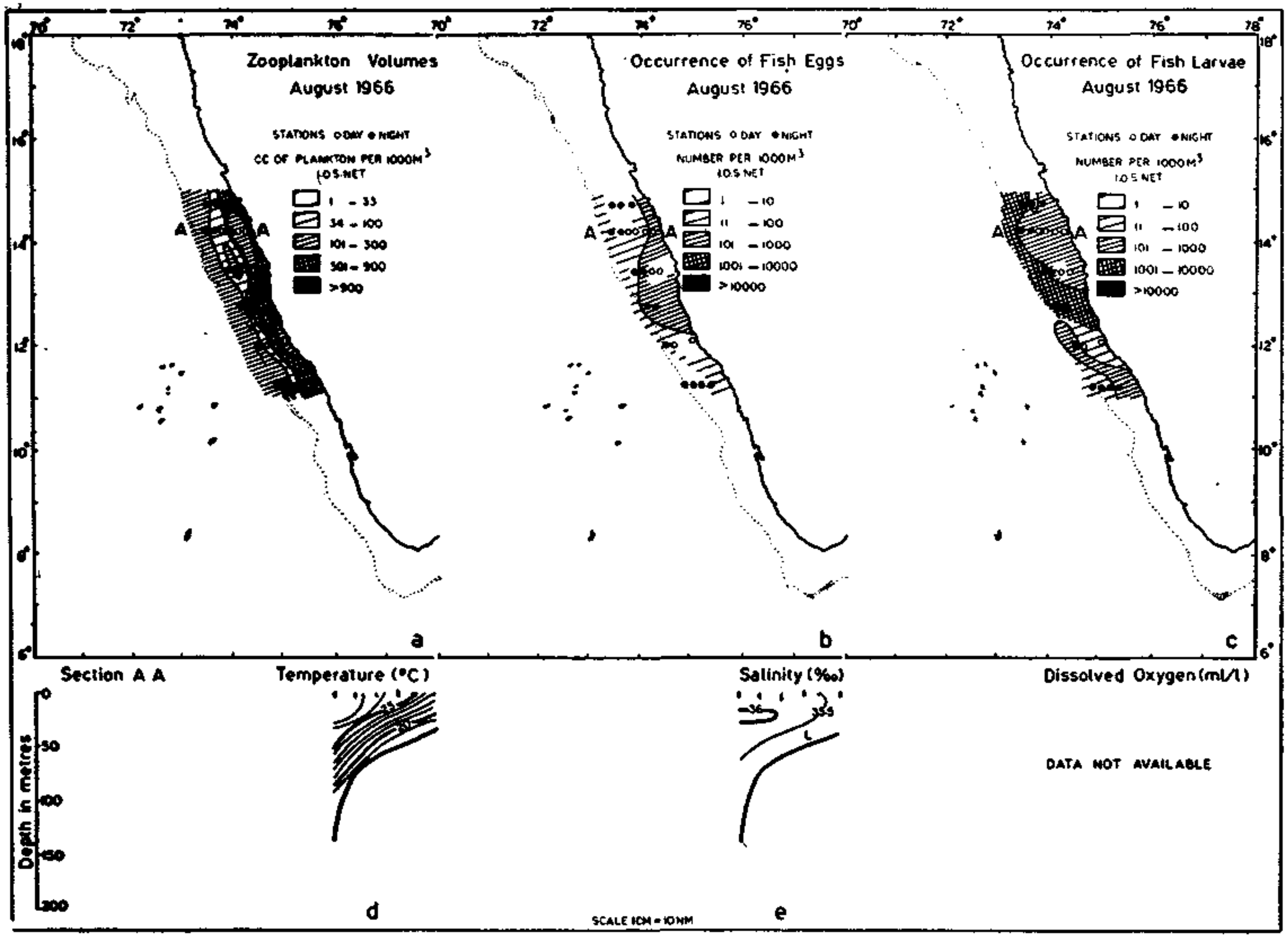

Fig. 25. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in August 1966.

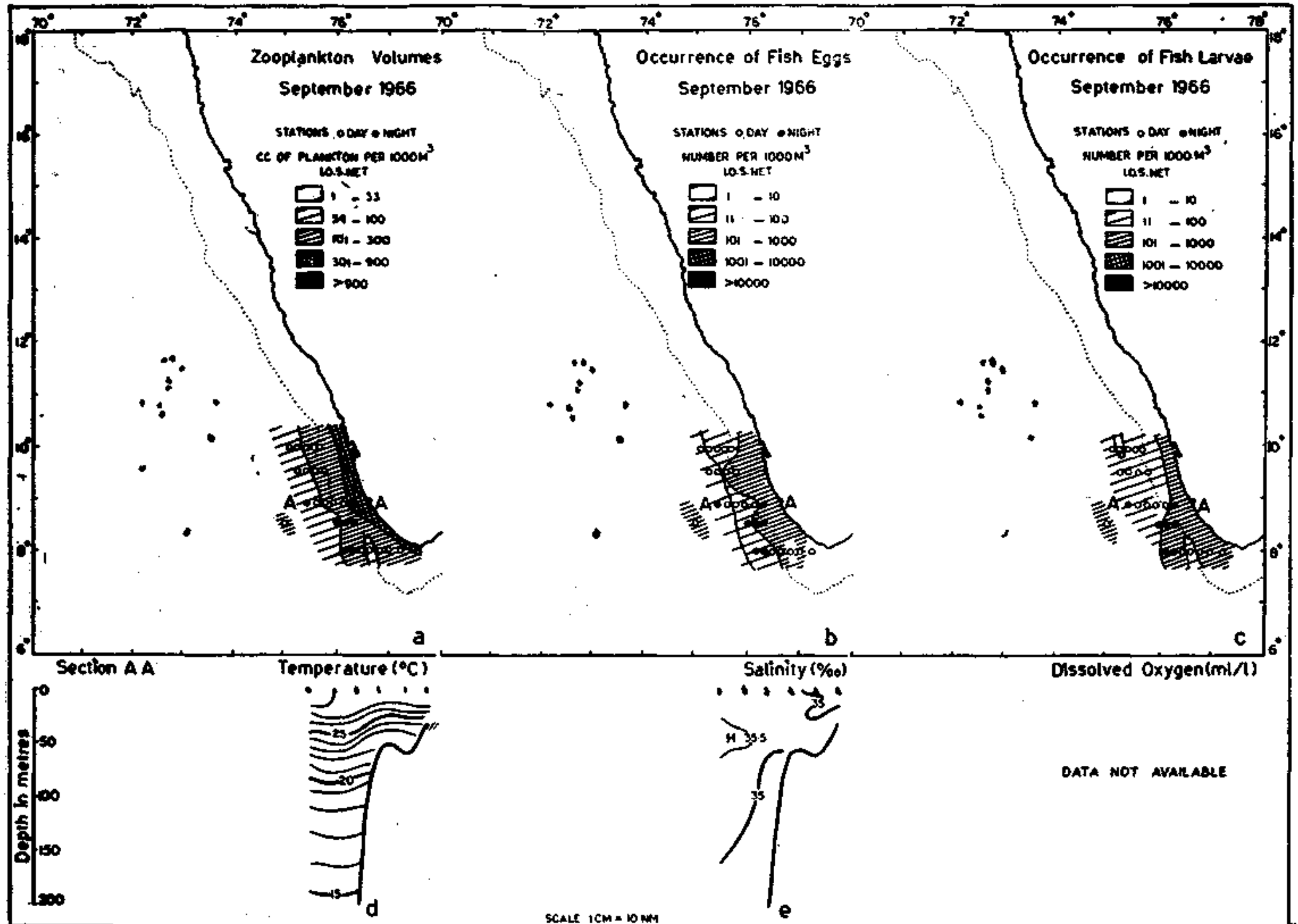

Fig. 26. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in September 1966.

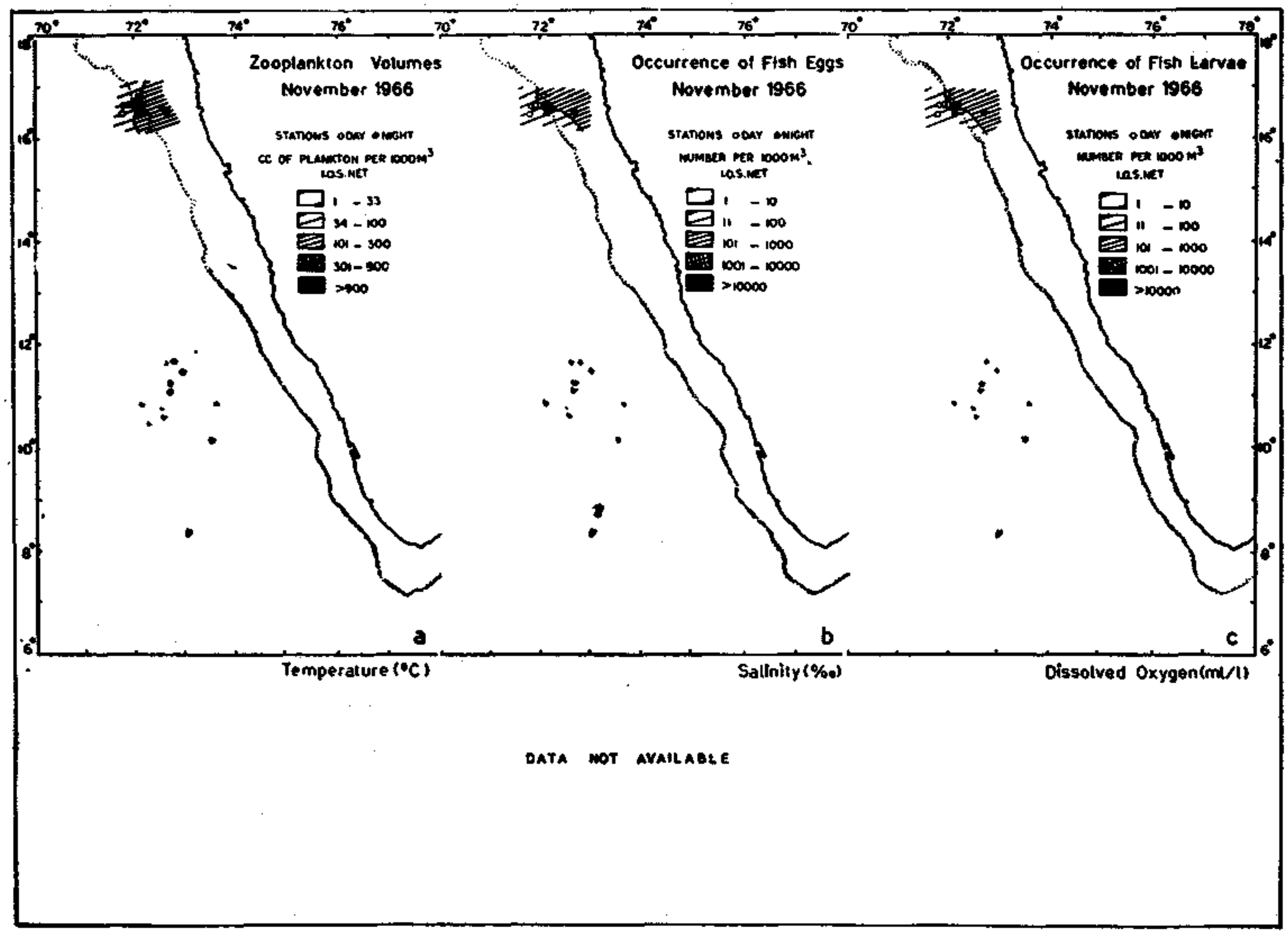

Fig. 27. Distribution of zooplankton biomass, fish eggs and larvae in November 1966.

