Temperature and Salinity Characteristics of Passamaquoddy Bay and Approaches Between 1990 and 1995

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ABSTRACT

Robinson, S. M. C., J. D. Martin, F. H. Page, and R. Losier. 1996. Temperature and salinity characteristics of Passamaquoddy Bay and approaches between 1990 and 1995. Can. Tech. Rep. Fish. Aquat. Sci. 2139: iii + 56 p.

Monthly temperature and salinity profiles were taken at twenty five stations within the Passamaquoddy Bay region in southwest New Brunswick for six years between January 1990 and December 1995. Secchi disk readings were also recorded concurrently at each station. The mean monthly patterns of temperature and salinity by depth intervals are presented. The data are also summarized in several formats to enhance the interpretation. One is a pixel format which bins the temperature and salinity data into colour-coded ranges by depth intervals. The second is temporal contouring of the overall mean values to show the changes of the water characteristics over the year. Cluster analyses of the temperature and salinity data suggest the study area can be divided into four subareas based on their physical attributes.

RÉSUMÉ

Robinson, S. M. C., J. D. Martin, F. H. Page, and R. Losier. 1996. Temperature and salinity characteristics of Passamaquoddy Bay and approaches between 1990 and 1995. Can. Tech. Rep. Fish. Aquat. Sci. 2139: iii + 56 p.

Des profils de température et de salinité ont été notés chaque mois, pendant une période de six ans allant de janvier 1990 à décembre 1995, dans vingt-cinq stations de la région de la baie Passamaquoddy, dans le sud-est du Nouveau-Brunswick. Les relevés du disque de Secchi ont également été enregistrés en même temps à chaque station. Les tendances mensuelles moyennes de la température et de la salinité par couche de profondeur sont présentées. Les données sont également résumées sous plusieurs formes pour que l'interprétation en soit facilitée. Sur un graphique, les données sur la température et la salinité sont représentées par des pixels, selon des codes de couleur correspondant à la profondeur. Sur le deuxième graphique, les valeurs moyennes globales sont précisées dans le temps de façon à mettre en évidence les variations des caractéristiques de l'eau au cours de l'année. L'analyses typologique des données sur la température et la salinité laisse supposer que le secteur à l'étude peut être subdivisé en quatre sous-secteurs, en fonction de leurs caractéristiques physiques.

INTRODUCTION

Detailed knowledge of the physical features of the marine environment is crucial to the successful and rational development of marine industries as well as the optimal management of the coastal zone (Strain et al. 1995). Collection and analyses of data from monitoring programs on the water characteristics can give valuable insights on how the physical mechanisms could interact with the various biological systems and how we might be able to exploit these characteristics. Therefore, gathering this type of knowledge is an essential first step in understanding how to exploit a fish population, where to site a new aquaculture operation or what factors to consider when setting up an ecological type of study.

Adequately describing a marine environment requires that a time series of measurements be taken so that the full range of frequencies over which variability occurs is monitored. If animals are exposed to their lethal limits of some variables, the extremes may be more important than the means.

Previous oceanographic work in the Quoddy region of the Bay of Fundy has occurred primarily due to concerns over particular issues. In the late 1950s, a proposal was submitted to harness the tidal energy in the Quoddy region with a series of tidal barrages to generate hydroelectric power (see for example: Ketchum and Keen 1953; Forgeron 1959; Forrester 1959; Chevrier and Trites 1960; Trites 1961, 1962). Further hydrographic research was done in the 1970s when proposals were made to construct an oil terminal in the Eastport area of the State of Maine (Loucks et al. 1974; Scarratt 1979) and the effects of a pulp mill on the Letang area (Kristmanson et al. 1976). In the mid- to late 1980s more oceanographic work was done in the L'Etang area studying the potential for benthic enrichment due to the salmonid aquaculture industry developing in that area (Loucks 1988, 1991; Trites and Petrie 1992, 1993, 1995).

In 1989, a program was initiated to study the scallop population in Passamaquoddy Bay (Quoddy region), in particular the distribution of scallop spat in relation to the hydrographic and planktonic properties of the water. The objective of this report is to describe the hydrographic data collected during this initiative for the period from January 1990 to December 1995.

MATERIALS AND METHODS

A systematic oceanographic monitoring program was initiated in September 1989 at 25 stations in the Passamaquoddy Bay area and approaches (Fig. 1). Stations were established in a uniform grid pattern (2 min of latitude and longitude) over the study area in order to develop a database on the spatial patterns of water properties. Monthly sampling of the water column for temperature and salinity at all stations was done using a Seacat SBE 19 internally recording CTD from Sea-Bird Electronics Inc. The CTD was programmed to record conductivity, temperature and depth every 0.5 s which corresponds to approximately two measurements per meter of water depth.

The sampling protocol consisted of a 2-d sampling period near the middle of each month where casts were taken from the 14-m R/V Pandalus III. The CTD was attached to a stainless steel wire cable from a hydraulic hydrographic winch such that the sensors were oriented towards the bottom approximately 1 m above a weight on the end of the cable. A sounding of the water depth was taken at each station prior to each cast on the ship's electronic depth recorder. At each station, the CTD unit was lowered 1 m below the surface, allowed to equilibrate for 1 min and then lowered to the bottom at a fall rate of 1 m per s. The distance of the instrument from the bottom was judged with a metered block on the hydrographic wire. When the bottom weight touched the seabed, the unit was retrieved, switched off and placed in a tank of water until the next station to minimise temperature fluctuations. Initially, the CTD measured salinity via water forced through the salinity cell with the drop rate of 1 m/s, but in August 1992, a pump was mounted on the CTD which provided a more consistent flow of water across the salinity cell. Surface temperatures from bucket samples were measured with a hand-held mercury thermometer at each station and standard secchi disk readings were taken.

The data from the CTD were down-loaded onto a personal computer using the proprietary Sea-Soft software. The downcast data from each profile were binned into 1 m intervals and were processed to remove data spikes, density inversions and anomalies due to inadequate instrument equilibration. These edited data were then stored in a computer database (ORACLE™) for data handling and basic analyses. The CTD was calibrated annually at the manufacturer's plant (Seabird, Seattle, Washington). Interannual drift in either temperature or salinity was negligible.

Cluster analysis of the data was accomplished with a SYSTAT™ Euclidean distance routine for the personal computer. Contouring of the temperature and salinity data was achieved with DISPLA software from Computer Associates Ltd. using the ENDMAT inverse distance weighting algorithm. The data set selected here was from January 1990 until December 1995.

RESULTS

SEASONAL VARIATION

The temperature and salinity data for each station are presented in Fig. 2a-2y. The January 1990 to December 1995 monthly values for five depths (2, 5, 10, 20 m and bottom) are shown with their monthly means. The plots show the variation in temperature and salinity is dominated by the seasonal cycle. The monthly temperature minima (based on mean values) at each of the stations were generally found in February and the maxima were found in August (Fig. 2a-2y). The annual range of temperatures for all stations and years combined was 17°C from approximately -1 to 16°C. The greatest temperature ranges as well as the largest variances around the monthly means were found in the closest inshore areas. Bottom temperatures were subject to less variation in monthly temperatures than the shallower depths. The inter-annual range in temperatures around the monthly mean was approximately 3°C.

The salinities at the sampling stations ranged from 26 to 33 practical salinity units[1] (psu) (Fig. 2). The spring freshet was apparent at all stations and could be characterised by a slow decline in salinity from February to May and a subsequent more rapid rise to July. At some sites, (i.e. Station 2 near the mouth of the St. Croix River) the salinity dropped to 25 psu for brief periods. The impact of the spring freshet was greatest in the inshore areas, especially those stations which were close to a freshwater source. Salinity generally increased with depth except for those stations and months which had much more vertical mixing (i.e. stations near flow constrictions (Stations 18, 25) or the winter months (Jan., Feb.)). The periods of highest salinity in Passamaquoddy Bay were found in the late summer and early fall at depths below 12 m. This pattern was not as evident in the offshore stations.

INTER-ANNUAL VARIATION

The inter-annual variations in water temperatures and salinities at each site are indicated by shaded depth line plots (Fig. 3a, b). To facilitate comparisons between stations, the figures show the upper 20 m of the water column only. The plots of binned water temperatures over the period January 1990 to December 1995 suggest significant inter-annual differences in the pattern of temperature development (Fig. 3a). The summer months of 1992 show that the water at most of the stations was much cooler than previous or subsequent summers in that the warm water (dark areas) did not span as many months nor did it extend as deep into the water column. January to May of 1993 was also much cooler than the other years. Stratification was evident at many of the stations, particularly those in the northern part of Passamaquoddy Bay, where temperature gradients were observed between 8 and 12 m. The offshore stations tended to show a smoother transition in temperatures between months. Inter-annual variations in the salinities from the monthly mean decreased with increasing water depth and in the more offshore stations.

SPATIAL PATTERNS

Plots of the minima and maxima in temperature and salinity at 5 m over the 5-yr time series reflected the spatial variation found in the annual patterns (Fig. 4a-d). The water temperature was coldest in the upper part of the St. Croix estuary where a minimum temperature of -0.83°C was recorded (Fig. 4a). Other relatively cold areas were found in the northwest section of Passamaquoddy Bay as well as an area just west of L'Etete passage (Stations 15 and 17). The outermost sampling stations (Stations 20 and 21) were above zero in all cases. Similar patterns were also found with the maximum temperatures (Fig. 4b). The upper part of the St. Croix estuary and the north-western section of Passamaquoddy Bay had peak temperatures between 15 and 17°C. There was a high to low gradient of temperatures from the inshore stations to the offshore ones.

The secchi disk readings indicate a drop in light penetration starting in spring (ca. March) at most of the estuary and bay stations (1-15), a temporary increase in July and a general rise in light

[1] These units (psu) are generally equivalent to the parts-per-thousand terminology (ppt or ‰)

penetration back to winter levels starting in the fall (ca. October) (Fig. 5). Values ranged from 1 m to over 9 m. Stations in the St. Croix estuary had consistently shallow secchi depths while the offshore stations had generally higher values. There were higher values in the late winter (January to March) than the summer.

The minimum salinities found at 5 m were in the upper parts of the St. Croix estuary and the northern part of Passamaquoddy Bay. There was generally a gradient from inshore to offshore and down the length of the estuary (Fig. 4c). The highest salinities found at 5 m at each station ranged from 30.9 to 32.7 psu. Spatial patterns were similar to the minimum values as there was generally a gradient from inshore to offshore and down the length of the estuary (Fig. 4d).

Spatial patterns in the temperatures and salinities were analyzed using cluster analysis of the raw data from 5 m for each of the stations. The clustering was based on the average linkage between the Pearson correlation coefficients calculated between the time series for each station. This technique clusters stations according to the degree of similarity in the temporal variation of temperatures and salinities. It does not consider differences in the mean conditions at each station. The analyses indicated that there were four general areas with similar patterns of thermal variations (Fig. 6, 7). The stations grouped into a St. Croix estuary cluster, an northern Passamaquoddy Bay cluster, a southern Passamaquoddy Bay cluster and a cluster outside of Passamaquoddy Bay. Clustering of the raw salinities using the same technique gave similar results as four very similar clusters were formed (Fig. 8, 9).

Contouring the mean temperatures by month indicated there were significant horizontal gradients at 5 m in the winter and summer while the months of March, April and October were mostly isothermal (Fig. 10). The mean salinity also showed horizontal variability (Fig. 11).

DISCUSSION

This study indicates there are distinct spatial and temporal differences in the hydrographic properties of the Passamaquoddy Bay area. In general, inshore areas have greater extremes and higher variability in both temperature and salinity. Minimum temperatures in the inshore areas were often less than zero while the offshore sites were very rarely below this value. In the inshore areas, the maximum temperatures were often over 13°C while the offshore areas rarely reached these levels. The spring freshet is apparent in the salinity profile at all stations and depths. While other studies have found similar results (i.e. Trites and Garrett 1983), this study provides better resolution of the spatial variation in the temperature and salinity profiles.

Binning the temperatures to give a vertical profile pattern was helpful in examining the inter-annual differences between temperatures and salinities. Temperature profiles of this sort may show promise as a crude prediction tool if patterns from the previous summer are correlated to subsequent winter temperatures. For example, the summer temperatures from 1992 showed that the water was cooler than other years and that the cool water did not extend as far down into the water column. The following winter was also colder than normal. A longer time series of data and a higher frequency of sampling will be required to determine the effectiveness of this technique.

Analyses of the data using clustering techniques suggest that the region can be grouped into four distinct areas: the St. Croix estuary, the northern part of Passamaquoddy Bay, the southern portion of Passamaquoddy Bay, and the outer seaward stations. The actual groupings changed slightly depending on whether temperature or salinity was used, but the general pattern remained evident. These groupings could be important to consider if ecological experiments were to be set up to test hypotheses in different temperature/salinity groupings.

Temporal contouring of the mean temperature and salinity data clearly showed the inverse inshore/offshore pattern in temperatures between winter and summer and also indicated the mixing of the water in the spring and fall. The contouring of salinity also clearly indicates the presence of the spring freshet and the extent to which it covers Passamaquoddy Bay.

The secchi depths revealed consistent patterns in the Passamaquoddy Bay region. The offshore sites had much higher light transmission rates than the more inshore sites. There was a dramatic decline of the secchi depth in the spring which correlated with the onset of the spring plankton bloom and the spring freshet which bring higher sediment loads and tannic acid levels. The increase in light penetration in July also corresponds with a shift in the phytoplankton community from a diatom to a dinoflagellate-dominated community

(J.L. Martin, St. Andrews Biological Station, pers. commun.).

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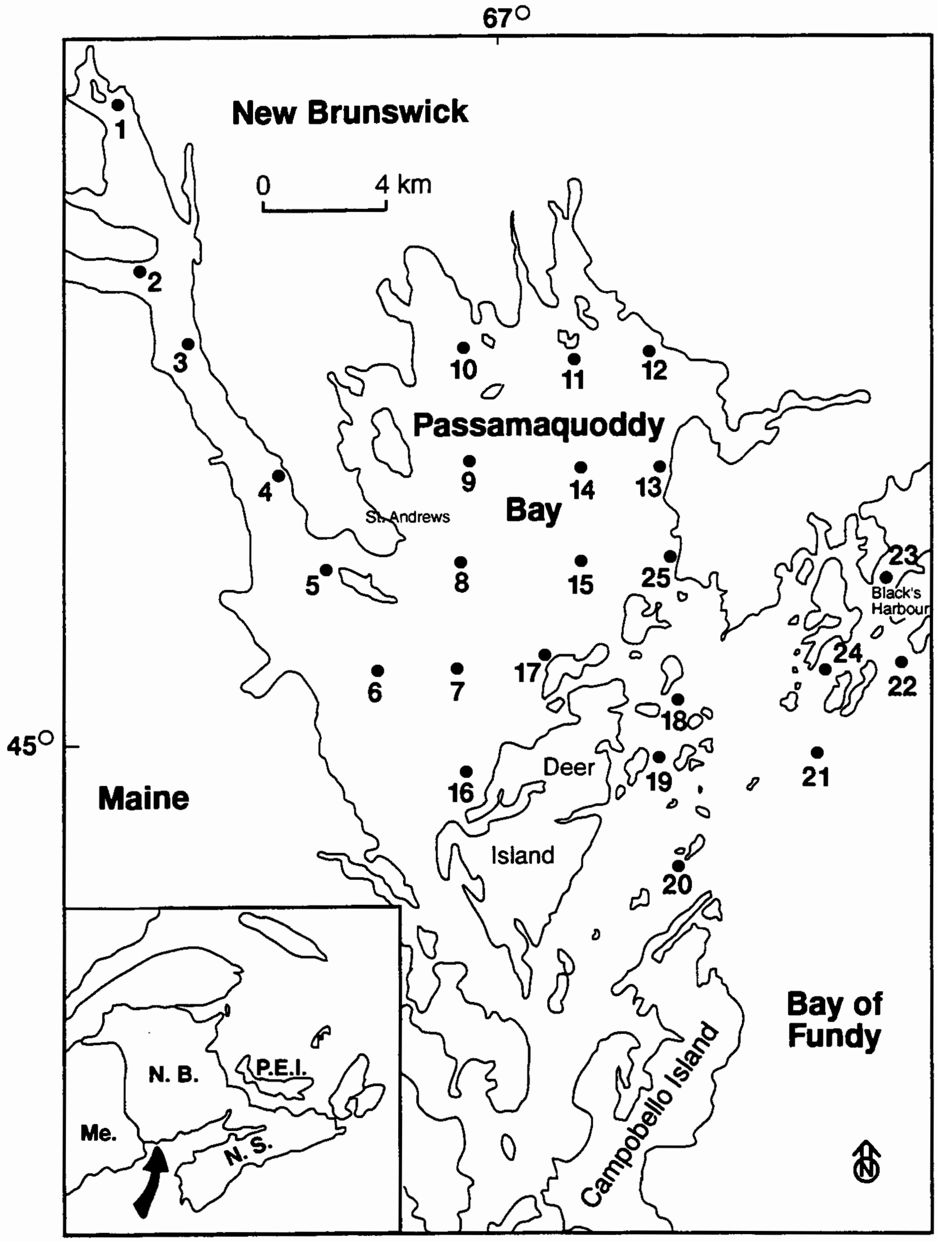


Figure 1. Map of Passamaquoddy Bay in the Quoddy Region showing the location of sampling stations.

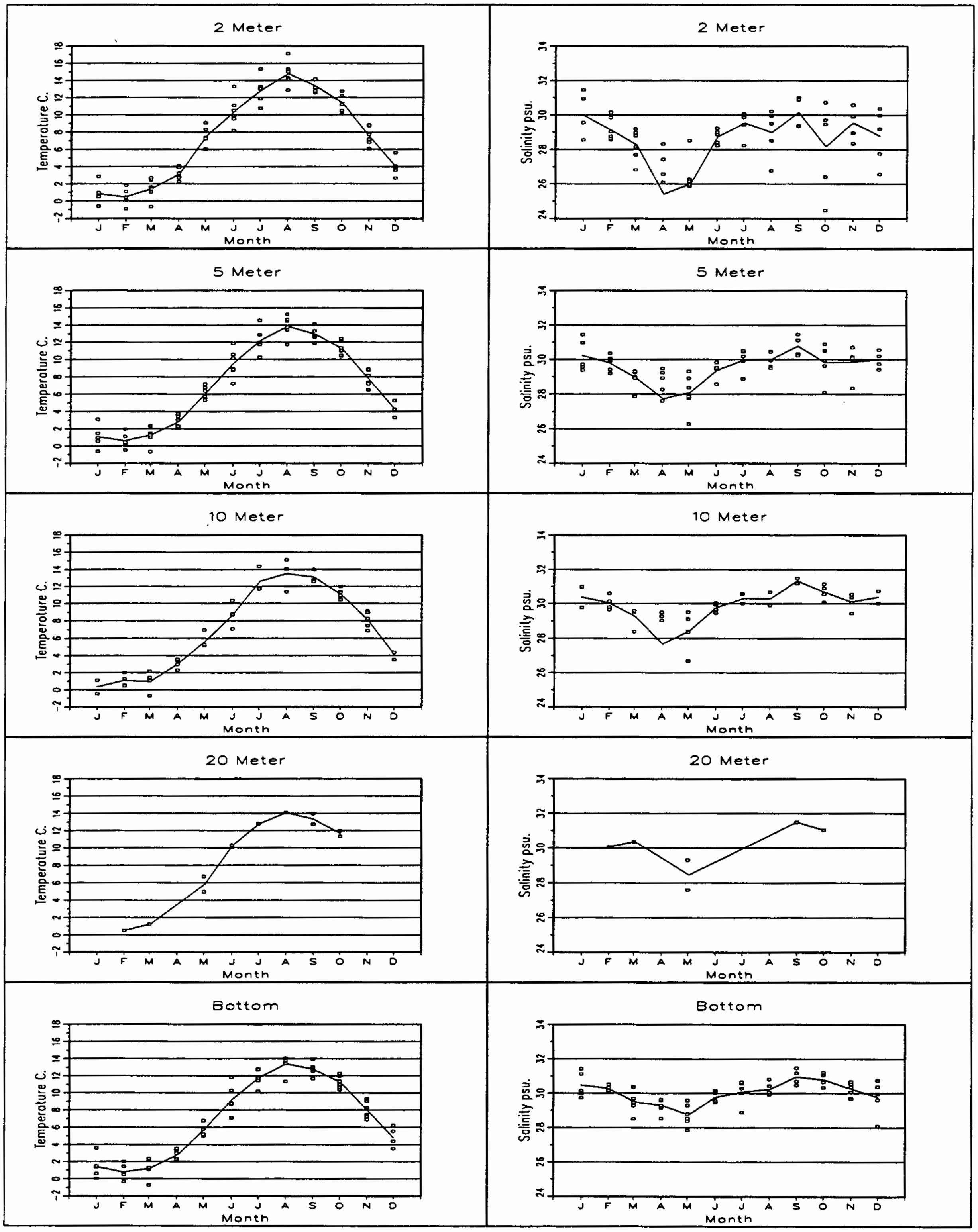
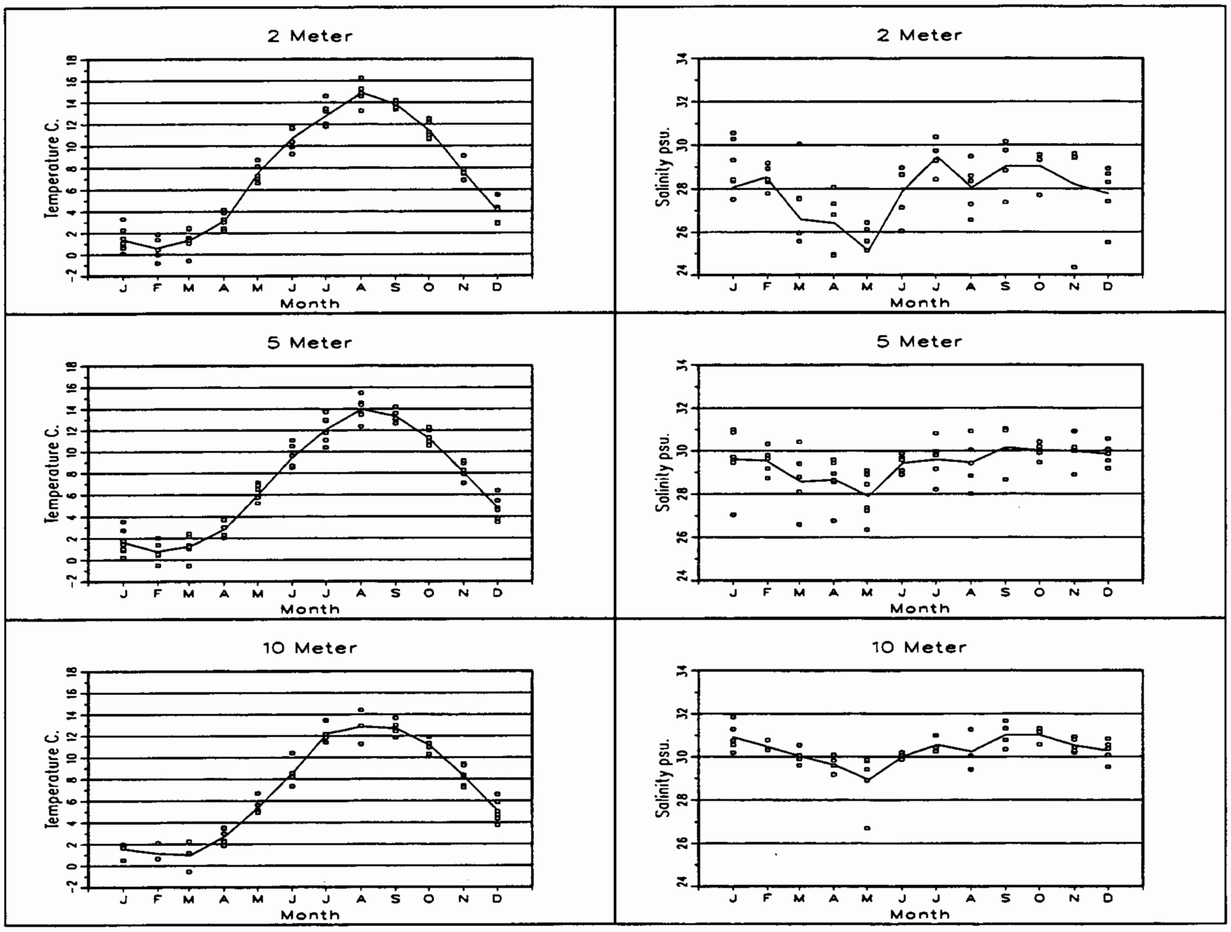
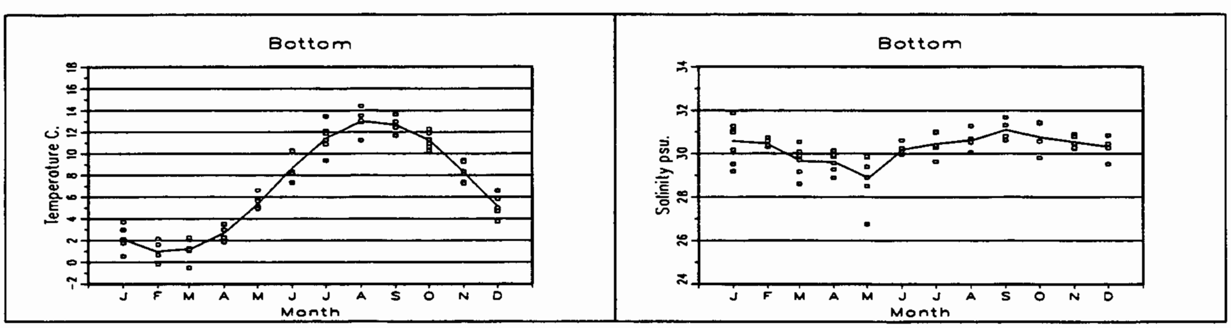


Figure 2: Monthly water temperatures and salinities taken during 1990 to 1995 at depths of 2,5,10,20m and bottom at station 1. Bottom is defined as within 1–2m of the sea bed. The open symbols represent a single record. The solid curve through the points joins the 1990 to 1995 monthly means.





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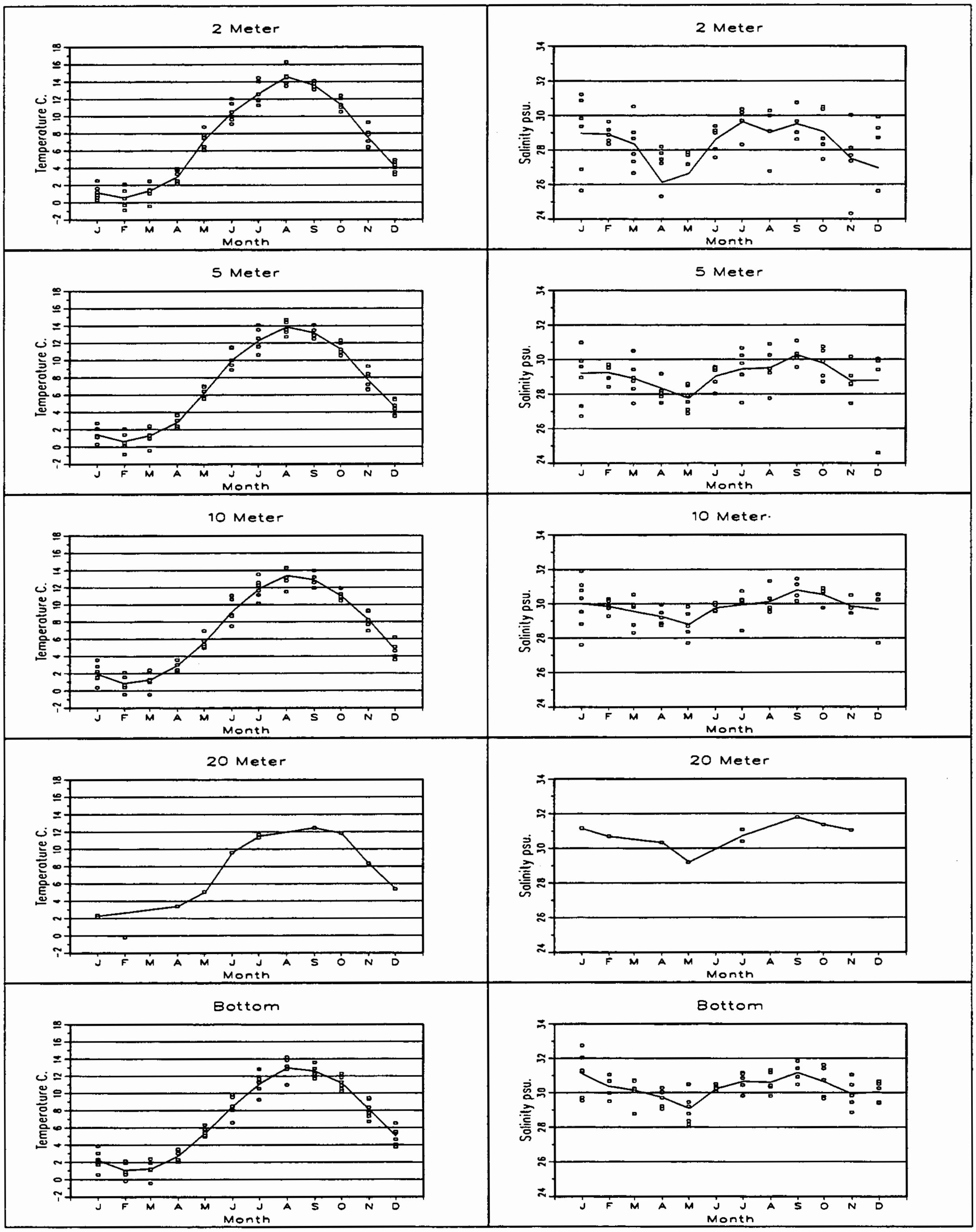