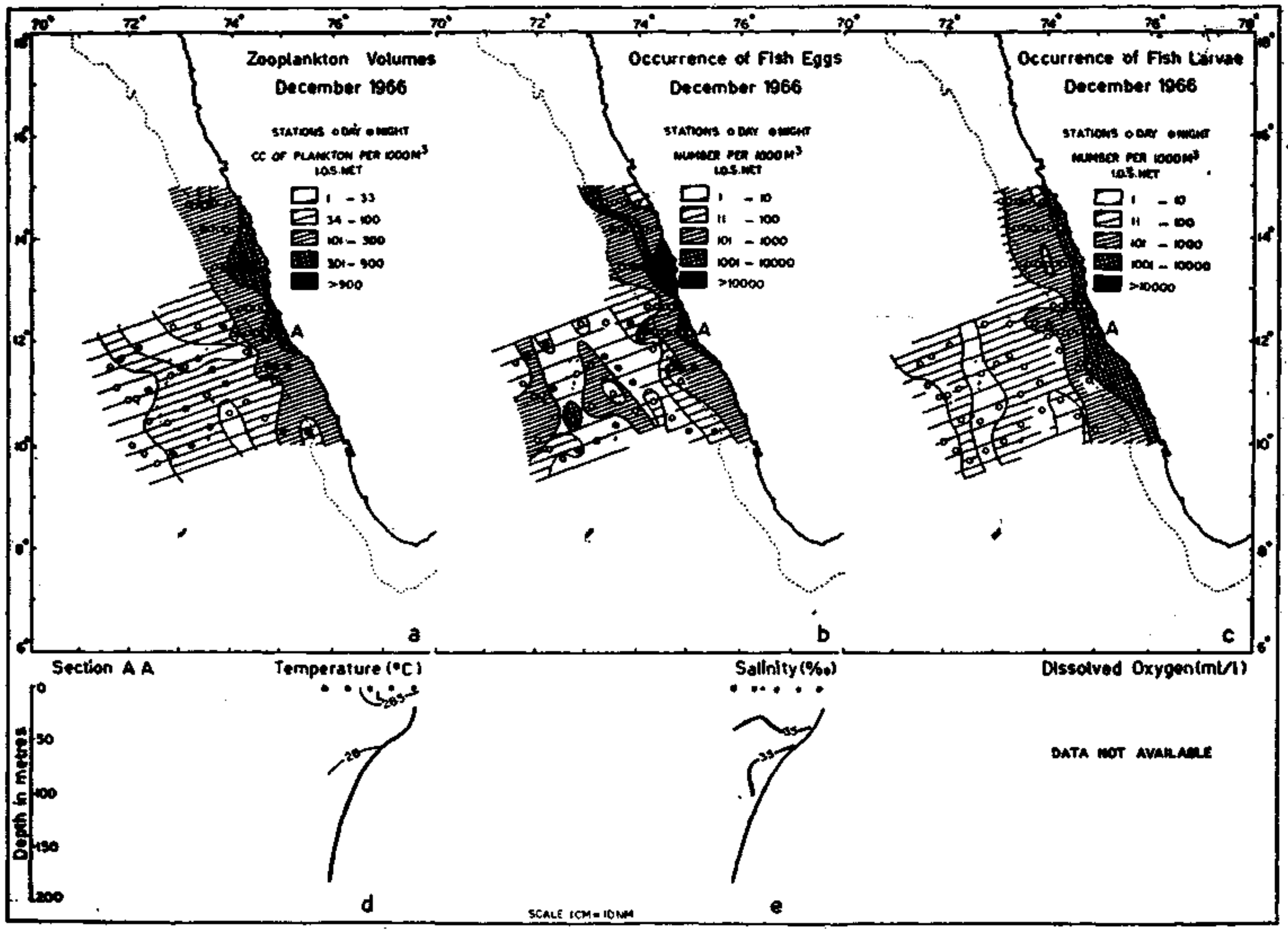

Fig. 28. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in December 1966.

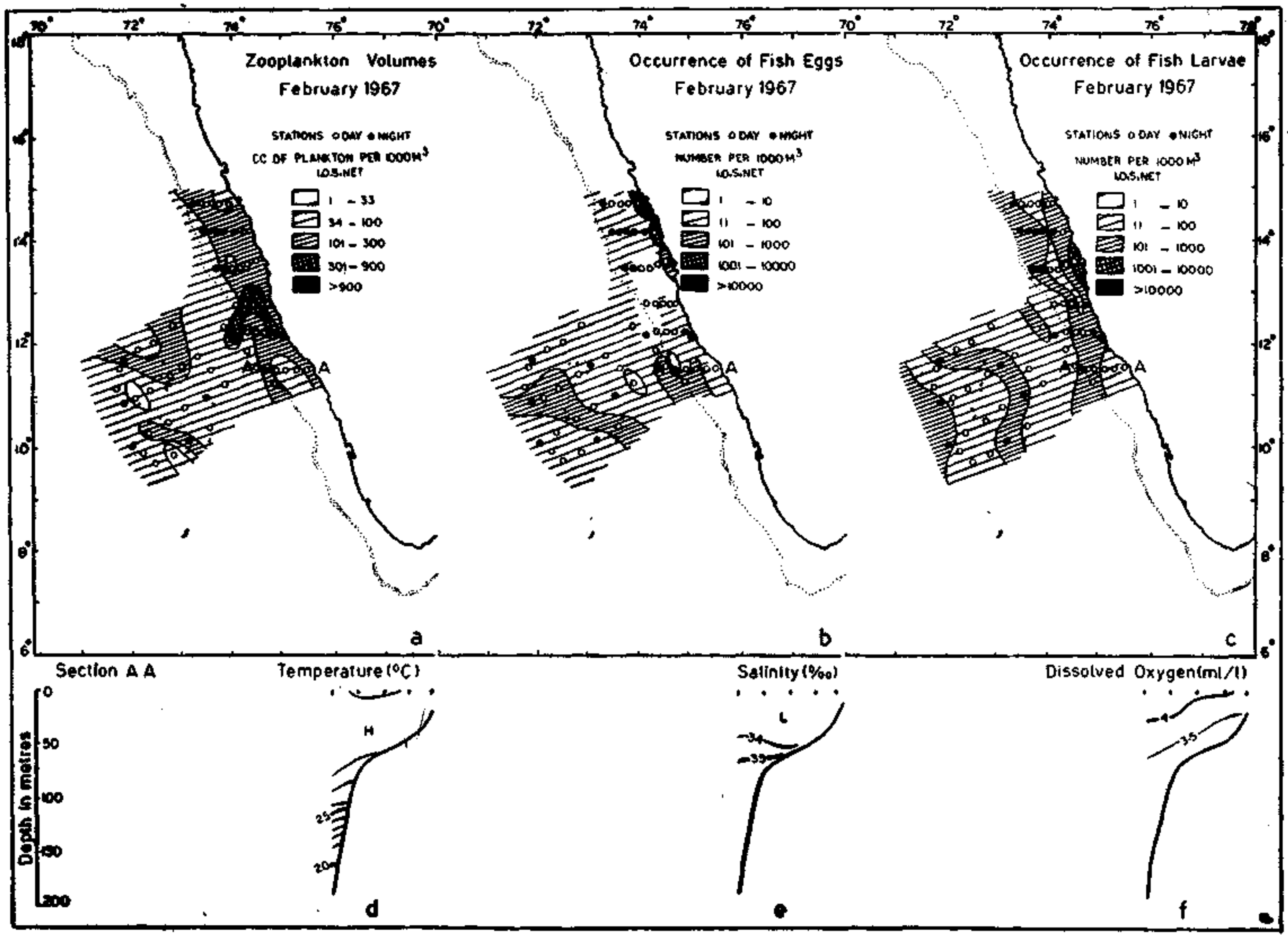

Fig. 2.9 Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in February 1967.

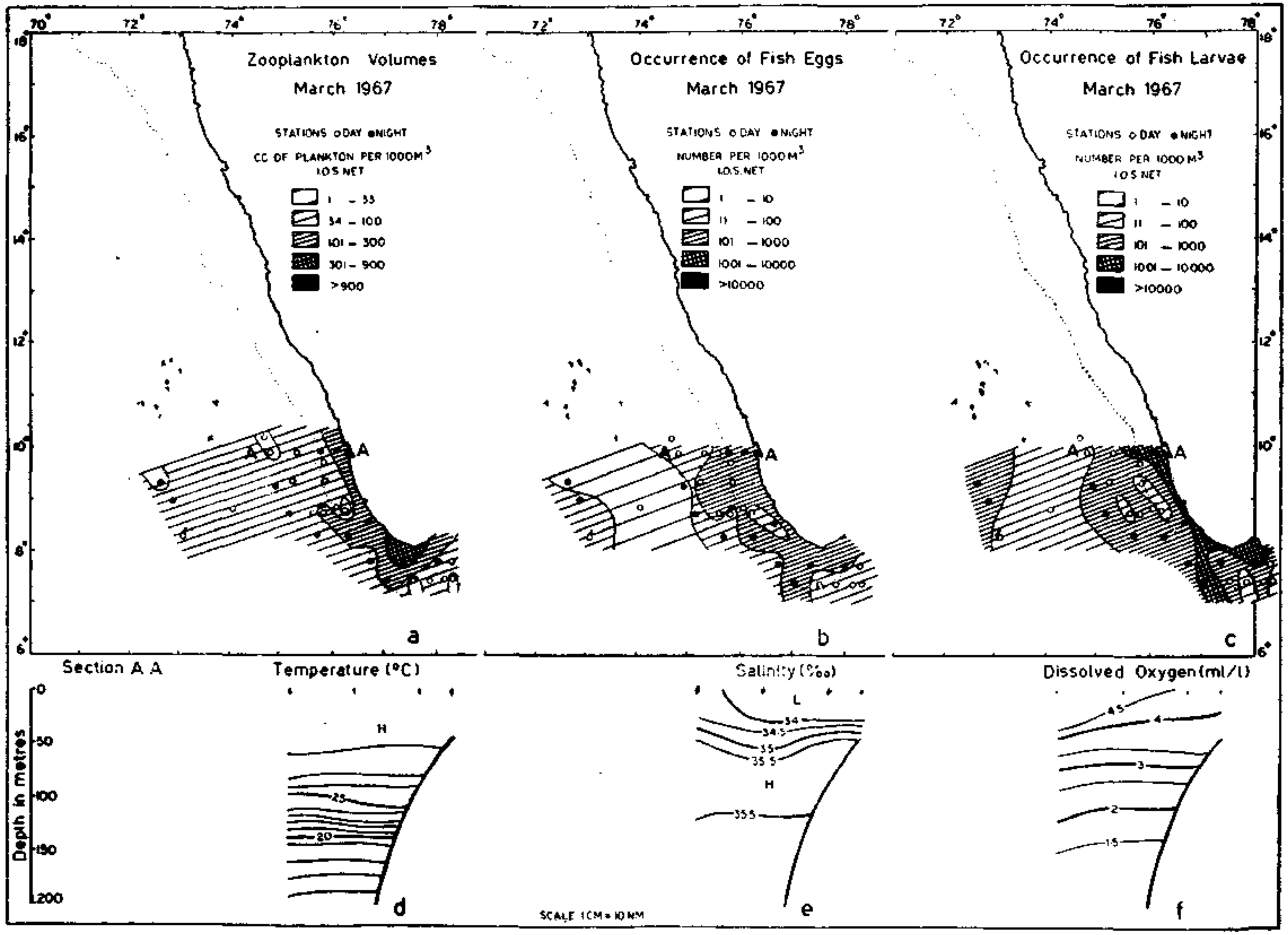

Fig. 30. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in March 1967.

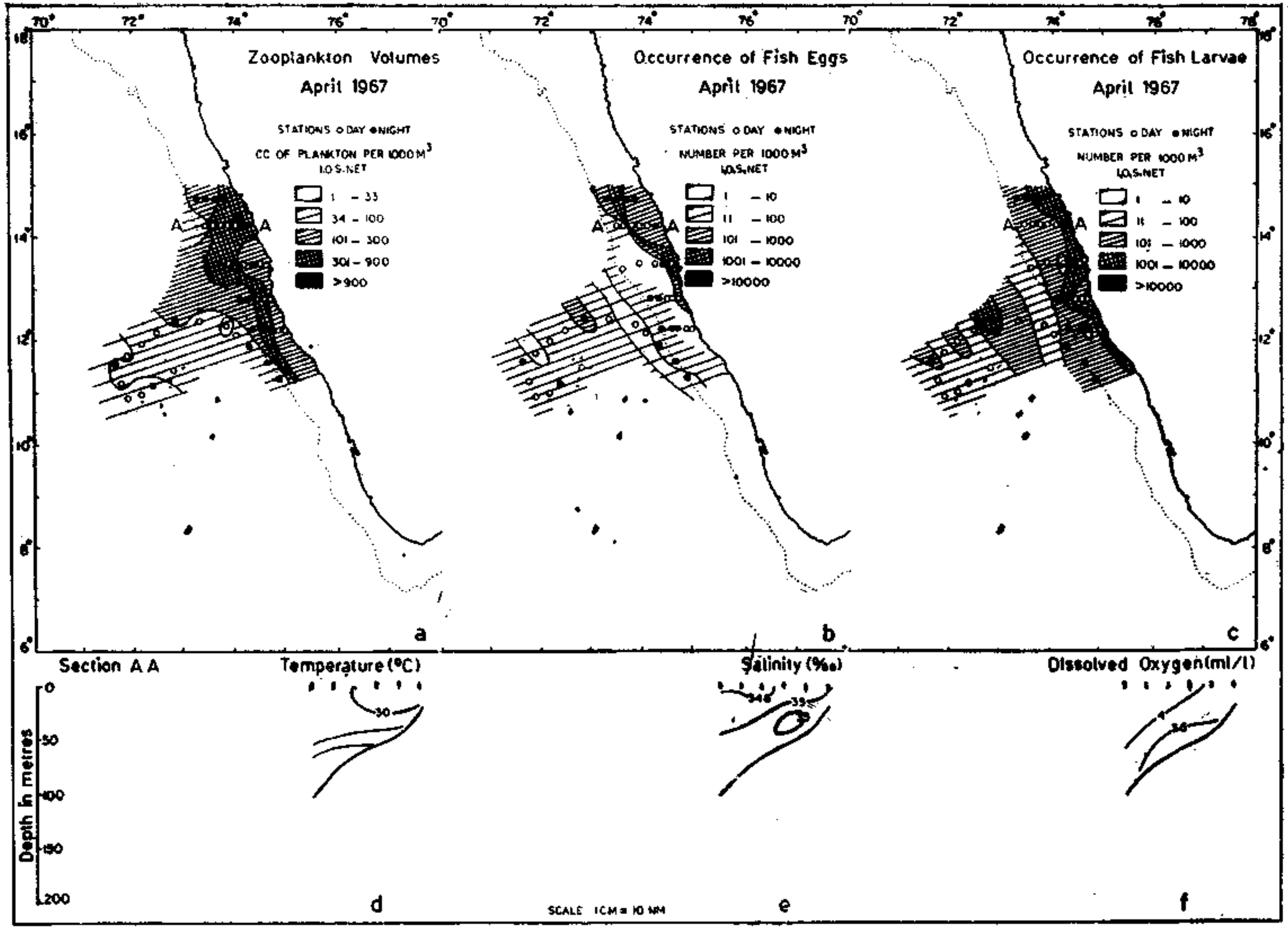

Fig. 31. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in April 1967.

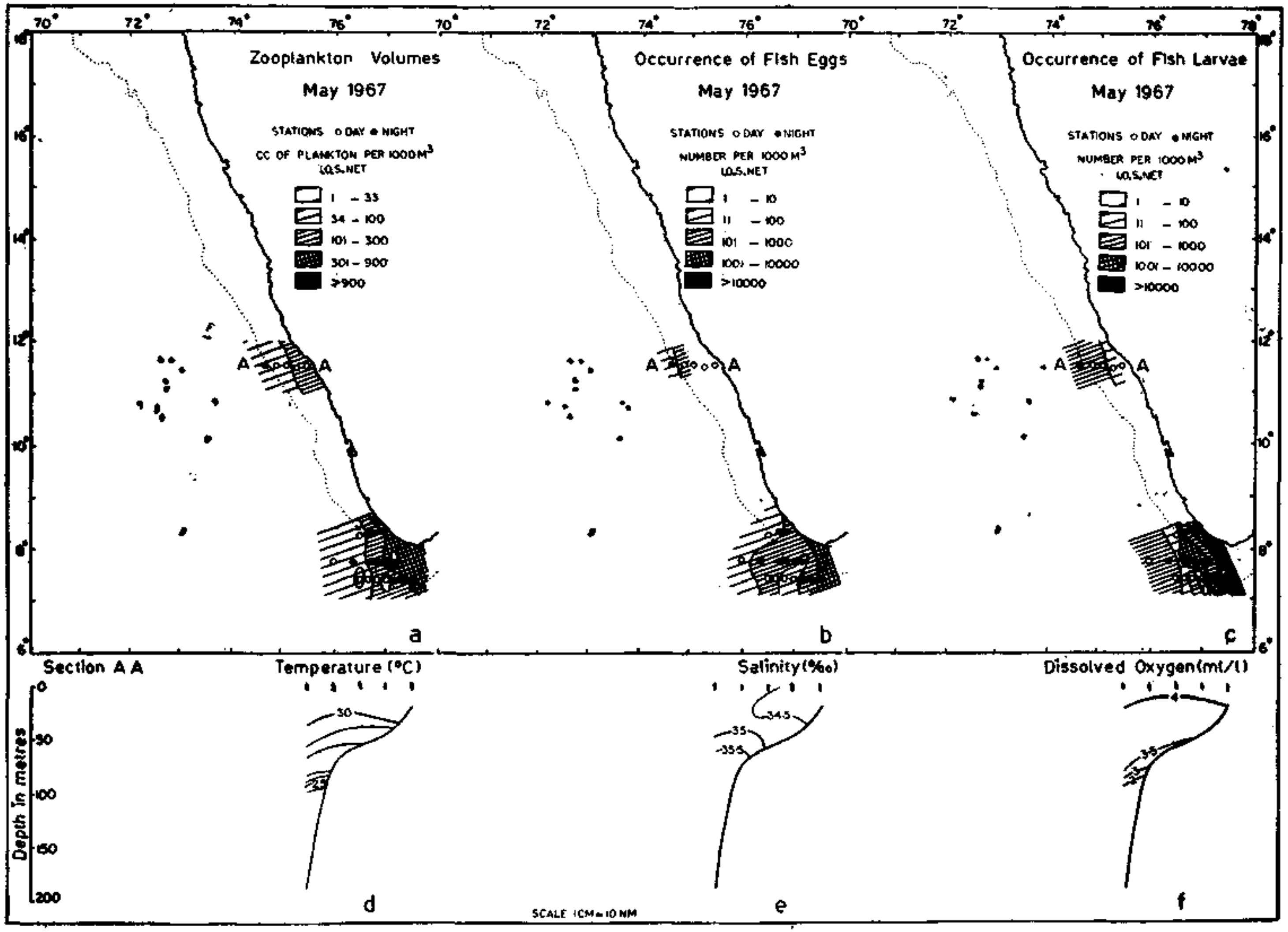

Fig. 32. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in May 1967.

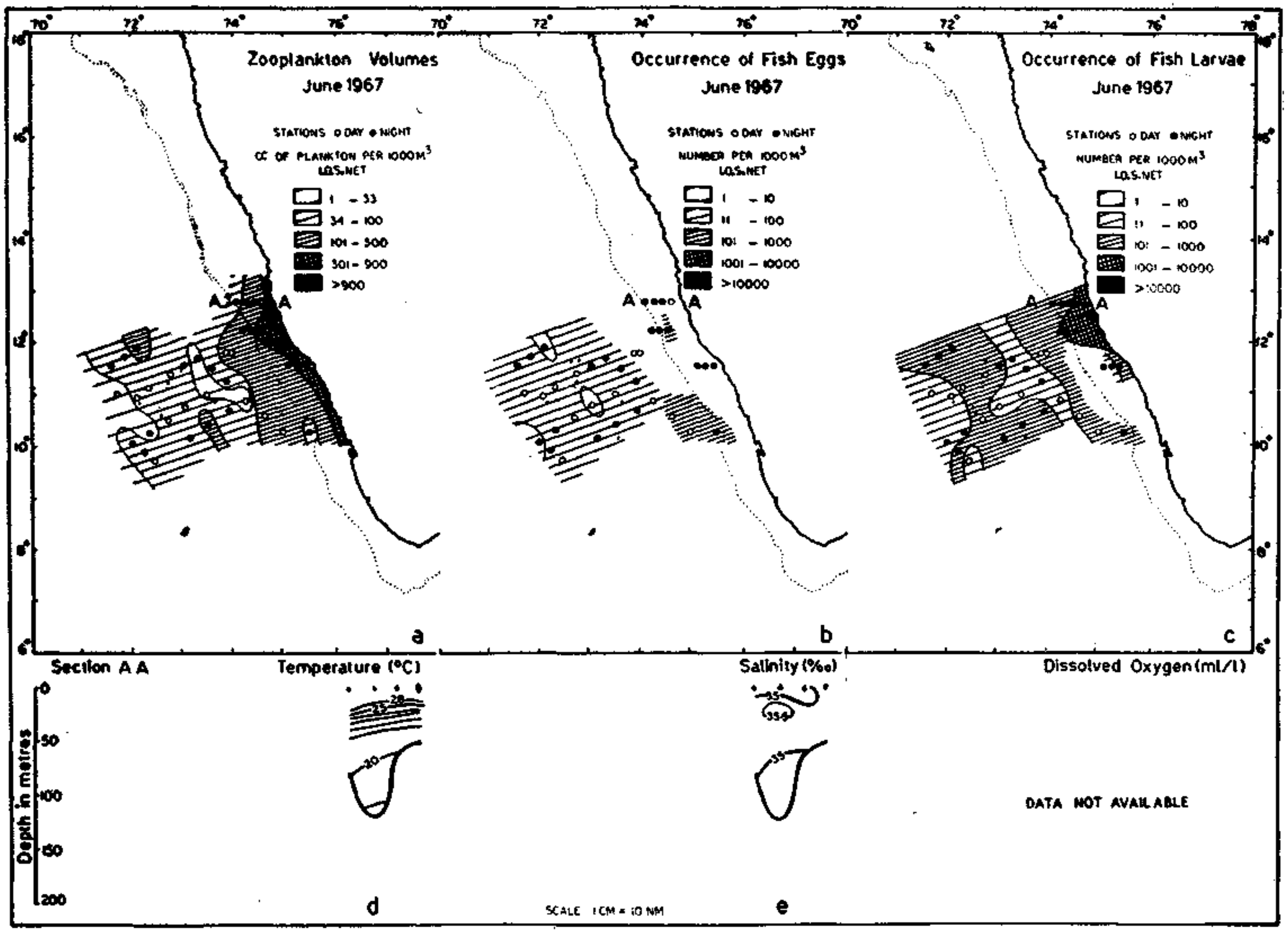

Fig. 33. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in June 1967.