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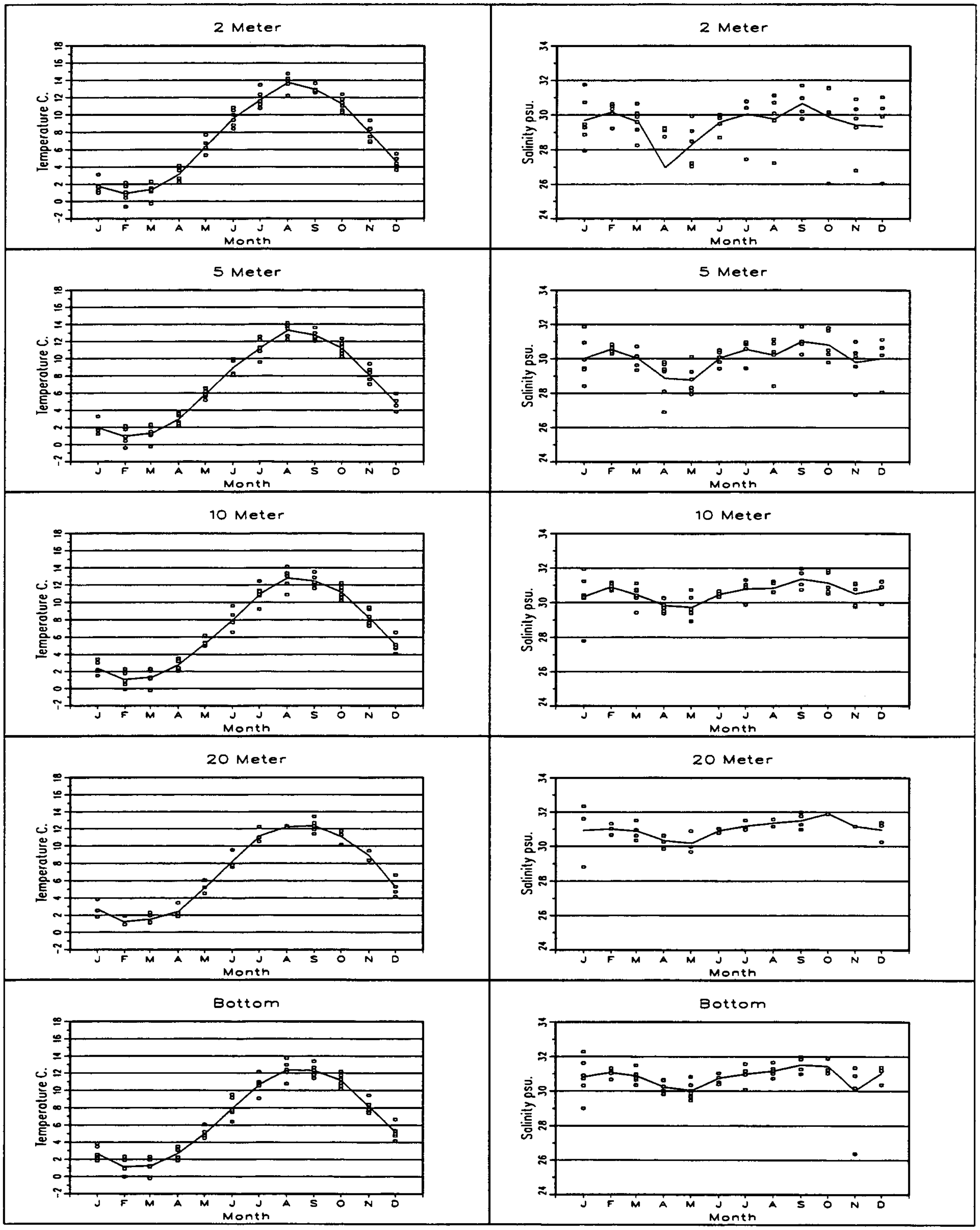

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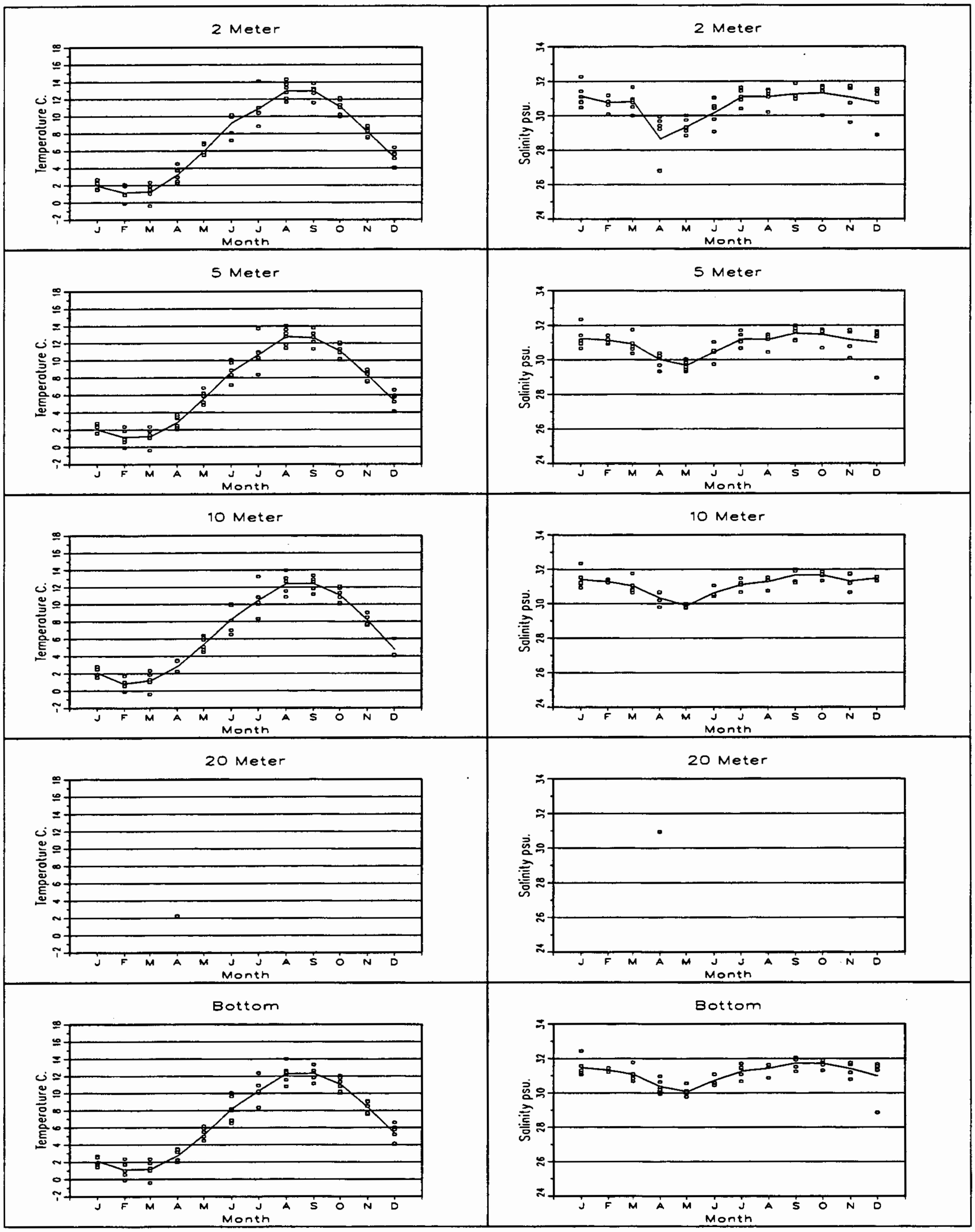

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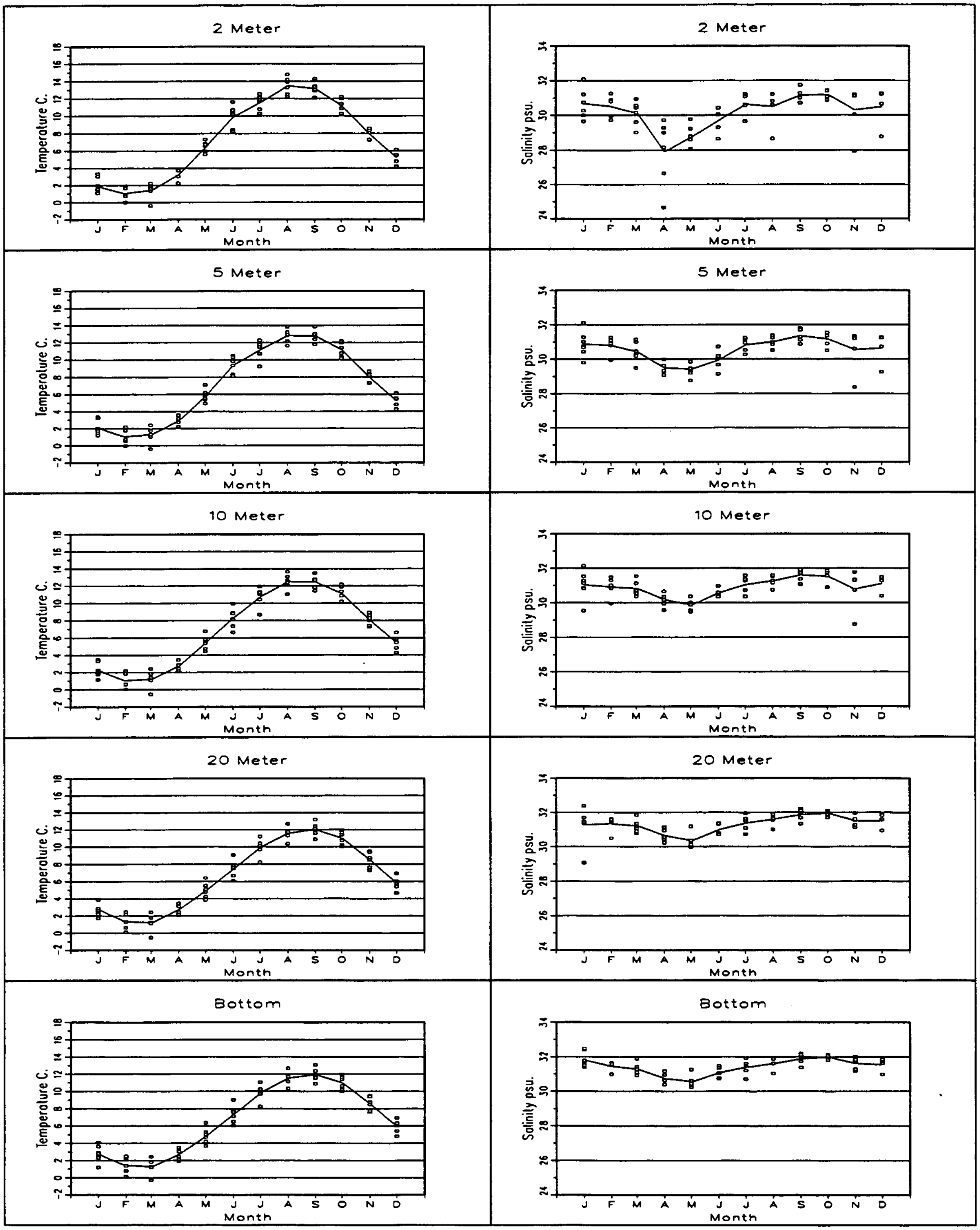

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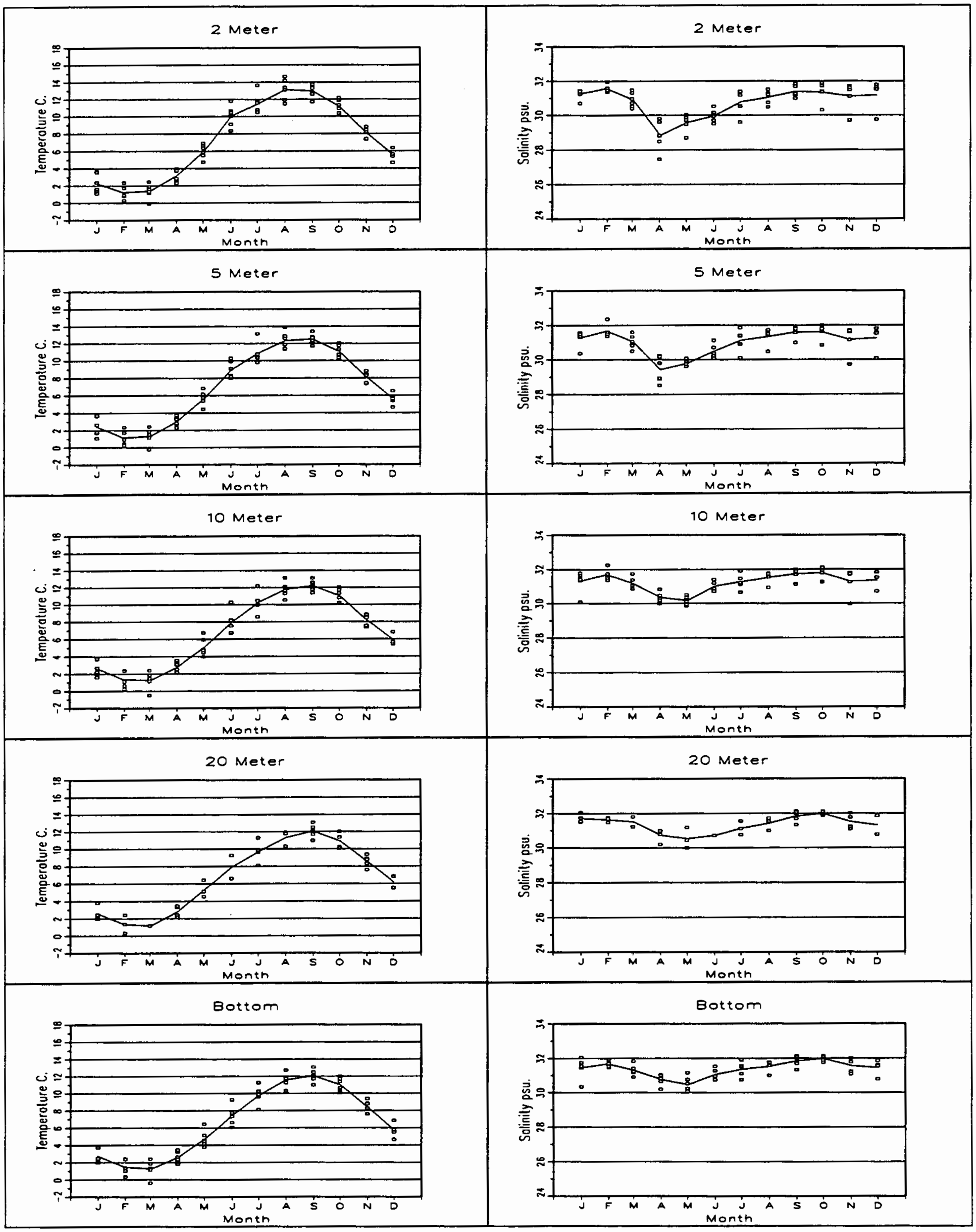

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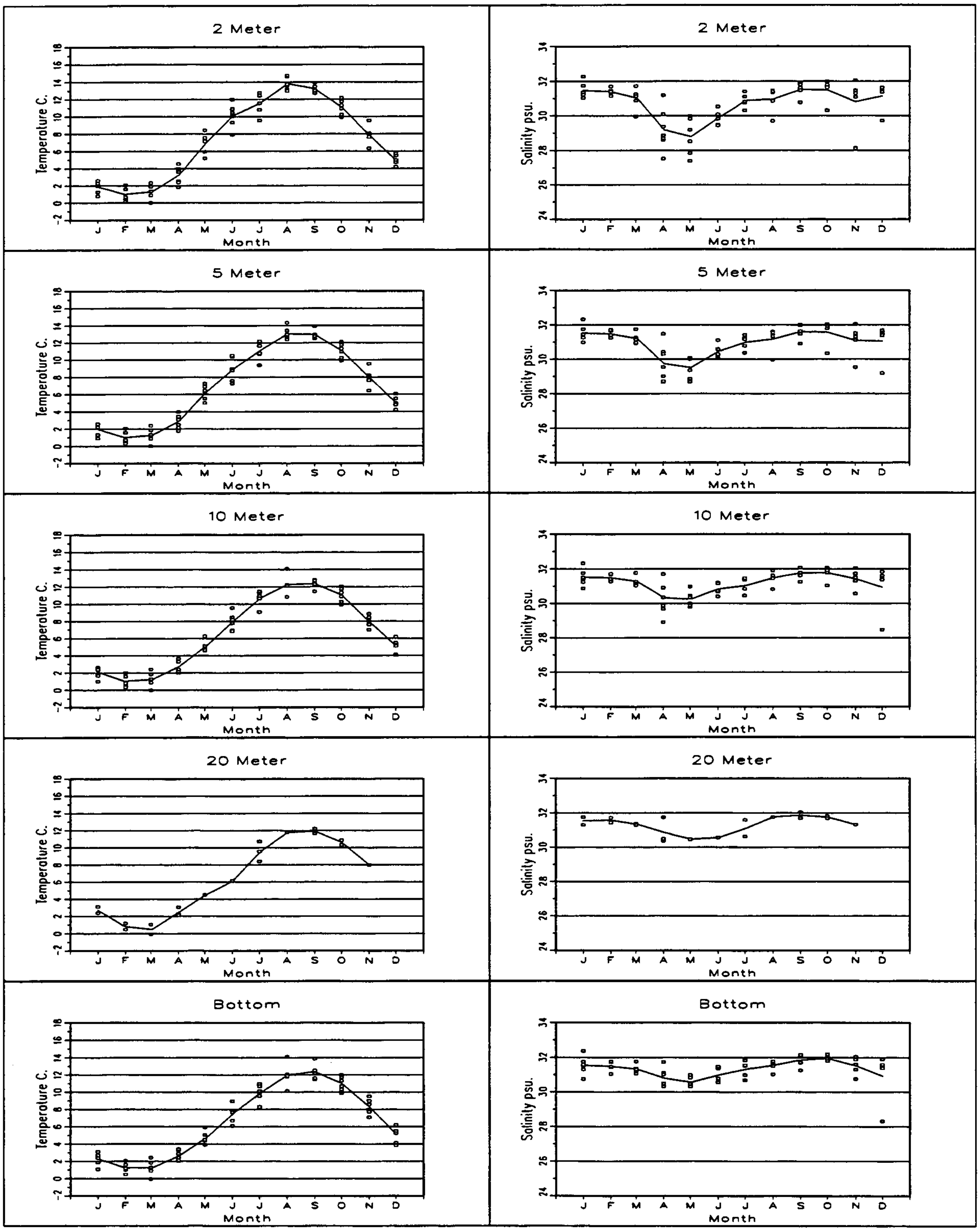