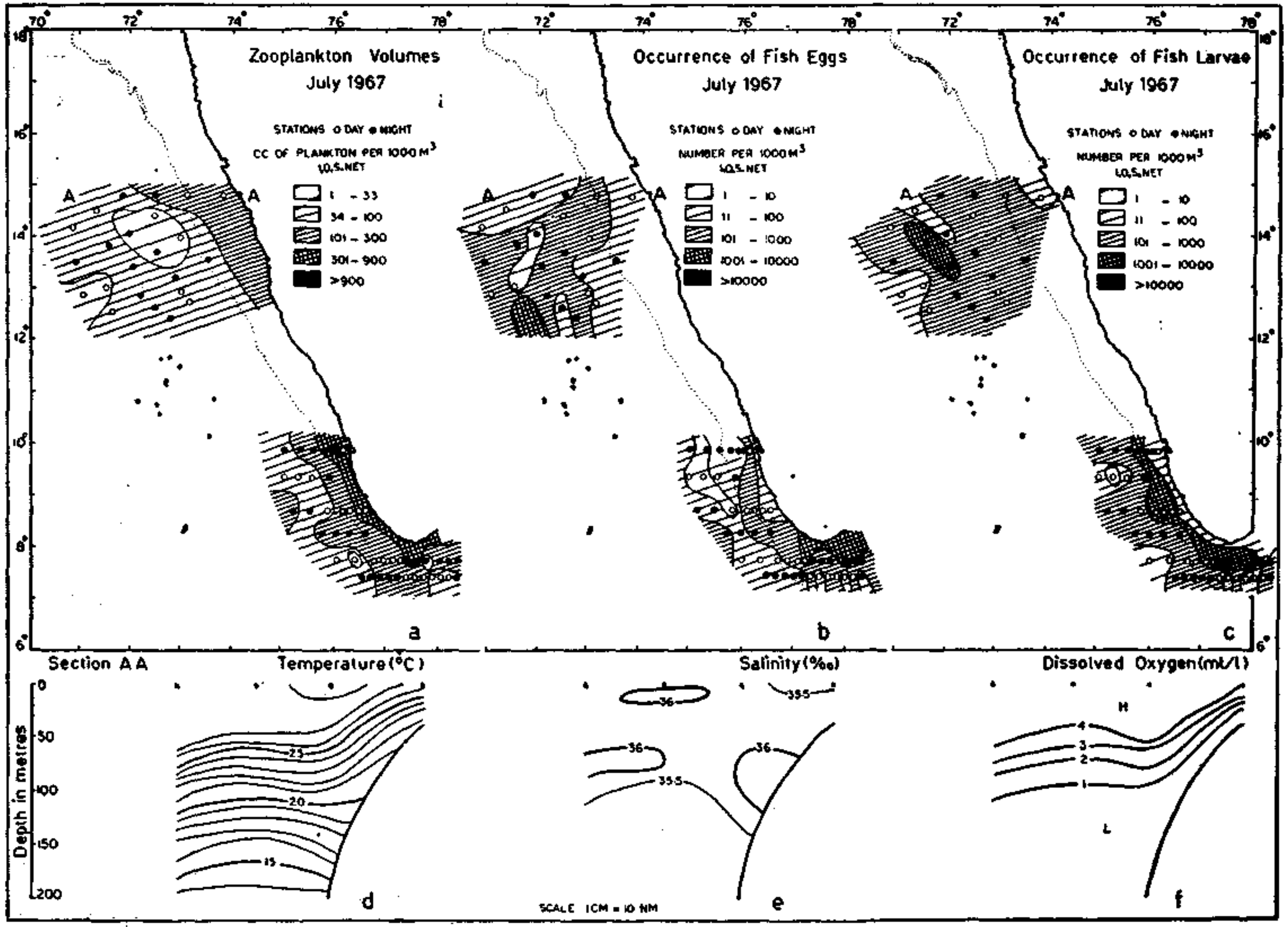

Fig. 34. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in July 1967.

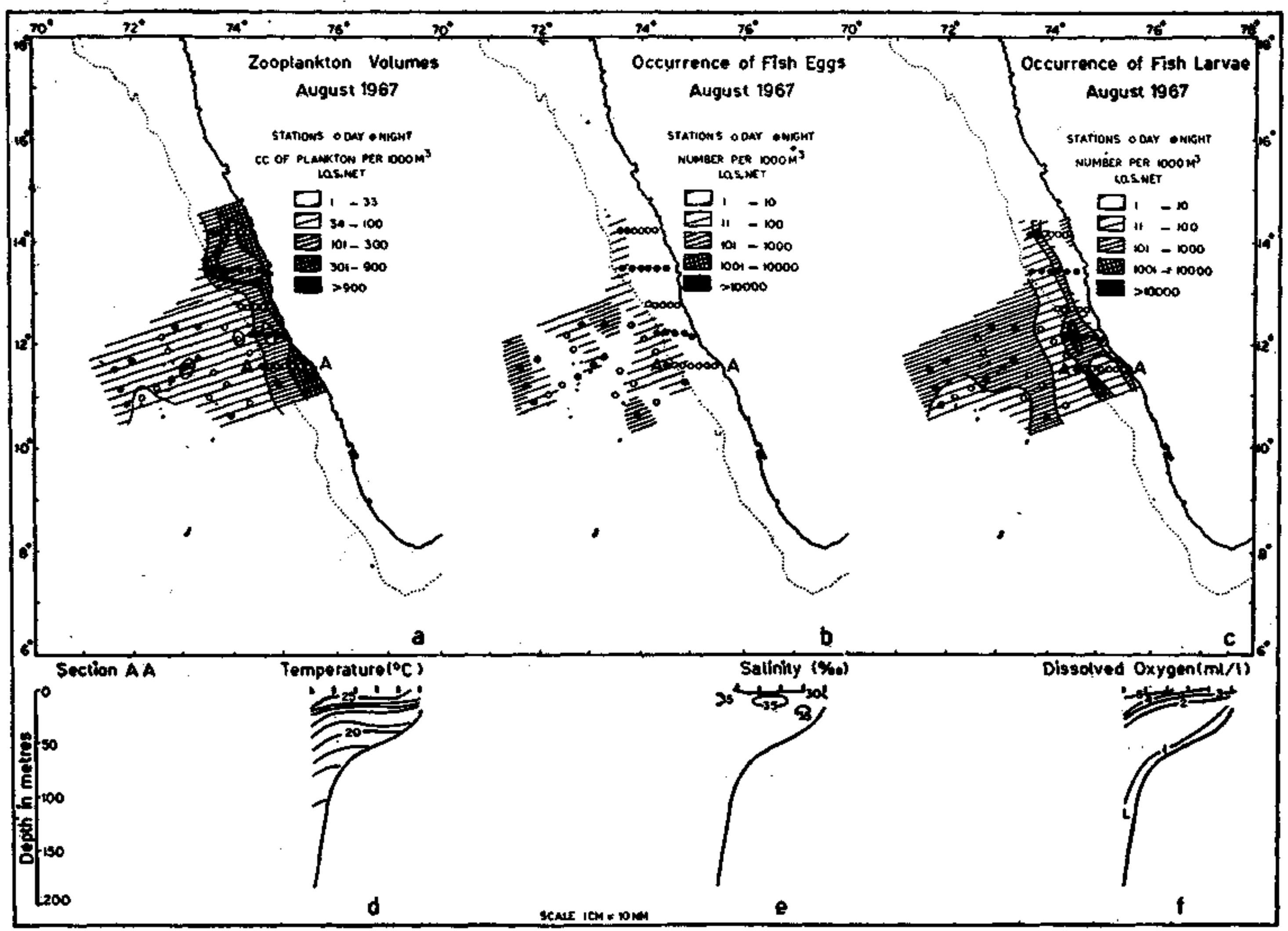

Fig. 35. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in August 1967.

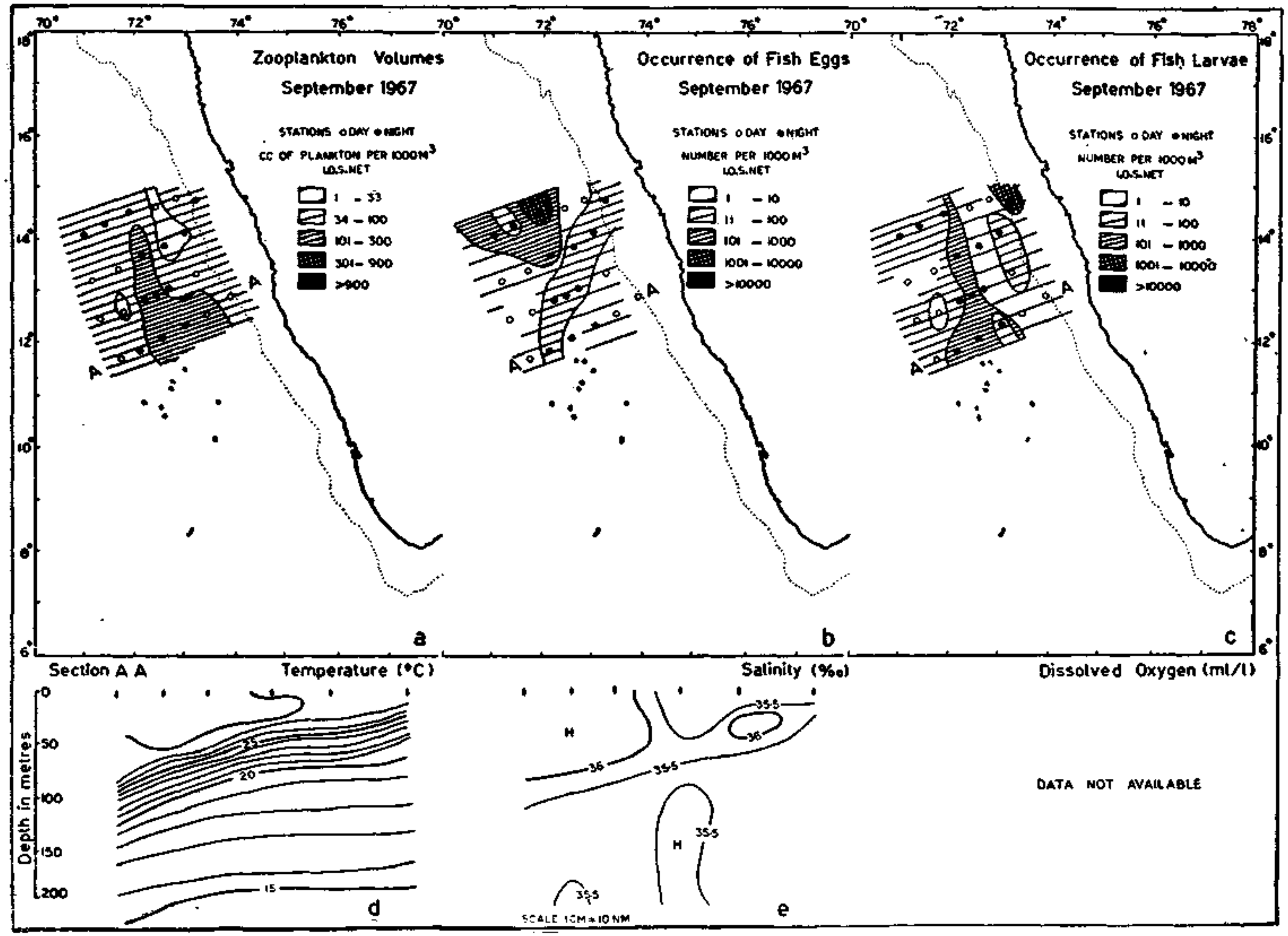

Fig. 36. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in September 1967.