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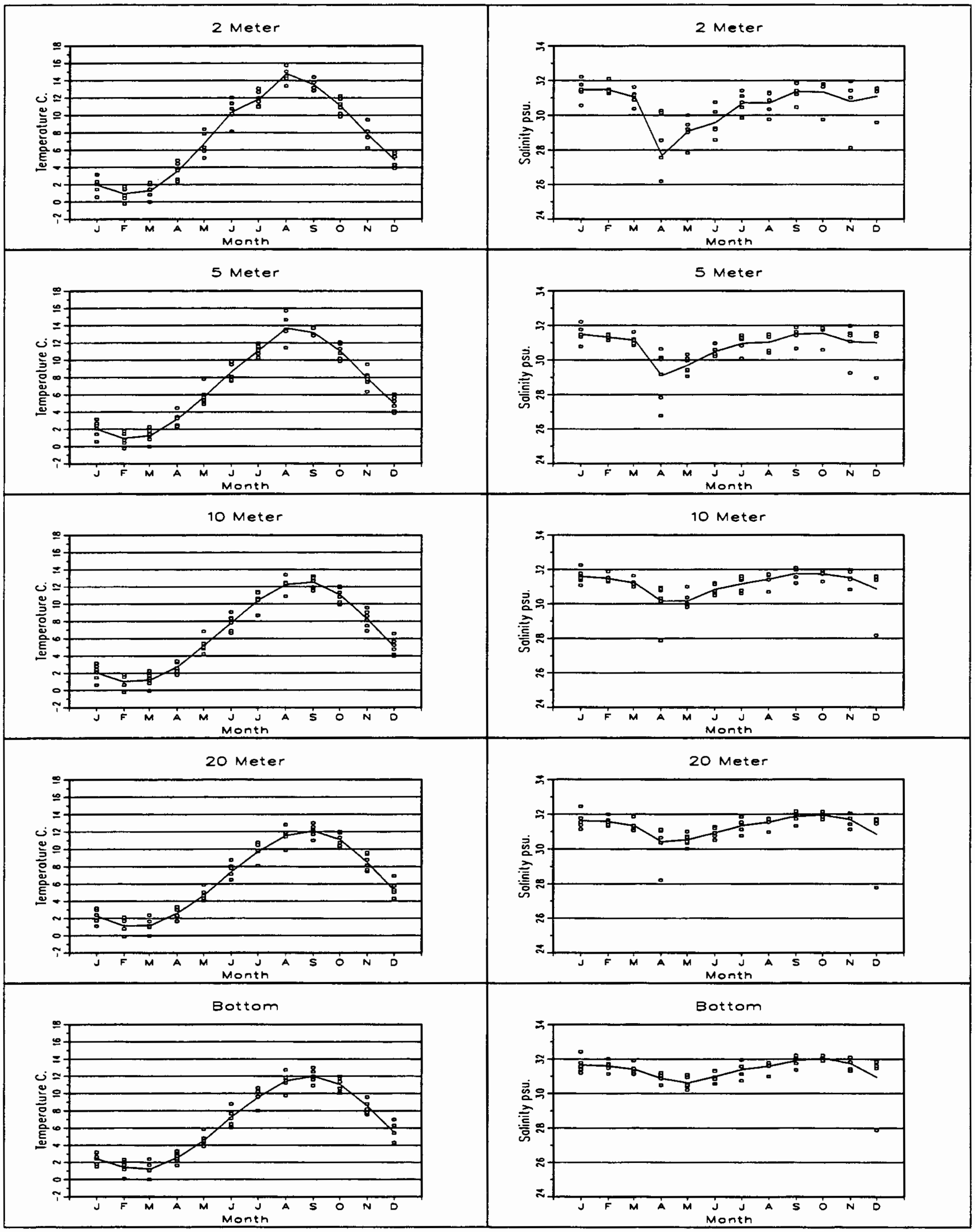

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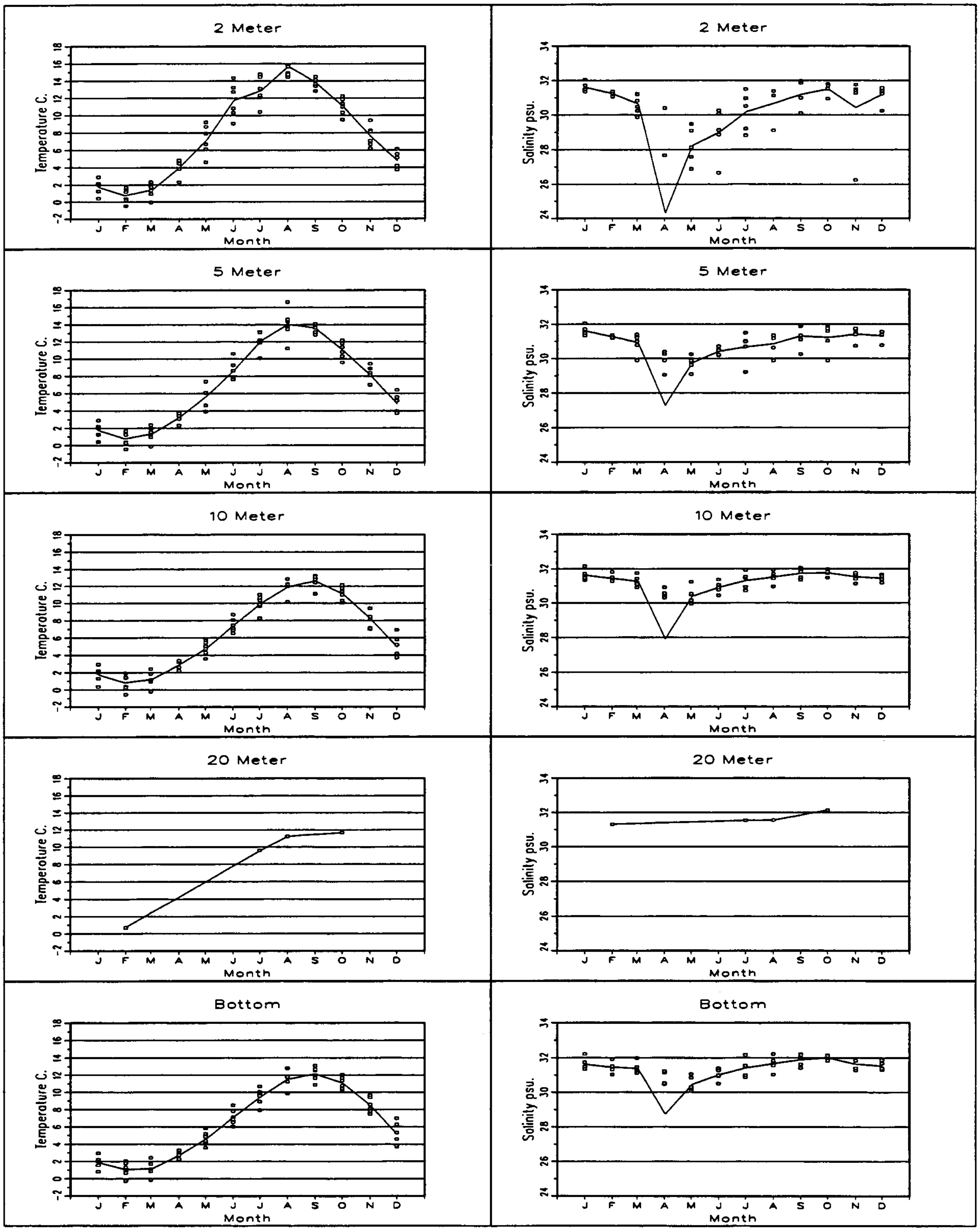

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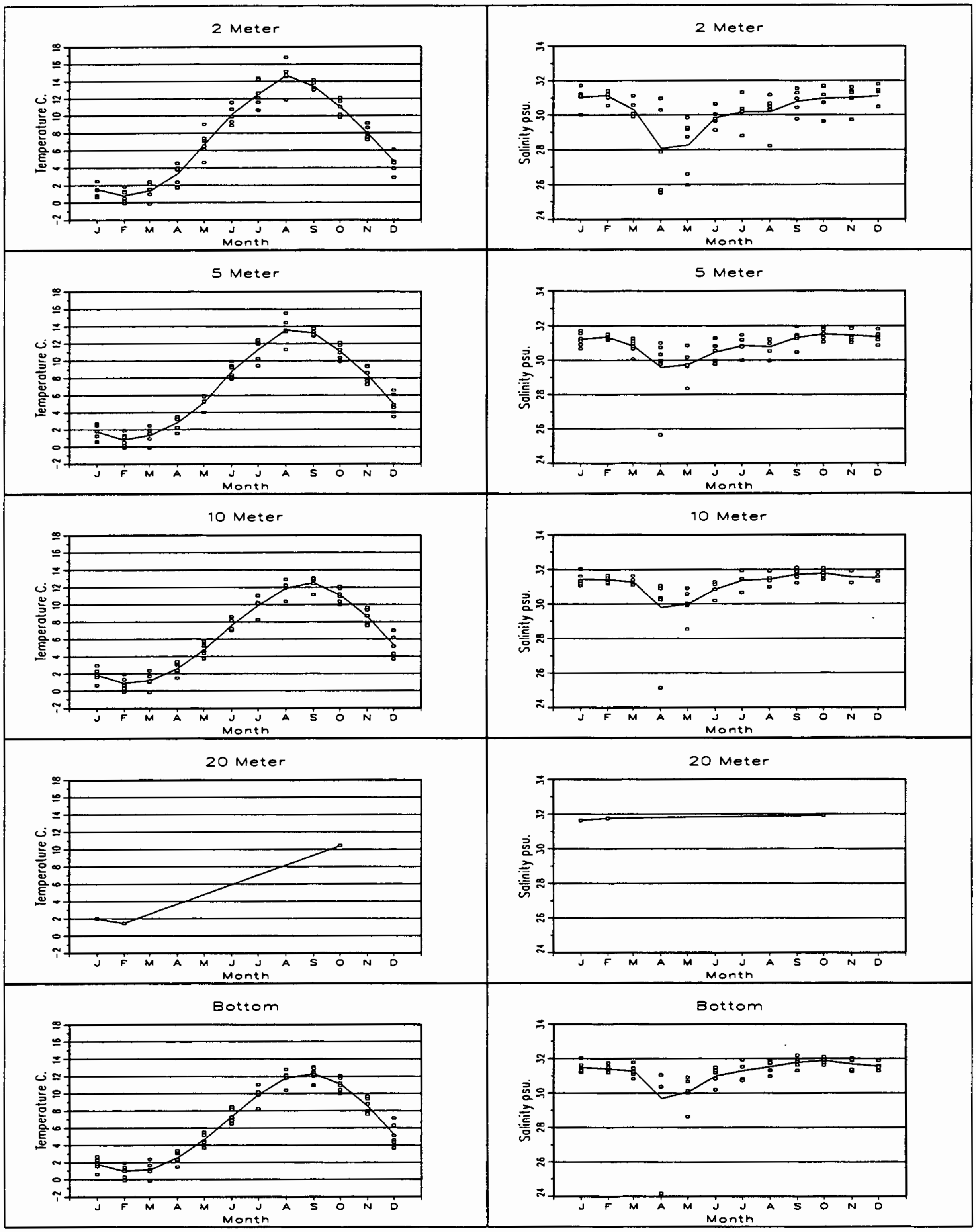

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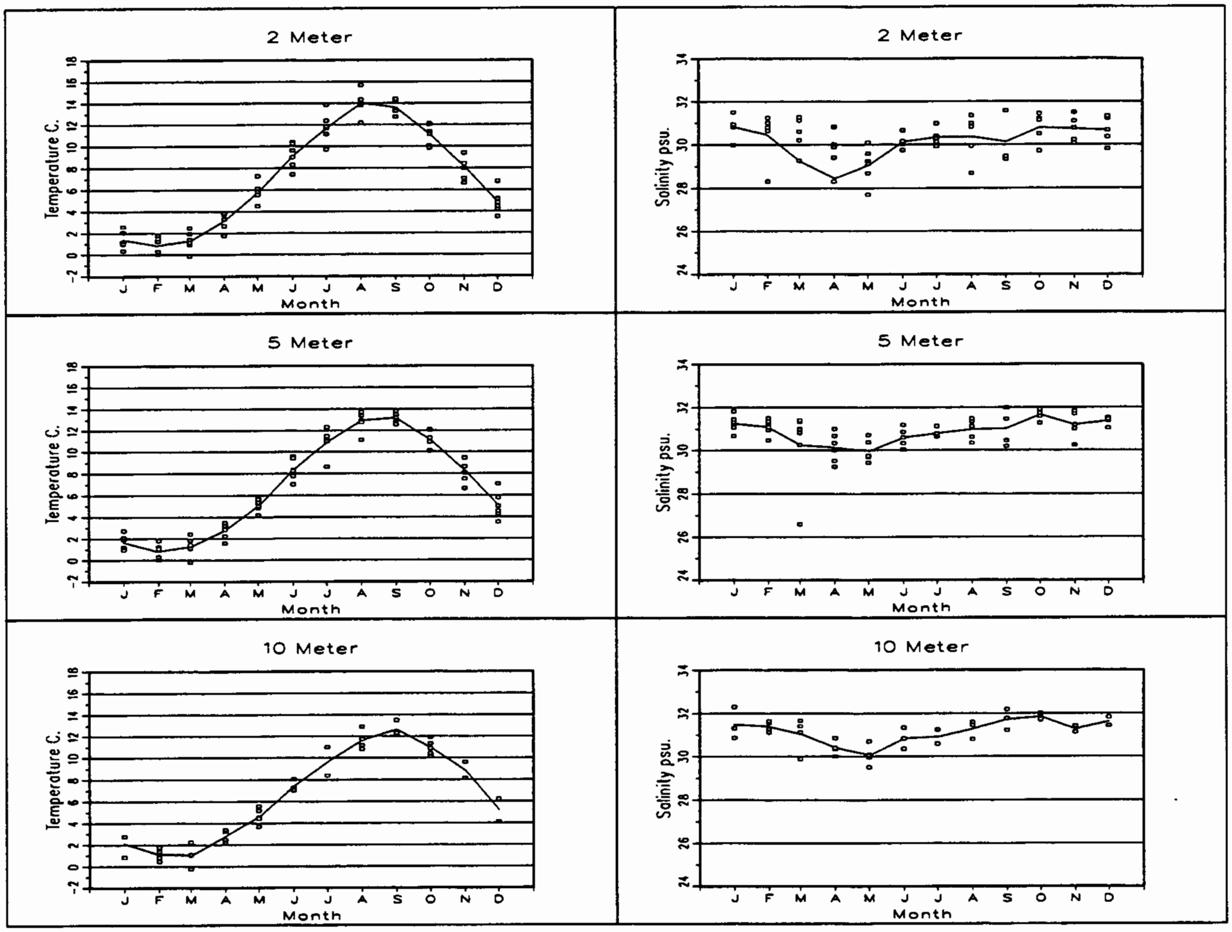