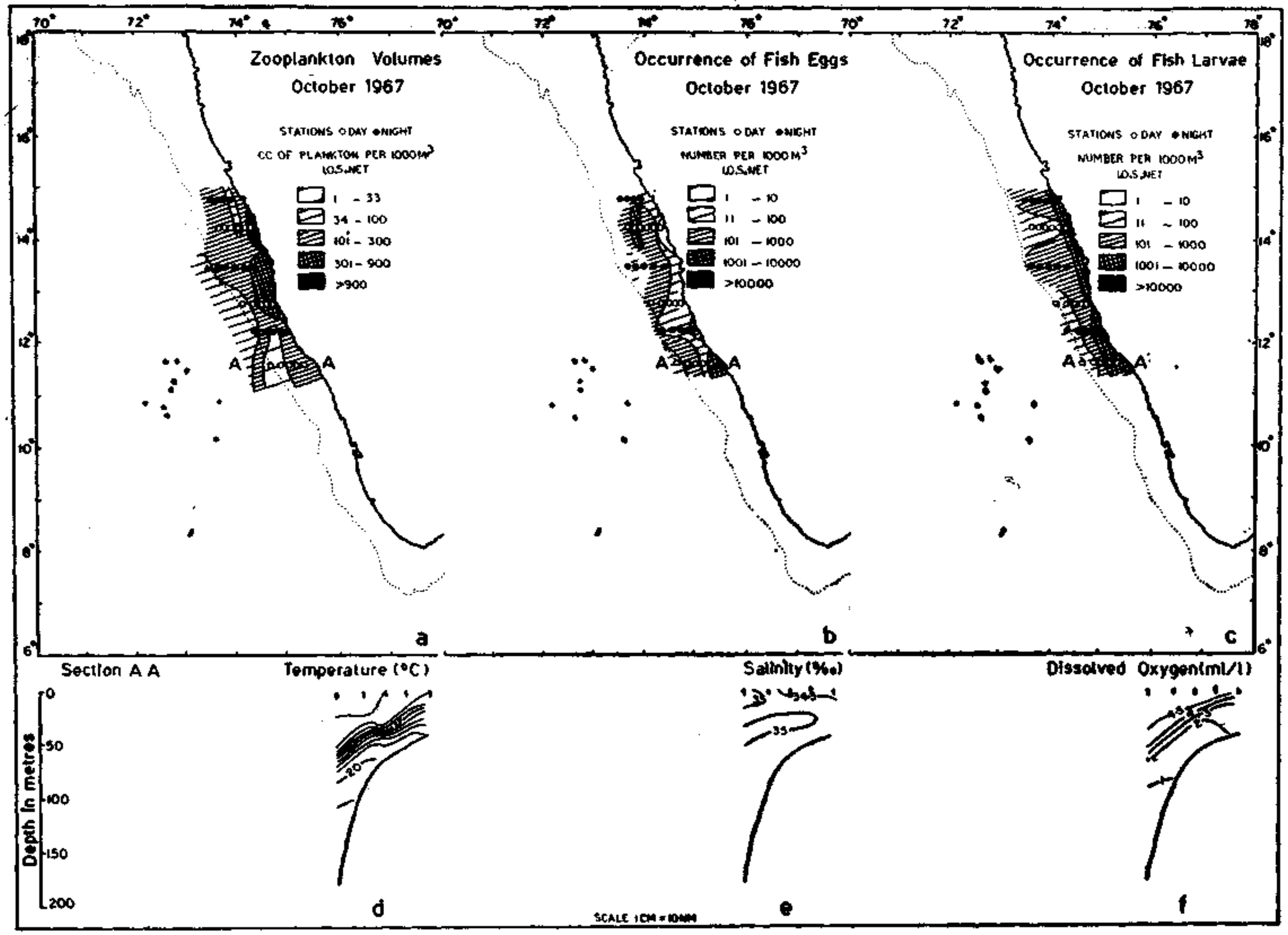

Fig. 37. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in October 1967.

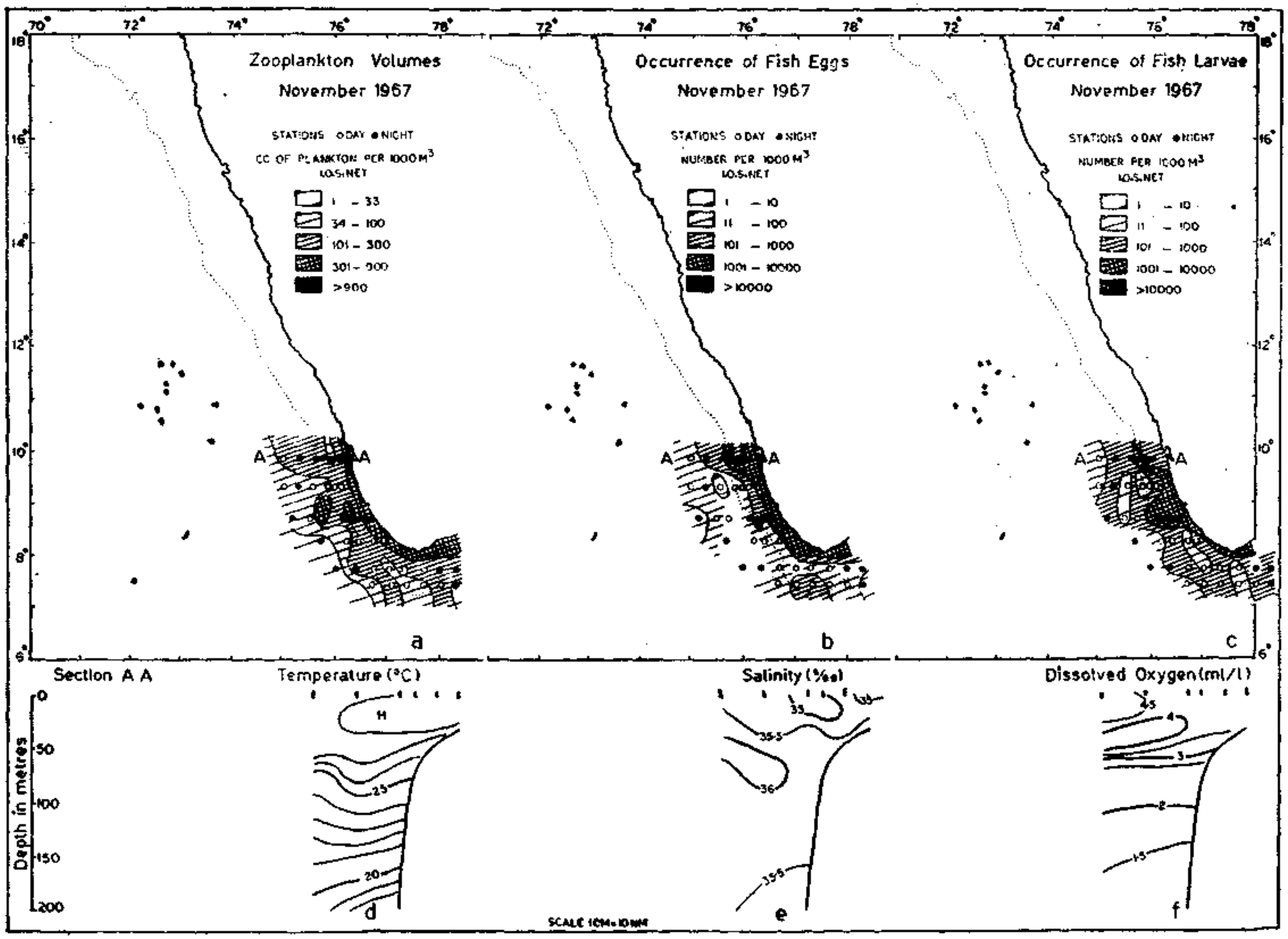

Fig. 38. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in November 1967.

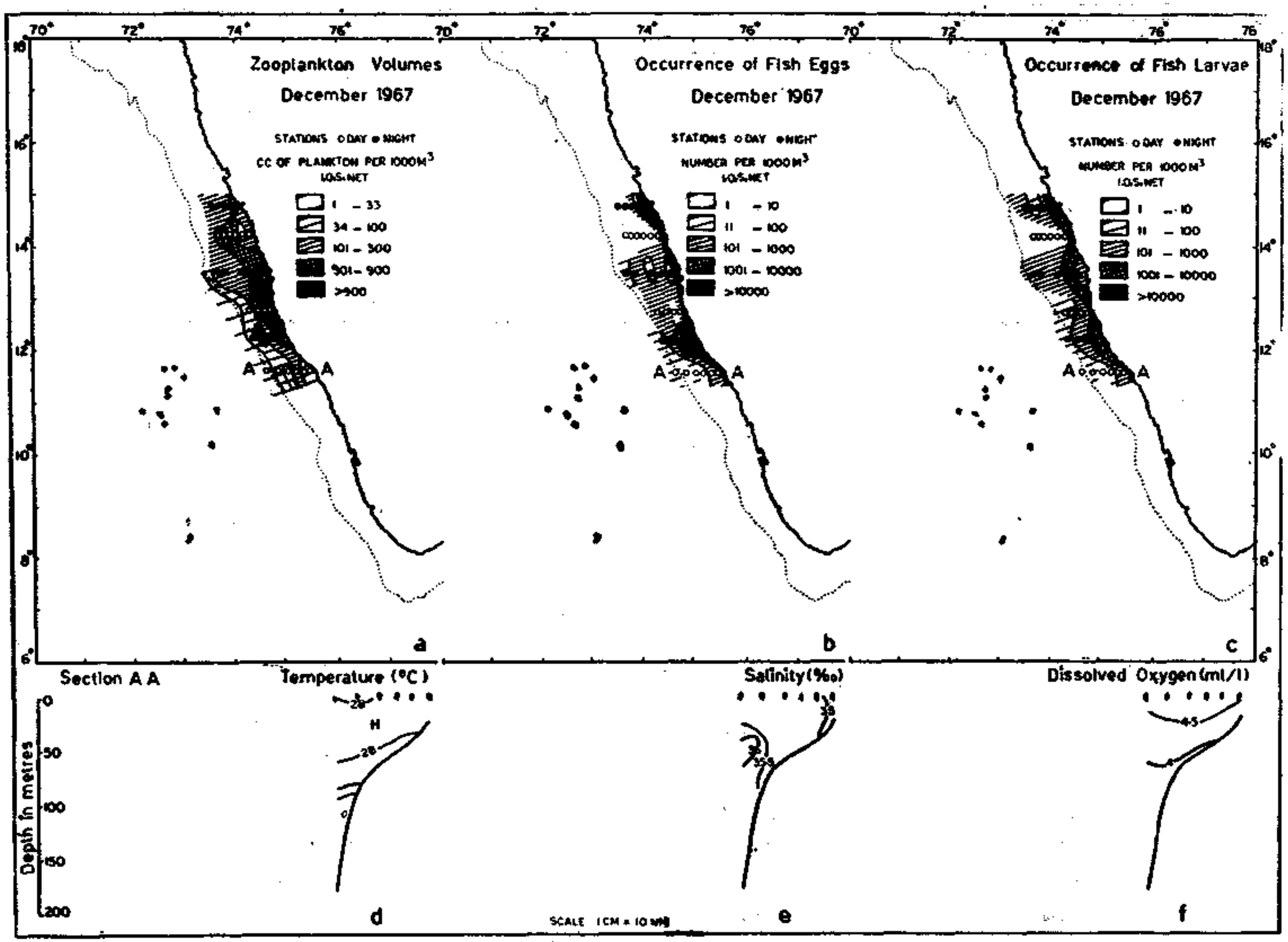

Fig. 39. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in December 1967.

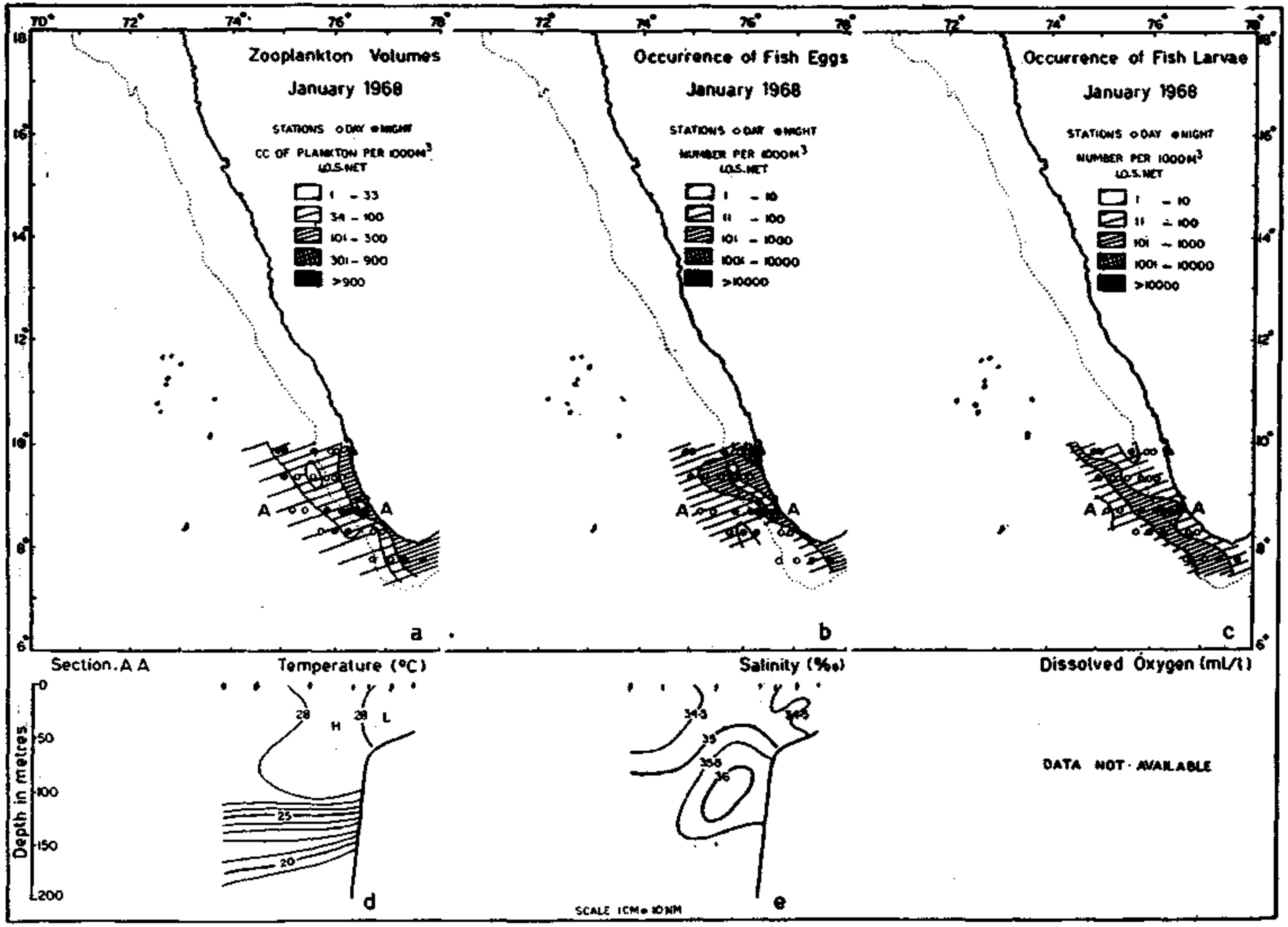

Fig. 40. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in January 1968.

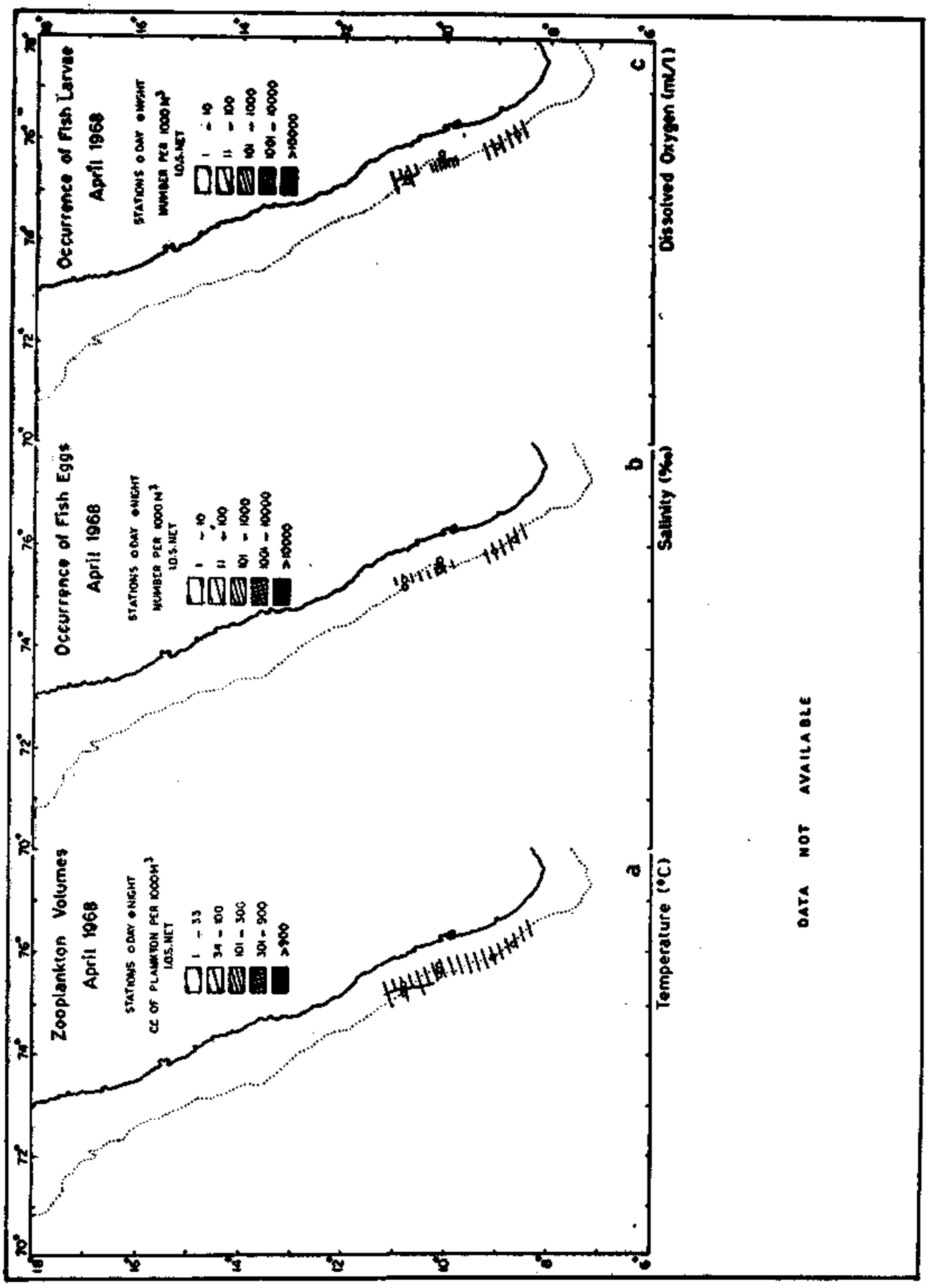

Fig. 41. Distribution of zooplankton biomass, fish eggs and larvae in April 1968.

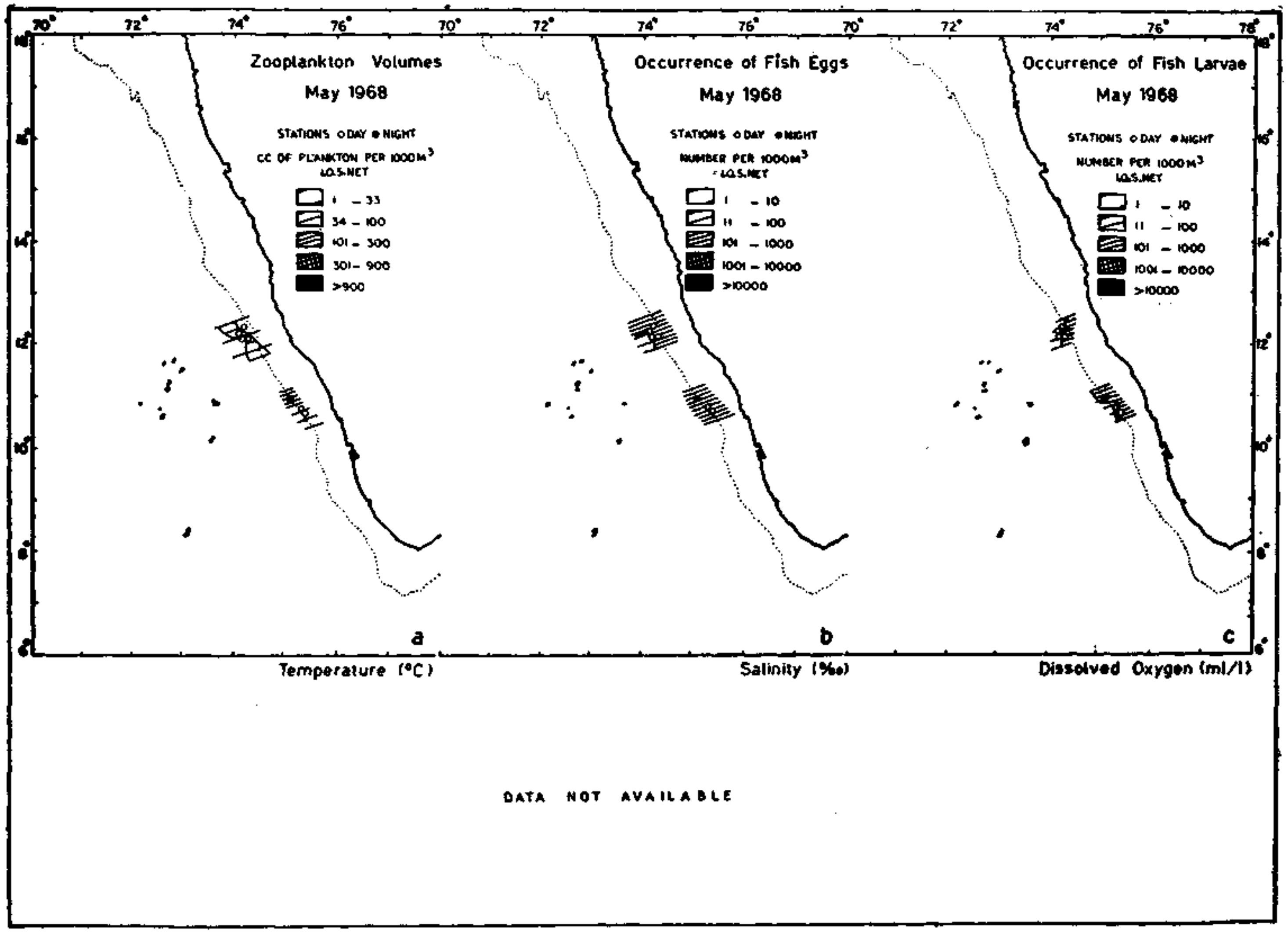

Fig. 42. Distribution of zooplankton biomass, fish eggs and larvae in May 1968.