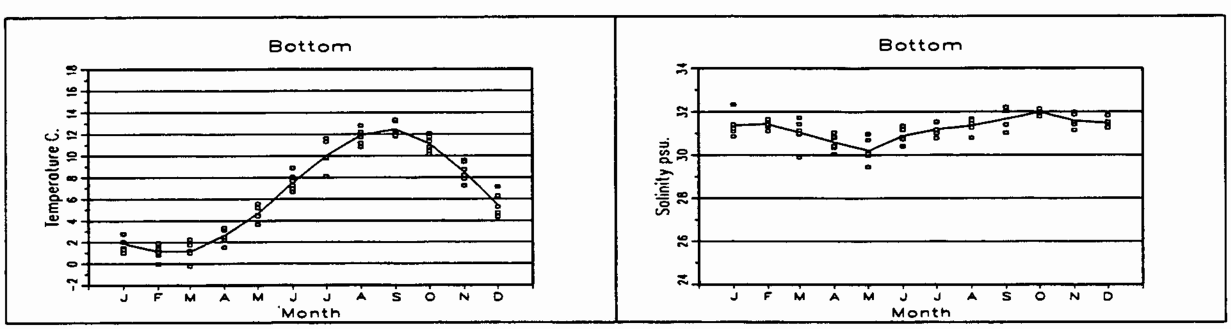

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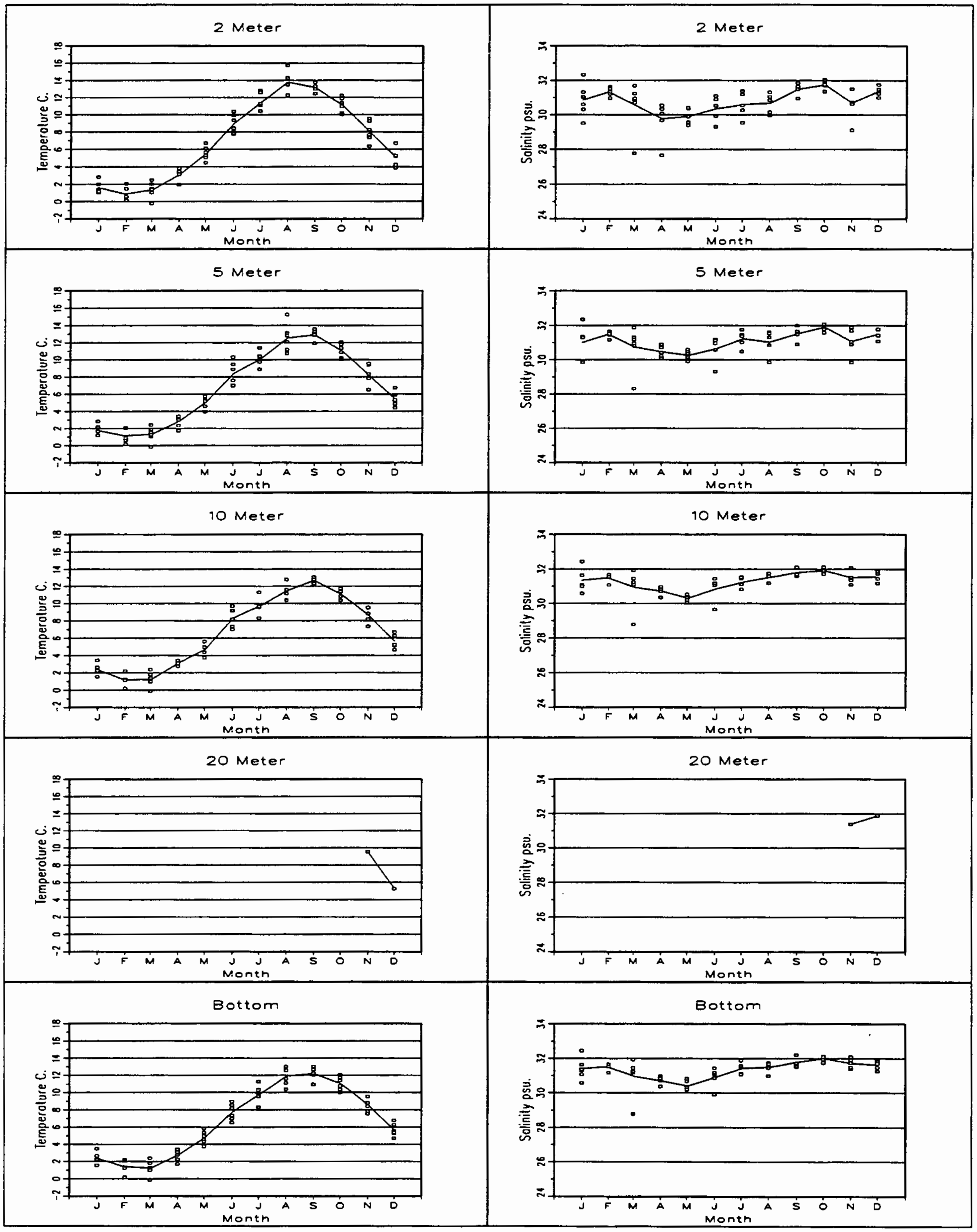

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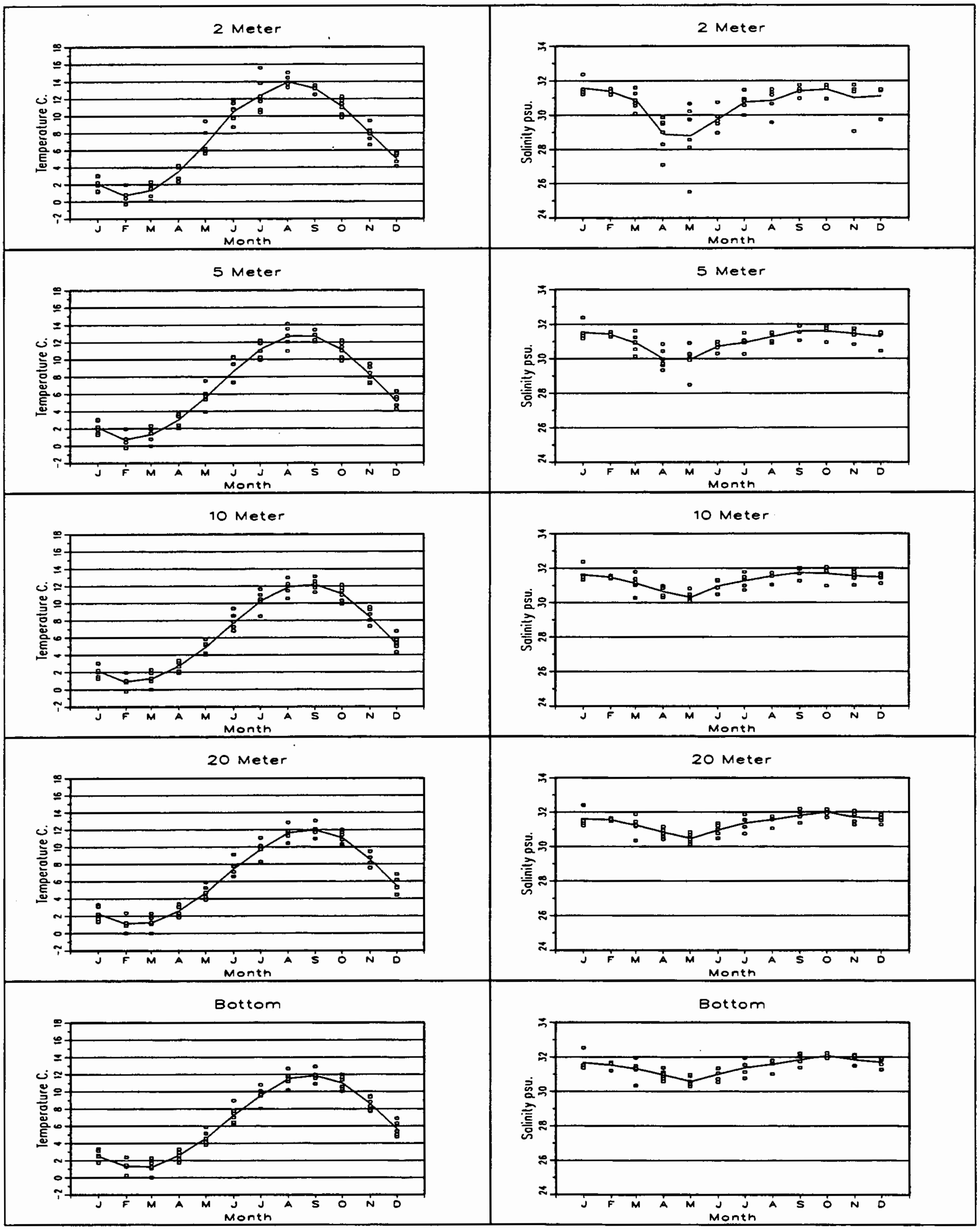

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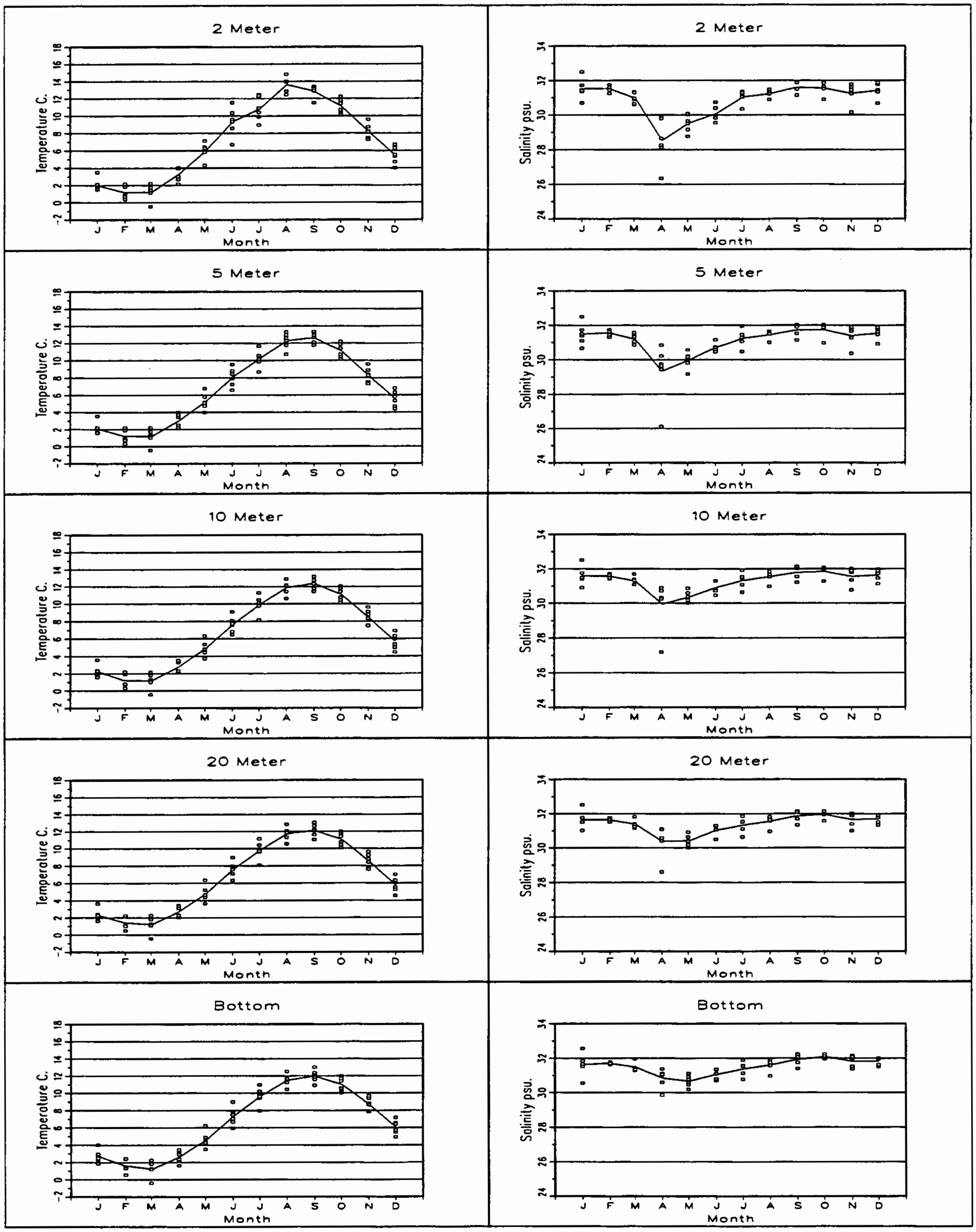

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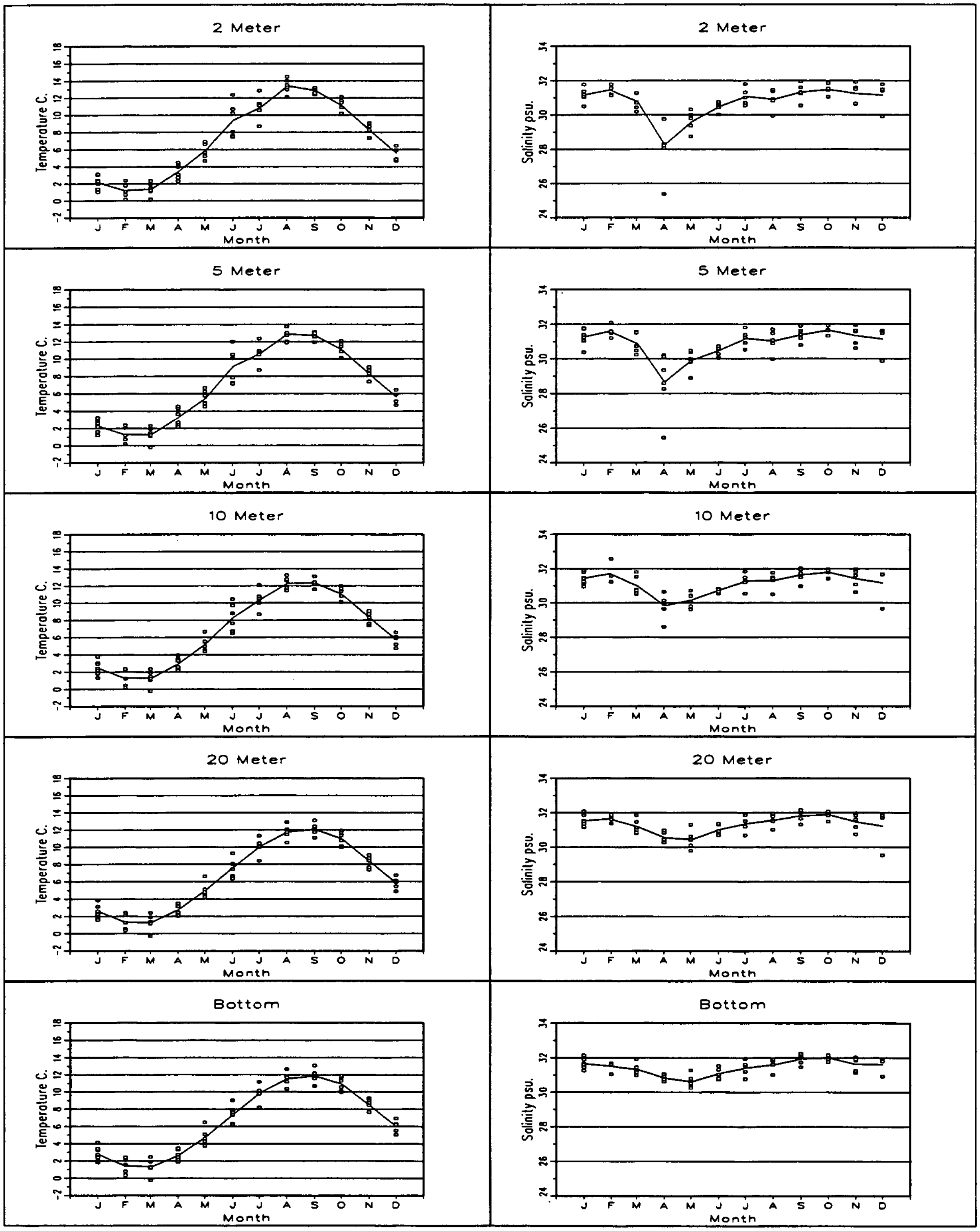

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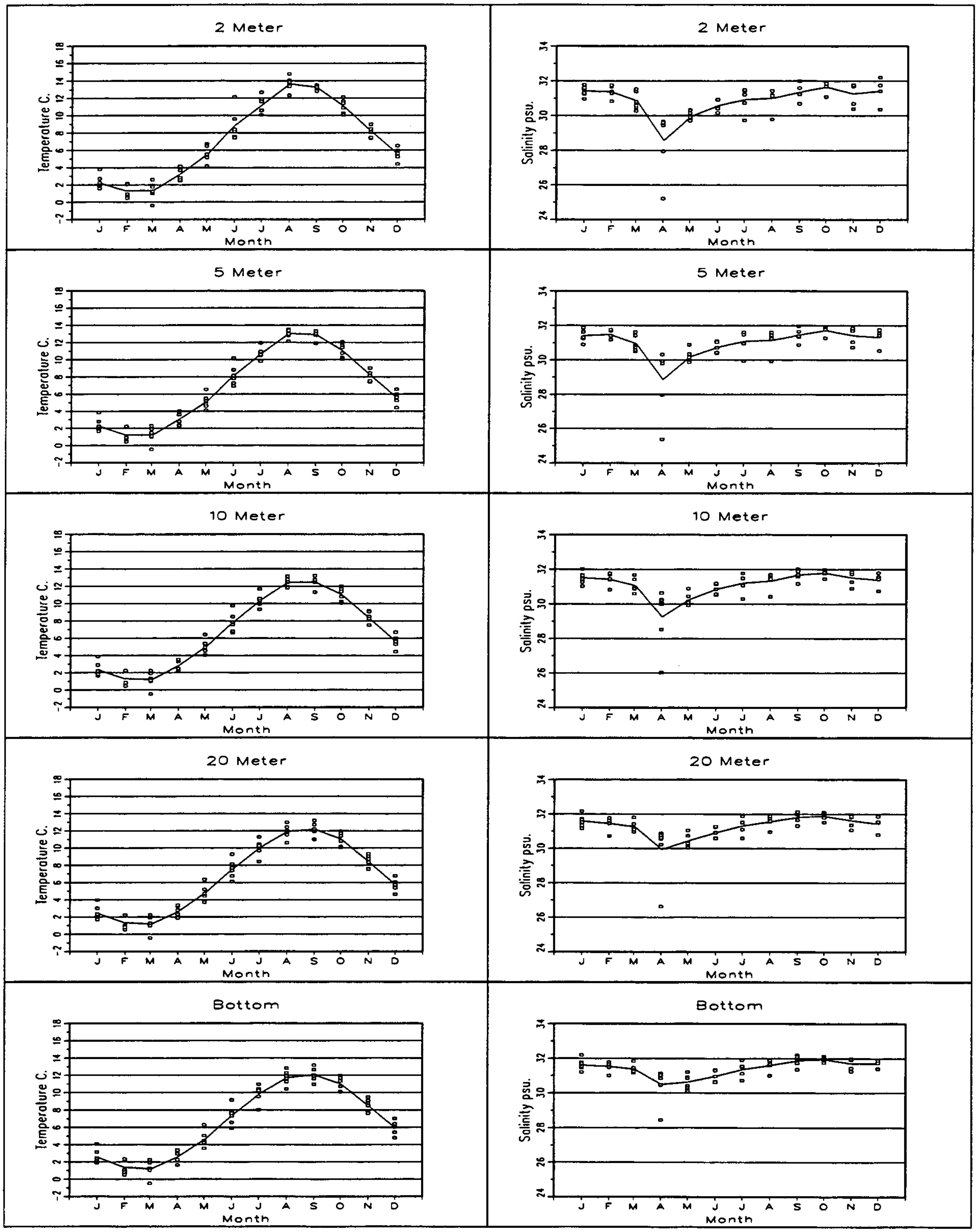

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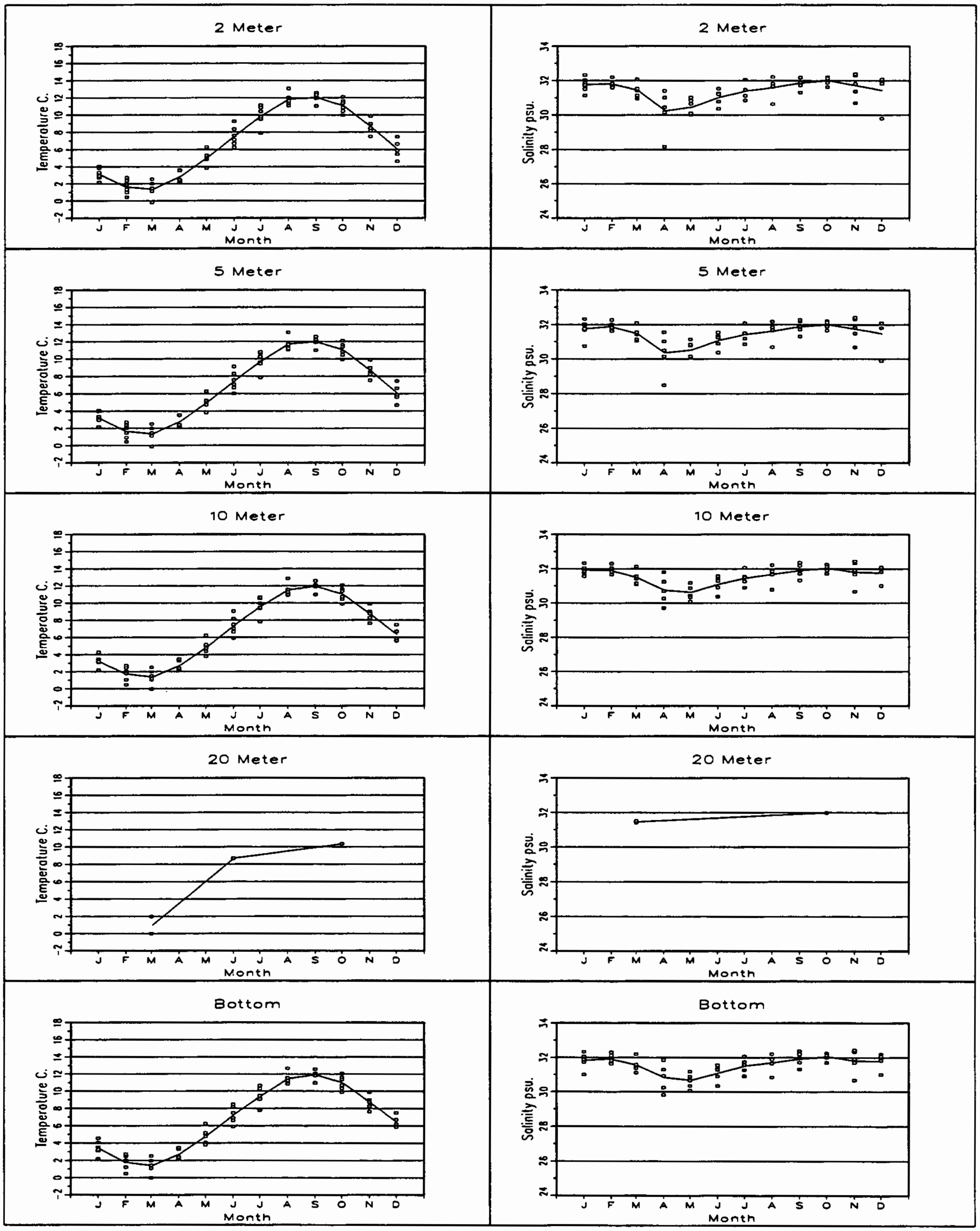

Figure 2: continued (STATION 18)

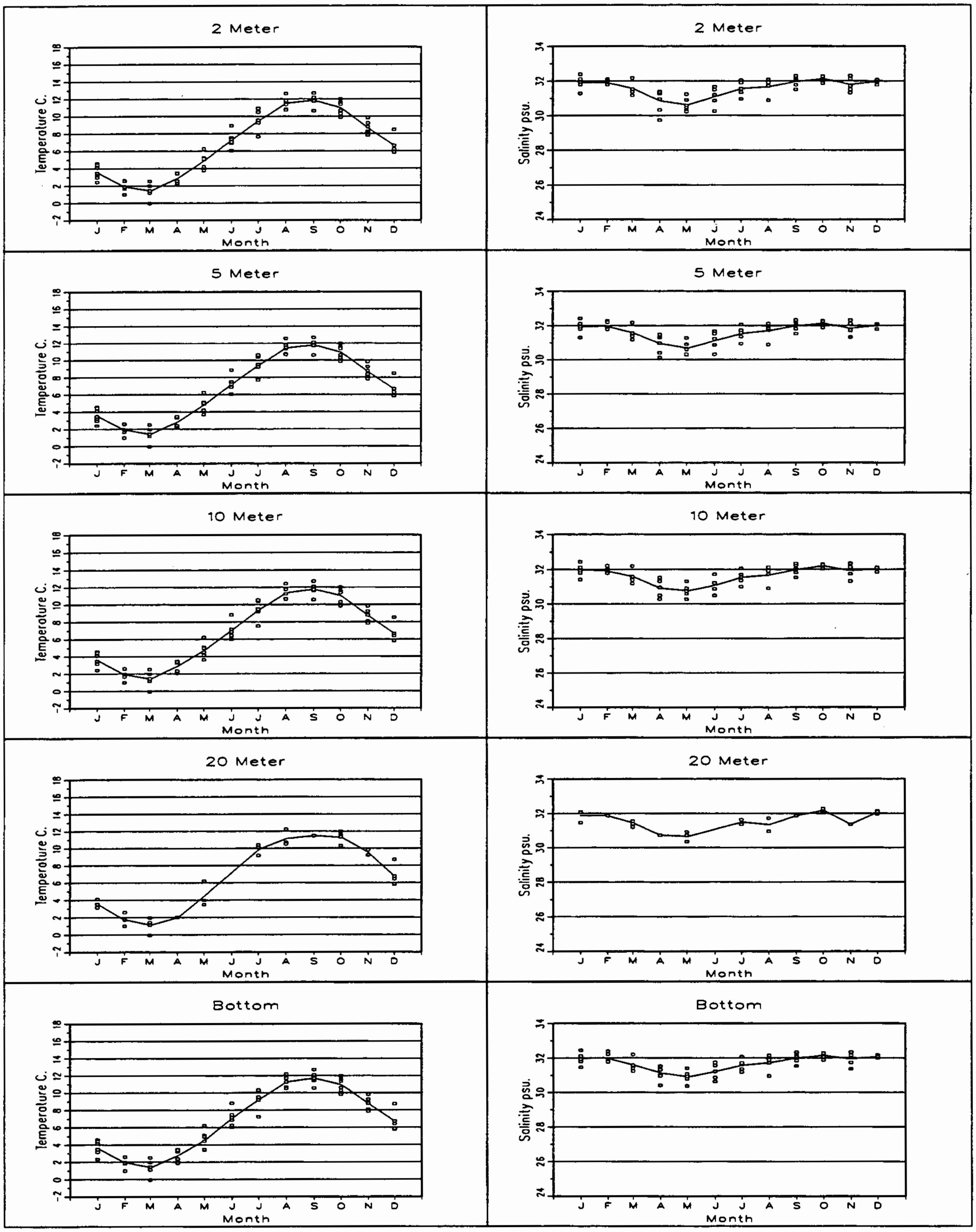

Figure 2: continued (STATION 19)

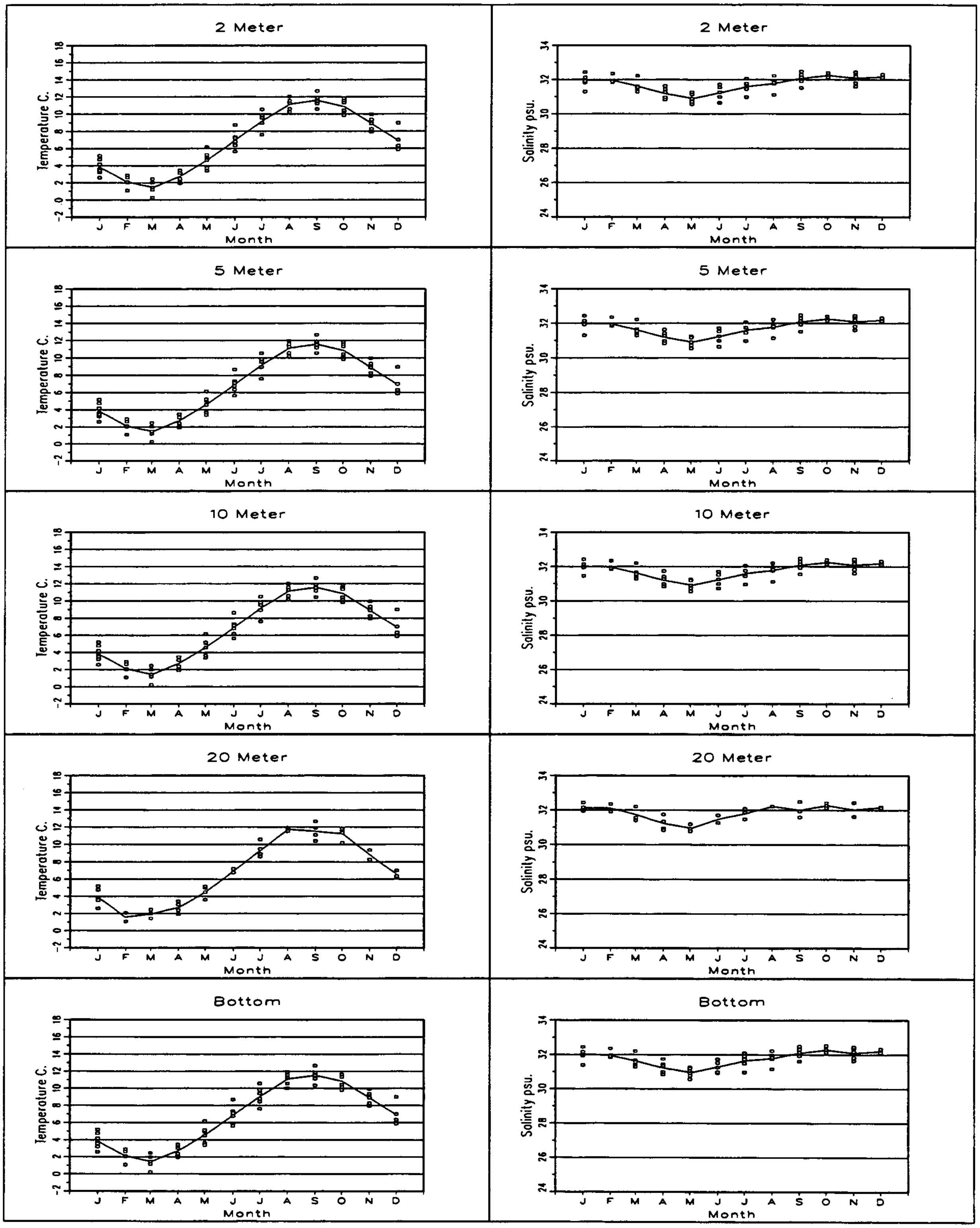

Figure 2: continued (STATION 20)