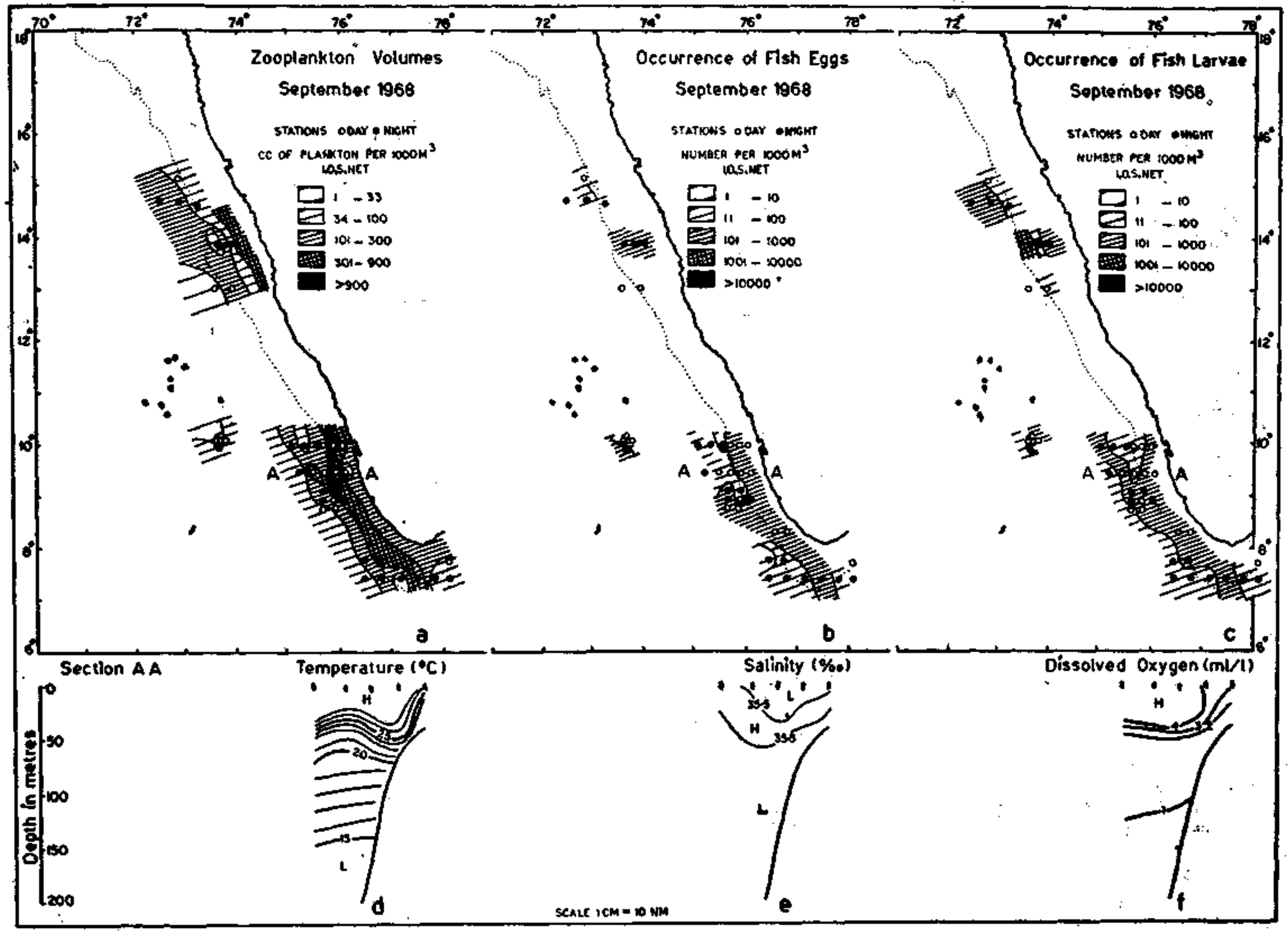

Fig. 43. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in September 1968

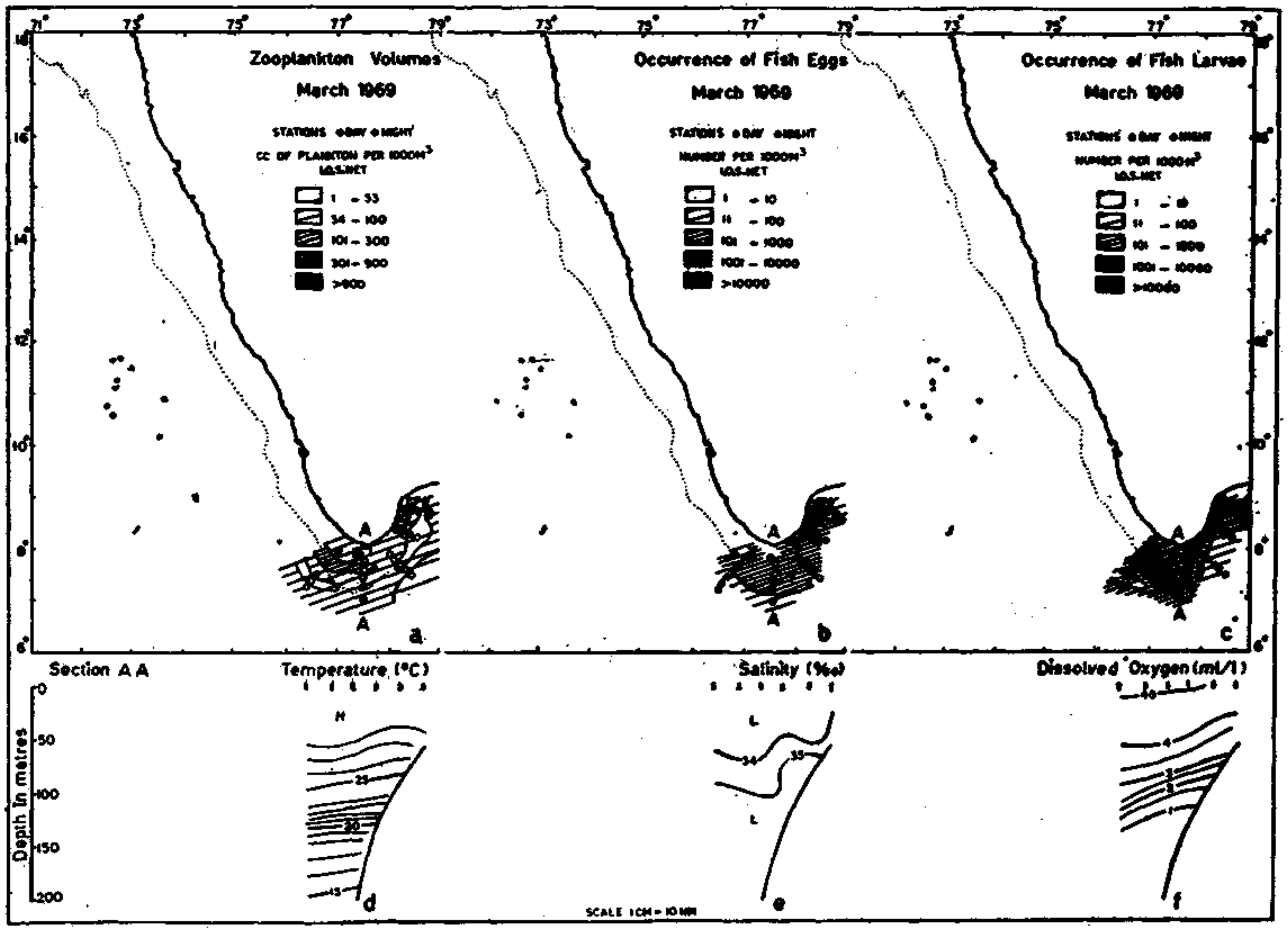

Fig. 44. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in March 1969.

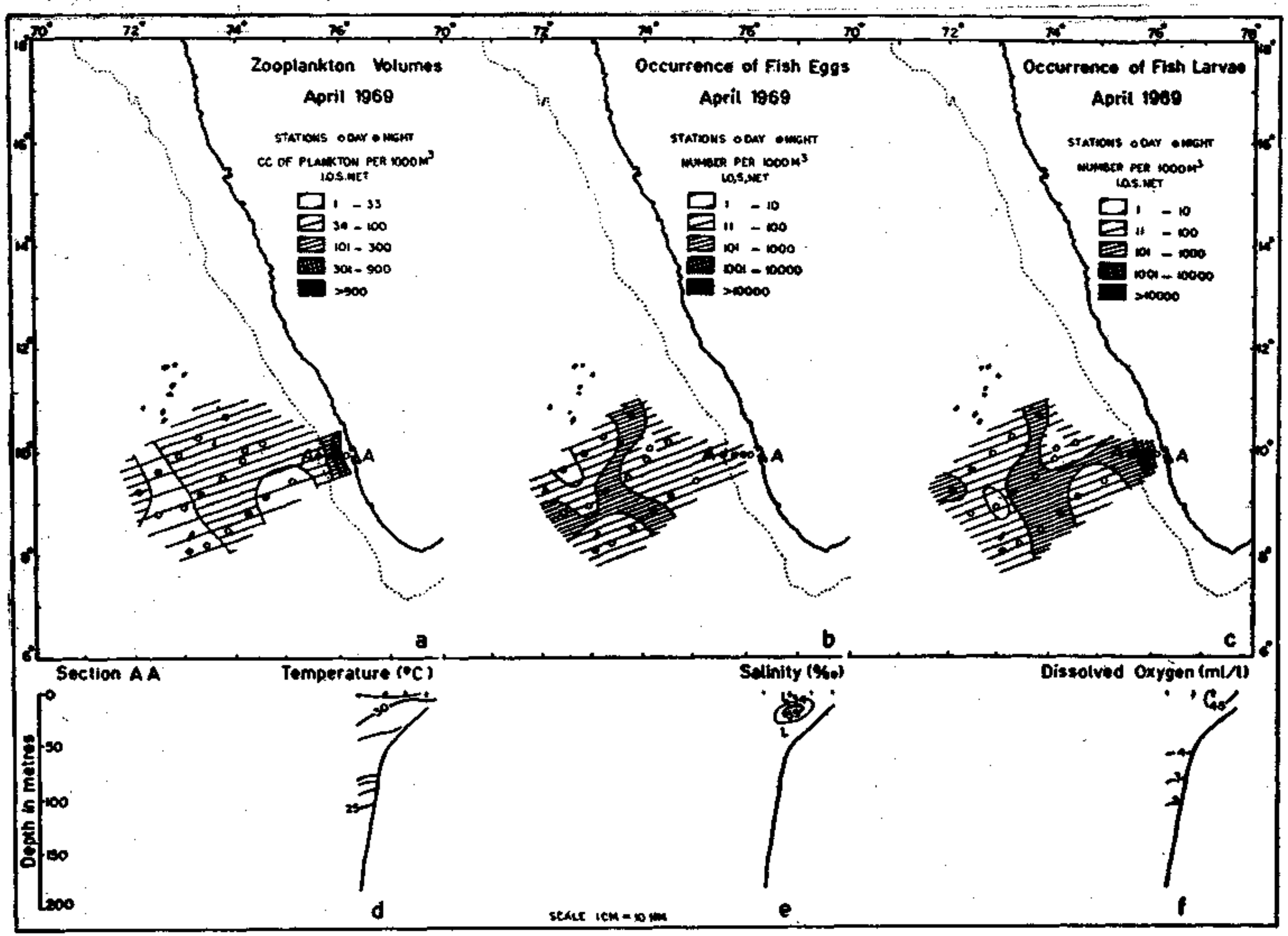

Fig. 45. Distribution of zooplankton biomass, fish eggs and larvae in relation to hydrography in April 1969.

December 1965 (Fig. 21 c). More or less comparable features existed in February 1966 also, but the near coastal abundance of zooplankton was a distinguishing feature (Fig. 22 a) compared to that in January 1966. Lateral coastal drifts being very weak, the eggs and larval abundance were also satisfactory (Fig. 22 b, c).

The conspicuous summer conditions during April 1966 *viz.*, higher temperature, salinity and higher oxygen (Fig. 23 d, e, f) than in 1965 appeared not to support a good plankton biomass over the continental shelf (Fig. 23 a). The paucity of data in the southern regions during April 1966 did not permit a comparison of eggs and larval abundance with those during April 1965. However from the available data, it could be noticed that the larval abundance was less than 1965 (Fig. 23 c).

During May 1966 a section off Cape Comorin was only available for study and the presence of internal waves at the top of the thermocline was observed. A significant upward migration of the thermocline also occurred (Fig. 24 d, e). The salinity maximum within the thermocline was less than that in April and so to say the plankton abundance was more or less comparable to those in May 1965 (Fig. 24 a). Although the data available was scanty along the coast, the larval abundance was comparable to those during the previous year (Fig. 24 b, c).

Data during peak monsoon season particularly during early August was available during 1966 whereas during 1964 and 1965 the data for August was missing. Thus, during 1966, upwelling was clearly perceptible during August (Fig. 25 d, e). The well stratified thermocline has migrated even to the very surface in the coastal waters and a conspicuous slope of the thermocline as a whole was observed. The bottom temperature over the continental shelf has decreased by about 7° C than in April. There is an overall increase in the salinity values over the continental shelf and all these combined warranted a conspicuous increase in the plankton abundance over the shelf area (Fig. 25 a). In this connection it is worthwhile to remember that during the previous monsoons also a comparable high abundance of plankton had existed. These monsoon features have resulted in a good larval abundance over the continental shelf and edge. Abundance of fish eggs over the continental shelf although low, were higher than the summer season (Fig. 25 b, c).

With the decrease in the intensity of upwelling during postmonsoon in September 1966, the thermocline has migrated down although it was still higher up than in the previous summer (Fig. 26 d). Hence an associated decrease in the width of the coastal plankton abundant belt was also observed (Fig. 26 a). The salinity distribution was more or less uniform in the vertical. The subsidence of the upwelling was observed to be again associated with the decrease in the larval abundance than peak monsoon, although the abundance of fish eggs were comparable to those during peak monsoon (Fig. 26 b, c).

Data was scanty for November 1966 (Fig. 27) and during December 1966, the thermocline was not perceptible in the shelf region. Sinking of offshore waters was observed to a certain extent and a noticeable decrease in the salinity values in the mixed layer was observed (Fig. 28 d, e). Meridional movements were highly restricted and a relatively high abundance of plankton over the continental shelf was also observed (Fig. 28 a). The eggs and larval abundance during December 1966 presented noticeable features compared to December 1964 and 1965 in the sense that the abundance was much higher during 1966 than the previous years. During this year, the investigation would be extended to the Lakshadweep area where again the zooplankton biomass was high (Fig. 28 a, b, c). The productive nature of the Laccadive Sea could also be visualised.

More or less comparable conditions existed during February 1967 and with slightly higher temperature and salinity values (Fig. 29 d, e, f) the plankton biomass was lesser than that in December 1966 (Fig. 29 a). But in the case of the eggs and larval occurrence especially in the Lakshadweep area a higher abundance was perceptible (Fig. 29 b, c).

The progressing season exhibited the presence of a well stratified isothermal mixed layer and a thermocline (Fig. 30 d). Such a stratification was common to the salinity structure also (Fig. 30 e) and these early summer conditions were associated with the slightly higher plankton abundance during March 1967 (Fig. 30 a). In the coastal areas the quantum of eggs and larvae was a little higher than in February 1967.

Comparable conditions existed in April and May 1967 (Fig. 31, 32). But the abundance of larvae during May 1967 showed a remarkable increase than the previous months (Fig. 32). This again coincided with the area of maximum abundance of fish eggs.

Noticeable reduction of temperature values in the mixed layer occurred in June (Fig. 33) and in July 1967 (Fig. 34). Indications of coastal upwelling were again evident during July. A further increase in the plankton biomass has again occurred which in previous years also was conspicuous during monsoon. The eggs and larval abundance was higher in July (Fig. 34 b, c) than in June 1967 (Fig. 33 b, c). In August 1967 the process of upwelling seems to have subsided (Fig. 35 d) but the after effect of the phenomenon was reflected in the very shallow thermocline (5-10 m) much lower temperature and oxygen values in the mixed layer (Fig. 35 d, e, f). The plankton abundance during the monsoon period was also high. But the abundance of eggs has decreased than that in July 1967 likewise that of fish larvae also (Fig. 35 b, c).

A divergent trend in the offshore waters during September 1967 seems to favour a good abundance of plankton biomass in the region off Mangalore (Fig. 36 a, d). Unfortunately data for coastal waters was not available for this month. In the offshore regions noticeable amount of fish eggs and larvae were also observed (Fig. 36 b, c).

The region between 11° and 14° N exhibited a good deal of upwelling during October 1967, *i.e.*, even towards the fag end of the monsoon (Fig. 37 d, e, f). This area has been identified as one of the regions of maximum upwelling along the west coast (Ramamirtham and Rao, 1973) whereas during 1965 a section off Cape Comorin during the same period did not at all exhibit any feature of the latter process, and during 1965 a very low abundance of plankton only was supported by these features. At any rate, during October 1967 due to a good deal of upwelling in the northern regions a conspicuously high abundance of plankton biomass was observed (Fig. 37 a). The thermocline was, so to say, at the very surface and the oxygen minimum layer (Fig. 37 f) could be observed even from 30 m downwards. Abundance of fish eggs was less than those of larvae (Fig. 37 b, c).

By the retreat of monsoon and the associated oceanic disturbances, the hydrographical conditions again reverted to those during the premonsoon (Fig. 38 d, e, f). Thus, in November 1967 the thermocline has migrated down to 60 m depth and the oxygen values showed a remarkable increase over the continental shelf. It can be observed that a resultant decrease in the abundance of plankton biomass has also occurred with an associated increase in the fish eggs and larvae (Fig. 38 b, c).

A mostly isothermal mixed layer in the region around 12° N during December 1967 (Fig. 39 d, e, f) again seems to support a high plankton abundance even comparable to that during October (Fig. 39 a). This region-wise intensity of plankton and upwelling has been observed during the previous years as well. Another noticeable feature during this month was the very high abundance of fish eggs in the region between 11° and 14° N especially in a narrow coastal belt (Fig. 39 b). The larval abundance was also good.

The January section during 1968 was confined to the southern regions and mostly the isothermal nature of the mixed layer from surface to 100 m was still maintained (Fig. 40 d). Lower salinity values were in existence in the mixed layer (Fig. 40 e). All these combined resulted in a much lower abundance of plankton biomass than that in December 1967. A relatively high abundance of fish eggs and larvae was also observed.

During April 1968 only 3 stations over the continental slope could be worked out and with the summer temperatures the abundance of plankton in the offshore waters were low (Fig. 41 a). Comparable conditions existed during May 1968 also although a little increase in the plankton biomass and fish eggs and tlarvae were observed (Fig. 42 a, b, c).

Again, with the onset of monsoon and the associated oceanic disturbances resulting in the incursion of offshore subsurface waters rich in nutrients, into the continental shelf, the plankton biomass exhibited rapid and conspicuous increase during September 1968 (Fig. 43 a, d). The eggs and larvae also exhibited a similar trend.

Data from October 1968 to February 1969 was not available; and during March 1969 a meridional section in the region off Cape Comorin showed the presence of thermocline at about 40-50 m (Fig. 44 d) and the salinity values in the mixed layer were much lower than those in the northern regions (Fig. 44 e). With all these features, this area contained only a low abundance of plankton although the mixed layer contained a good amount of oxygen (Fig. 44 a, f). But the abundance of fish eggs and larvae was quite good in this region. It is worthwhile to recollect that a comparable abundance occurred in this area during March 1967 also.

With more or less the same oceanic features in the continental shelf, the plankton abundance was much higher in the region off Cochin during April 1969 (Fig. 45 a, d). The investigated region was in the further northern areas than March and the high abundance of eggs and larvae in the wadge bank was not observed during April 1969, in the northern areas.

Discussion

It could be observed that along the west coast of India, the hydrographic features, plankton biomass and abundance of fish eggs and larvae are closely inter-related. The seasonal variations in the environmental conditions are observed to be clearly depicted in the bioproperty distribution patterns. Due to unavoidable gaps in the observations, a conclusive correlation could not be presented, yet the seasonal patterns could be deduced with satisfactory accuracy.

As far as the spatial distribution of plankton biomass is concerned, it could be observed that the continental shelf region was markedly richer than the offshore regions in general. A reference to the IIOE Plankton Atlas published by the IOBC (IOBC, 1968 a, b) indicates that planktonic groups are more abundant over the continental shelf only and at times their abundance spills over into the adjacent oceanic waters.

Reference may be made in this connection to the Progress Report of the Pelagic Fishery Project No. 7, where it is stated that, "there is a broad agreement in the pattern of zooplankton density along the west coast in the sense that the average volumes tend to rise from April/May towards a peak in September subsequently falling in October/November- Relatively steady, but quite low volumes of plankton are noticed from December to April". During this investigation also comparable features prevailed eventhough monthwise variations were not agreeing decisively. Even then the peak of plankton biomass during the peak monsoon (July/ August) and postmonsoon season (September-October) were observed and a decreasing trend during the transient period (October/ November) was conspicuous in general. Low abundances occurring during summer and premonsoon period were also agreeing with the Project observations.

Qasim (1973) has stated that spawning of fishes largely occurs along the west coast during the monsoon and post-monsoon months. In the present observations the peak in zooplankton biomass is also observed during peak monsoon and postmonsoon months which feature can attract fish and subsequent spawning can be enhanced.

Menon and George (1977) have stated that there is a recurring pattern in the zooplankton abundance and distribution in the shelf waters of the southwest coast of India and in general the period from July to September is the time of peak plankton production.

Prasad (1969) during an investigation of the plankton biomass of the whole of the Arabian Sea has observed that richer zooplankton biomass during the southwest monsoon with high concentrations towards the coast of Somalia, Arabian peninsula, Iran and southwestern part of India occurs with a low productive zone in the central and northern regions. The present observations also more or less agree with the above conclusions as far as the southwest coast of India is concerned.

The abundance of fish eggs and larvae exhibited a different trend. During the summer months a generally increasing trend is obvious when the coastal drifts are at a minimum. During peak monsoon (July/August) the general trend is for a decrease taking into consideration the data from 1964 to 1969 in the abundance of eggs and larvae when there is a fairly good southward coastal drift but exceptions have also been observed when there was a higher abundance during the peak monsoon.

This monsoon paucity was more for the eggs than that for the larvae. Probably the transport of these along with the southward drift is more than the larval transport. By the fading away of the monsoon the southward current also weakens and thus from October to December the egg and larval abundance are quite high and that too in the further northern regions. The northward drift during winter (December/January) can help the transportation of the eggs and larvae towards the northern regions.

Reference may again be made to Report No. 7 of the Pelagic Fishery project where it is stated that "the biological cycle is influenced by the intensity of upwelling and therefore more pronounced in the south, while in the north it is not so clearly related to upwelling alone but also perhaps to the current systems of the northern Arabian Sea". The present investigations also support the inferences that the plankton biomass is more or less directly related to the intensity of upwelling along the west coast.

REFERENCES

CURRIE, R.I. 1963. The Indian Ocean Standard net. *Deep-Sea Res.*, 10: 27-32.

————, A.E. Fisher AND P.M. HARGREAVES 1973. Arabian Sea Upwelling. In: Bernt Zeitzschel (Ed.) *The Biology of the Indian Ocean. Ecological Studies-3*. pp. 37-52.

IOBC 1968 a. Maps on total biomass in the Arabian Sea and the Bay of Bengal. IIOE Plankton Atlas, 1(1).

IOBC 1968 b. Maps on total zooplankton biomass in the Indian Ocean. IIOE Plankton Atlas, 1(2).

JONES, S. AND S.K. BANERJI 1973. A review of the living resources of the Central Indian Ocean. *Proc. Symp. Living resources of the Seas around India, CMFRI., India*, pp. 1-17.

MENON, M.D. AND K.C. GEORGE 1977. On the abundance of zooplankton along the southwest coast of India during the years 1971-1975. *Proceedings of the Symposium on Warm Water Zooplankton, Special Publication, UNESCO/NIO*, pp. 205-213.

NAIR, P.V.R., SYDNEY SAMUEL, K.J. JOSEPH AND V.K. BALACHANDRAN 1973. Primary production and the potential fishery resources in the seas around India. *Proc. Symp. Living resources of the Seas around India, CMFRI., India*, pp. 184-198.

PRASAD, R.R. 1966. Some aspects of productivity and fisheries of the west coast of India. *Seafood Trade J.*, 1: 11-15.

———— 1969. Zooplankton in the Arabian Sea and the Bay of Bengal with the discussion on the fisheries of the regions. *Proc. natn. Inst. Sci.*, 35 (5) 8: 399-437.

————, S.K. BANERJI AND P.V. RAMACHANDRAN NAIR 1970. A quantitative assessment of the potential fishery resources of the Indian Ocean and adjacent seas. *Indian J. Anim. Sci.*, 40(1): 73-98.

QASIM, S.Z. 1973. An appraisal of the studies on the maturation and spawning in marine teleosts from Indian waters. *Indian J. Fish.*, 20(1): 166-181.

RAMAMIRTHAM, C.P. AND D.S. RAO 1973. On upwelling along the west coast of India. *J. mar. biol. Ass. India*, 15(1): 306-317.

RAO, T.S.S. 1973. Zooplankton studies in the Indian Ocean. In: Bernt Zeitzschel (Ed.) *The Biology of the Indian Ocean. Ecological Studies*-3. pp. 243-255.

SILAS, E.G. 1969. Exploratory fishing by R.V. VARUNA. *Bull. cent. mar. fish. Res. Inst.*, 12: 1-86.

————, S.K. DHARMARAJA AND K. RENGARAJAN 1976. Exploited marine fishery resources of India. *Ibid.*, 27: 1-25.

UNDP/FAO/PFP(IND/593) 1974. Plankton - Fish eggs and larvae studies. *Progress Report*, 7.