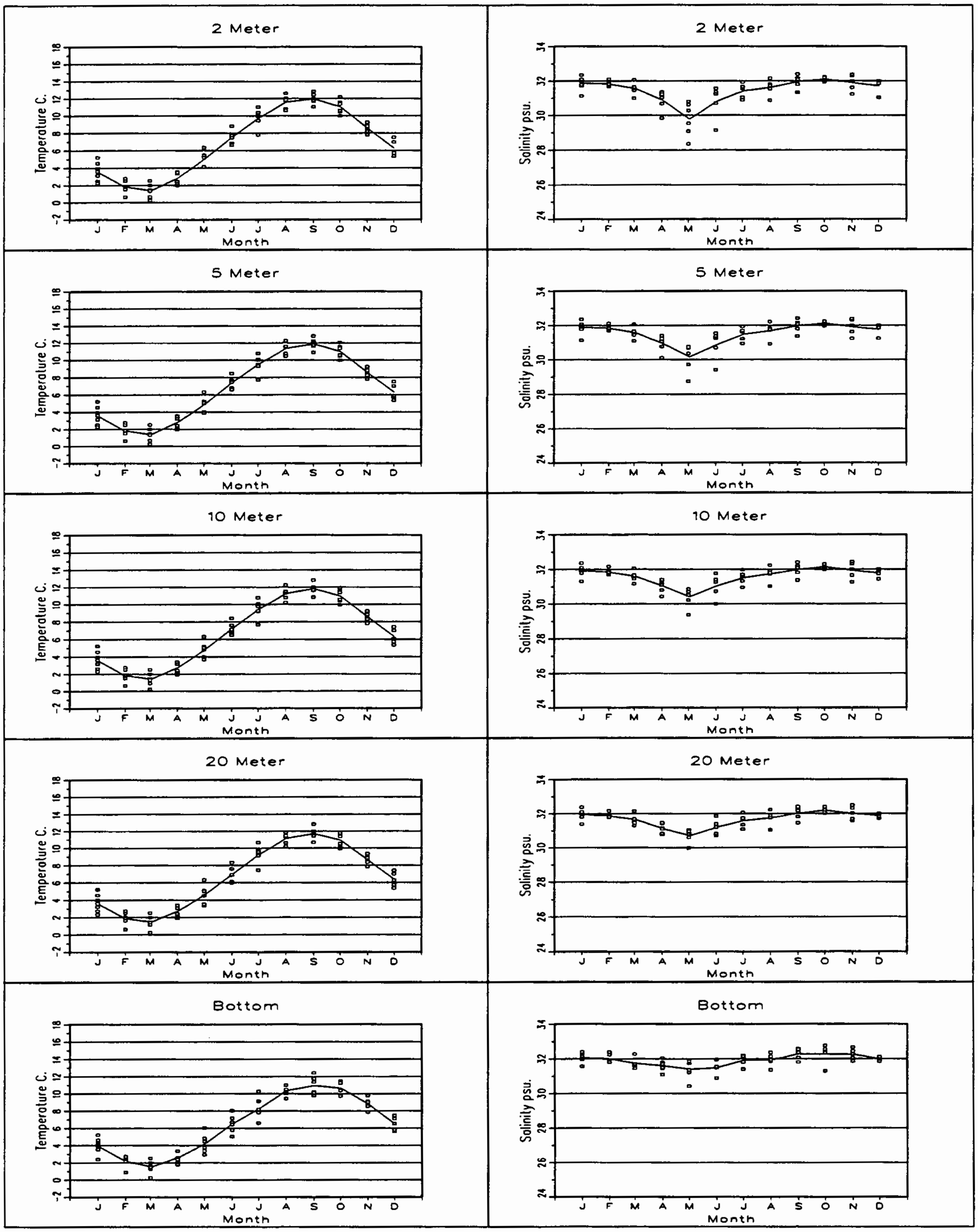

Figure 2: continued (STATION 21)

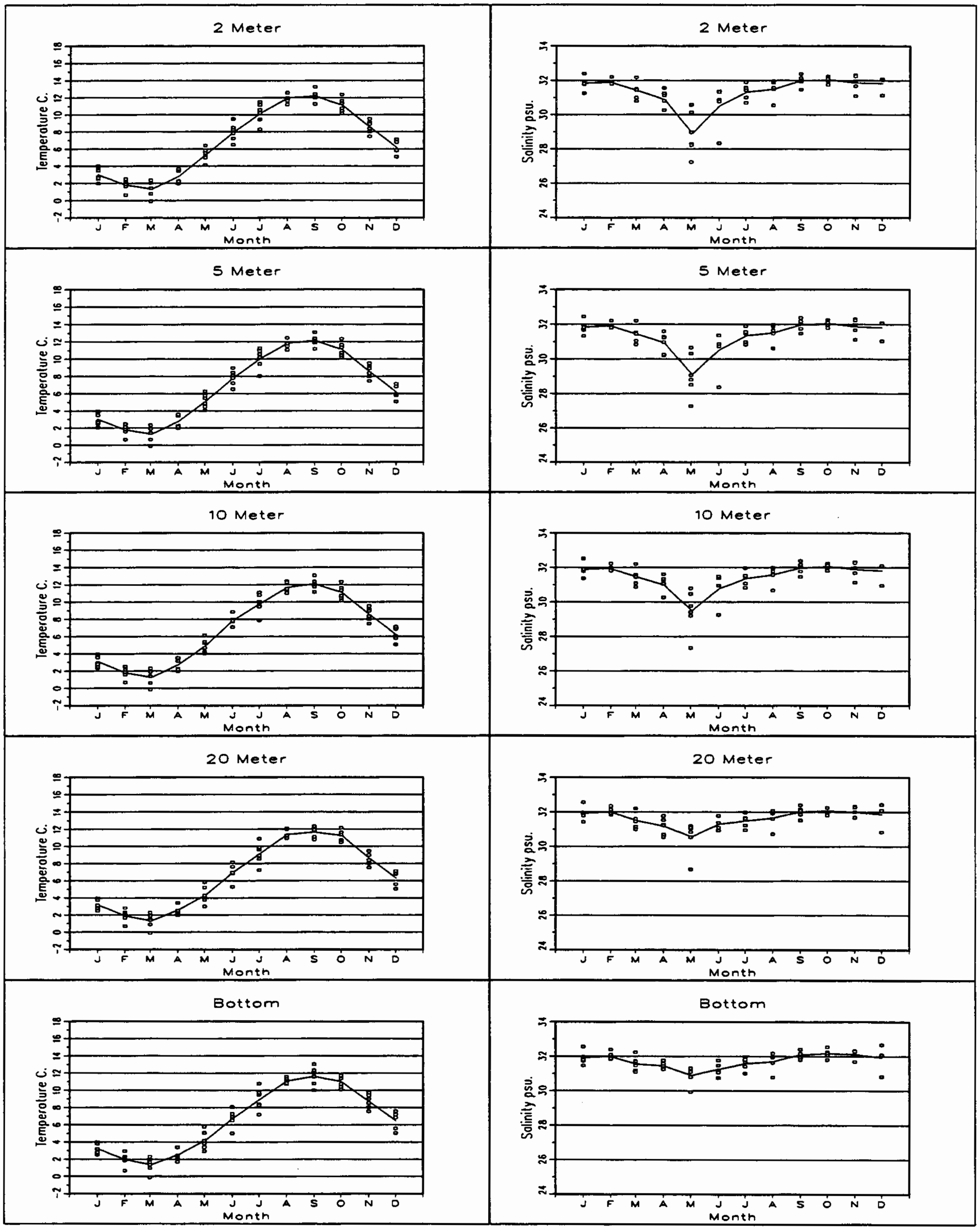

Figure 2: continued (STATION 22)

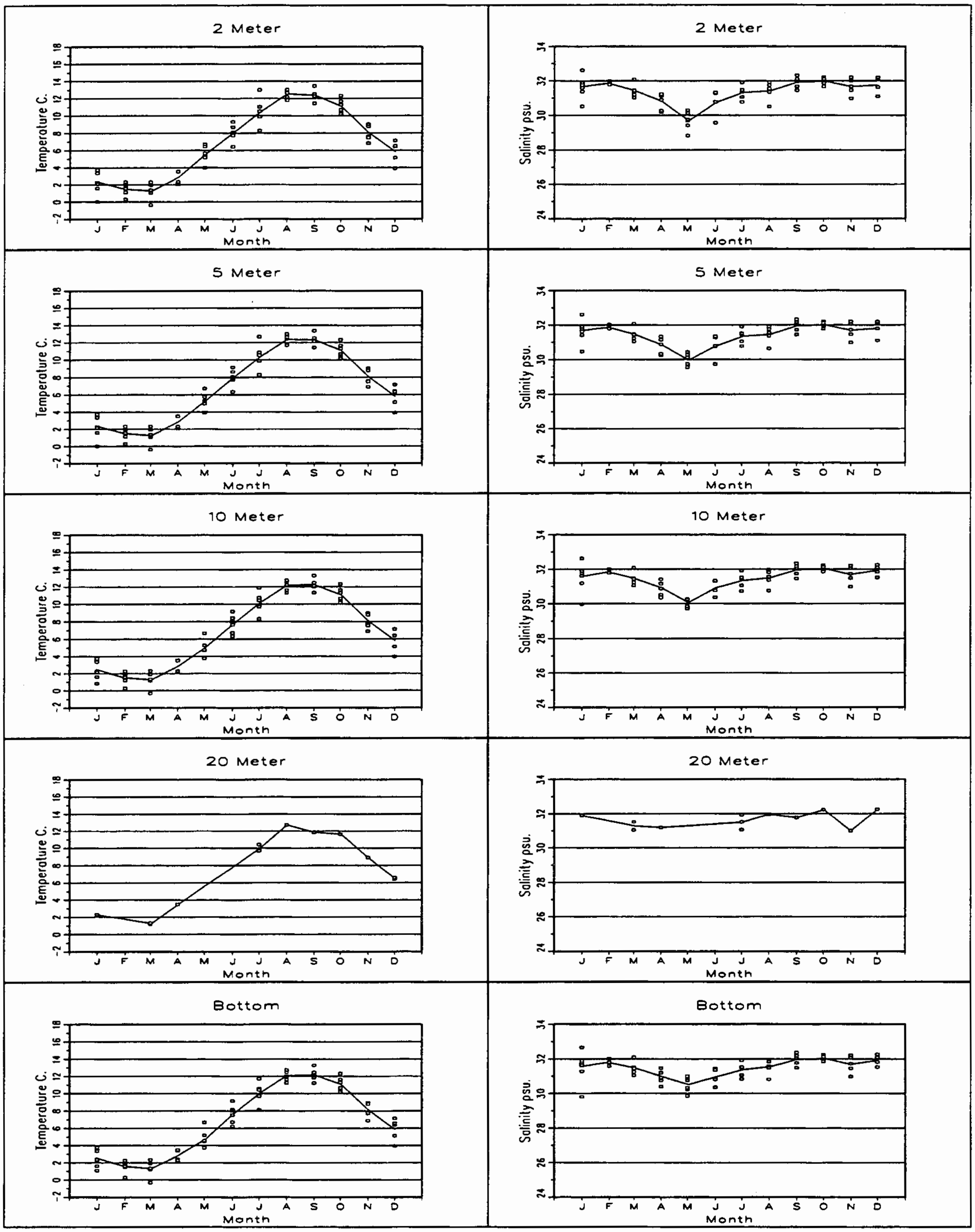

Figure 2: continued (STATION 23)

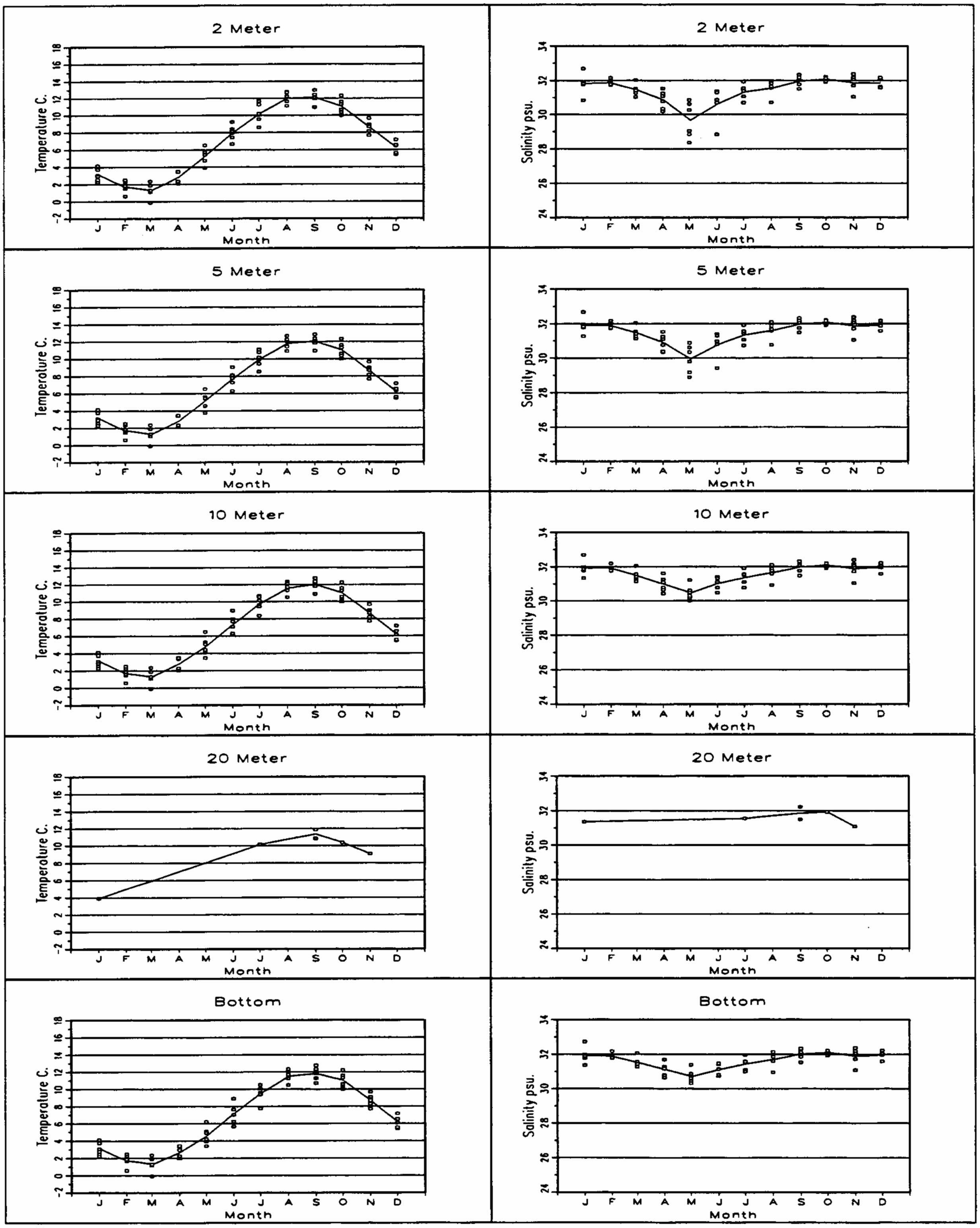

Figure 2: continued (STATION 24)

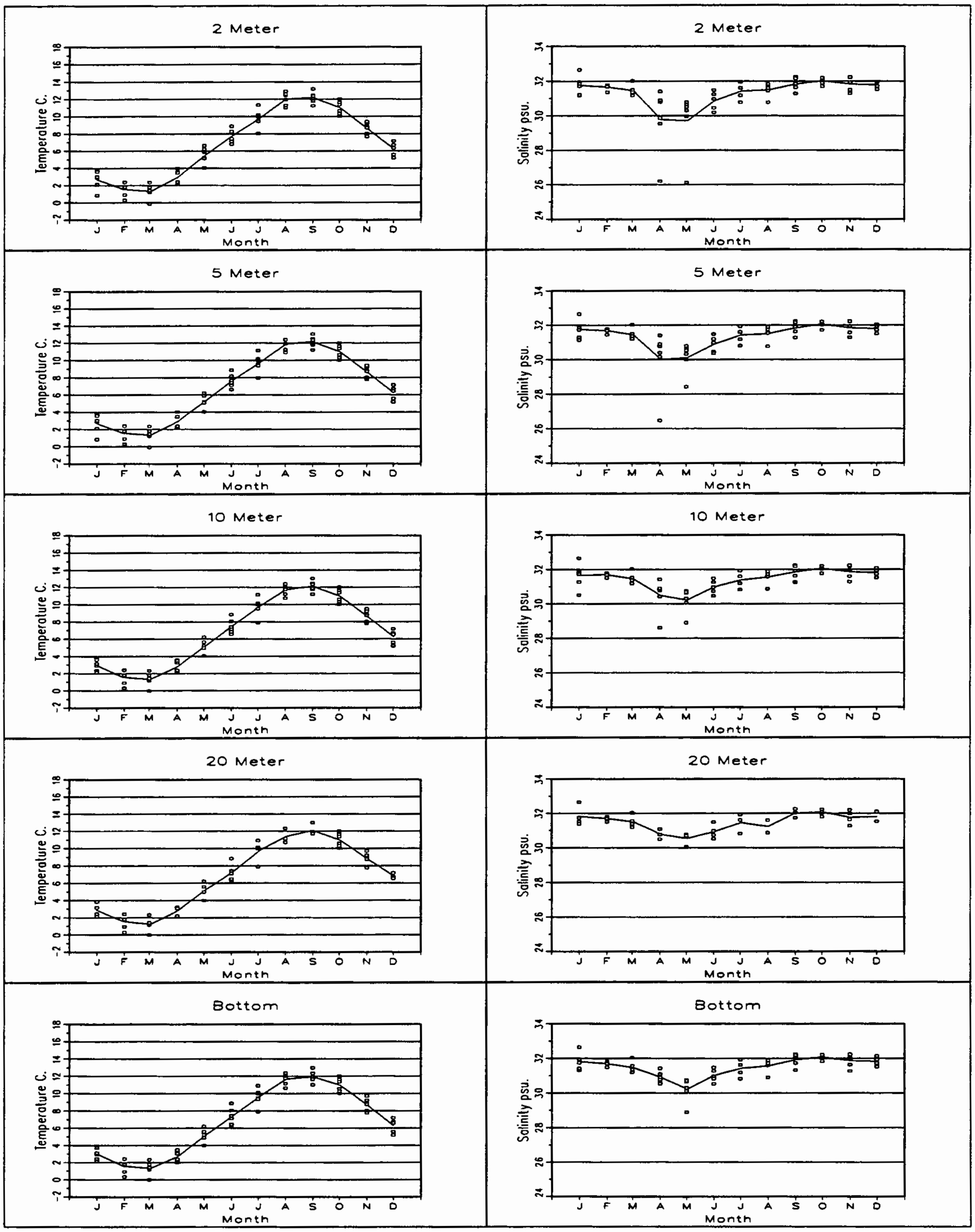

Figure 2: continued (STATION 25)

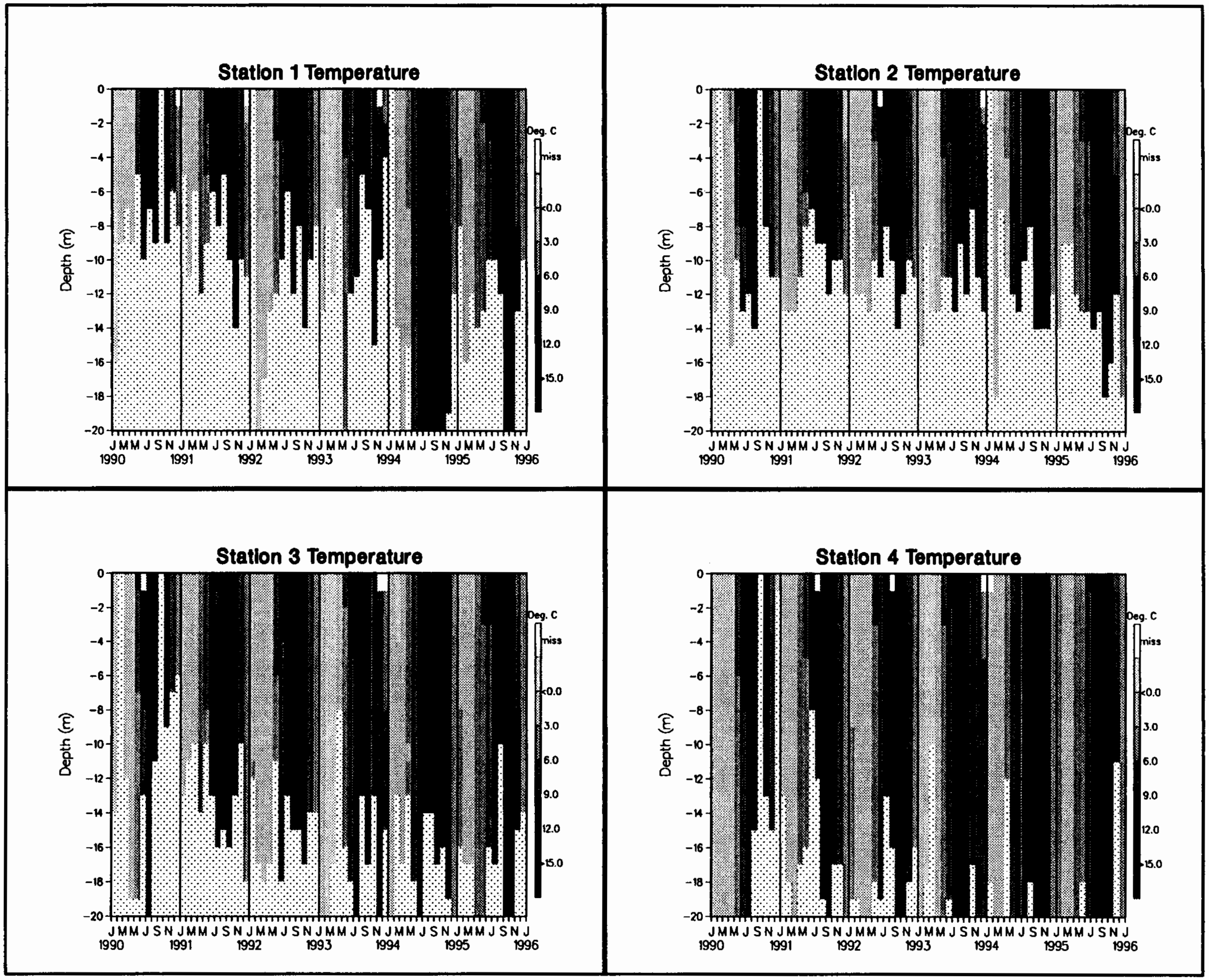

Figure 3a: Time series of depth binned temperatures for stations 1–25. The data are binned into 1m intervals. The dotted area represents the bottom and when the bottom extends to surface it indicates no data was taken. A white area represents missing data in the profile.

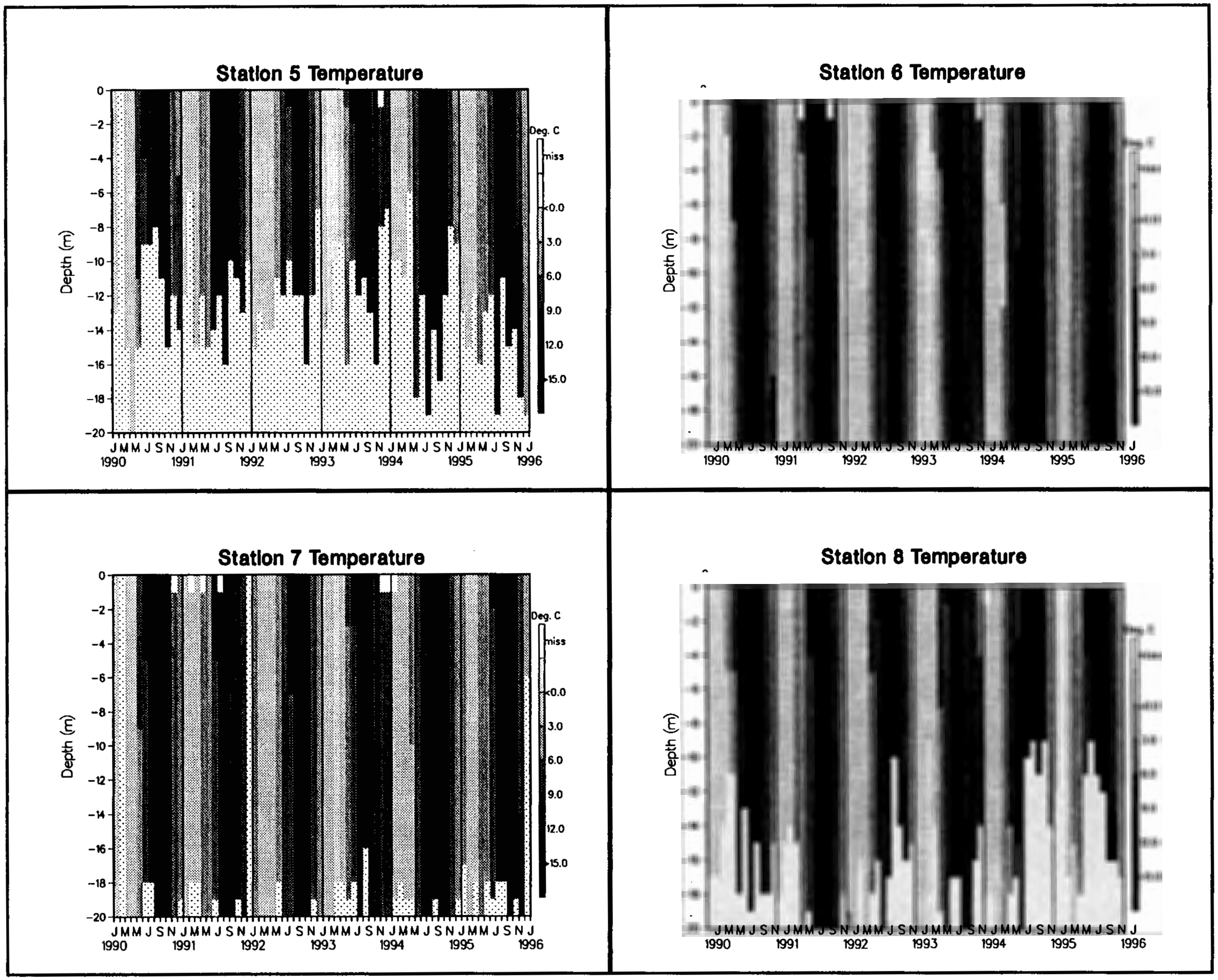

Figure 3a: continued

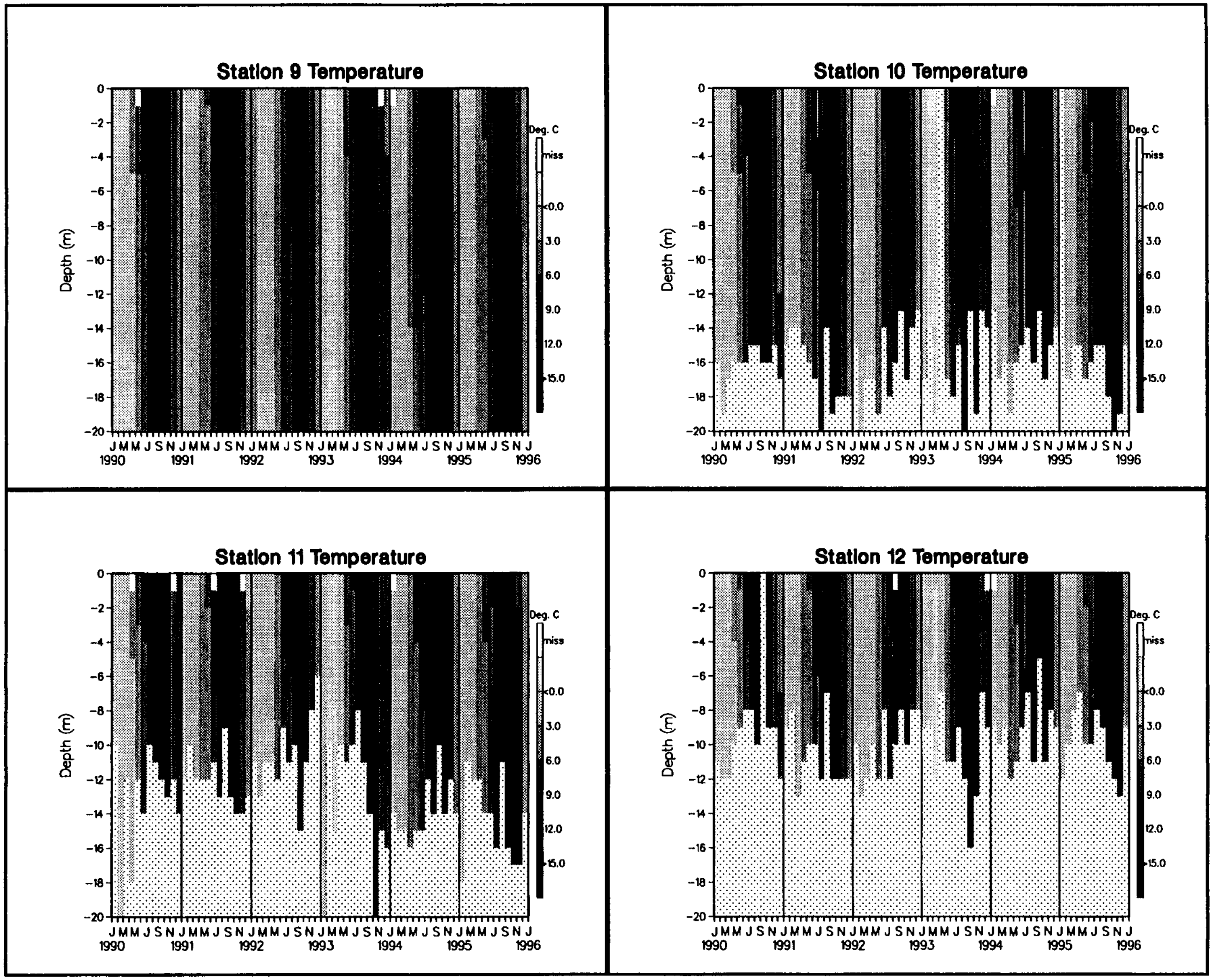

Figure 3a: continued

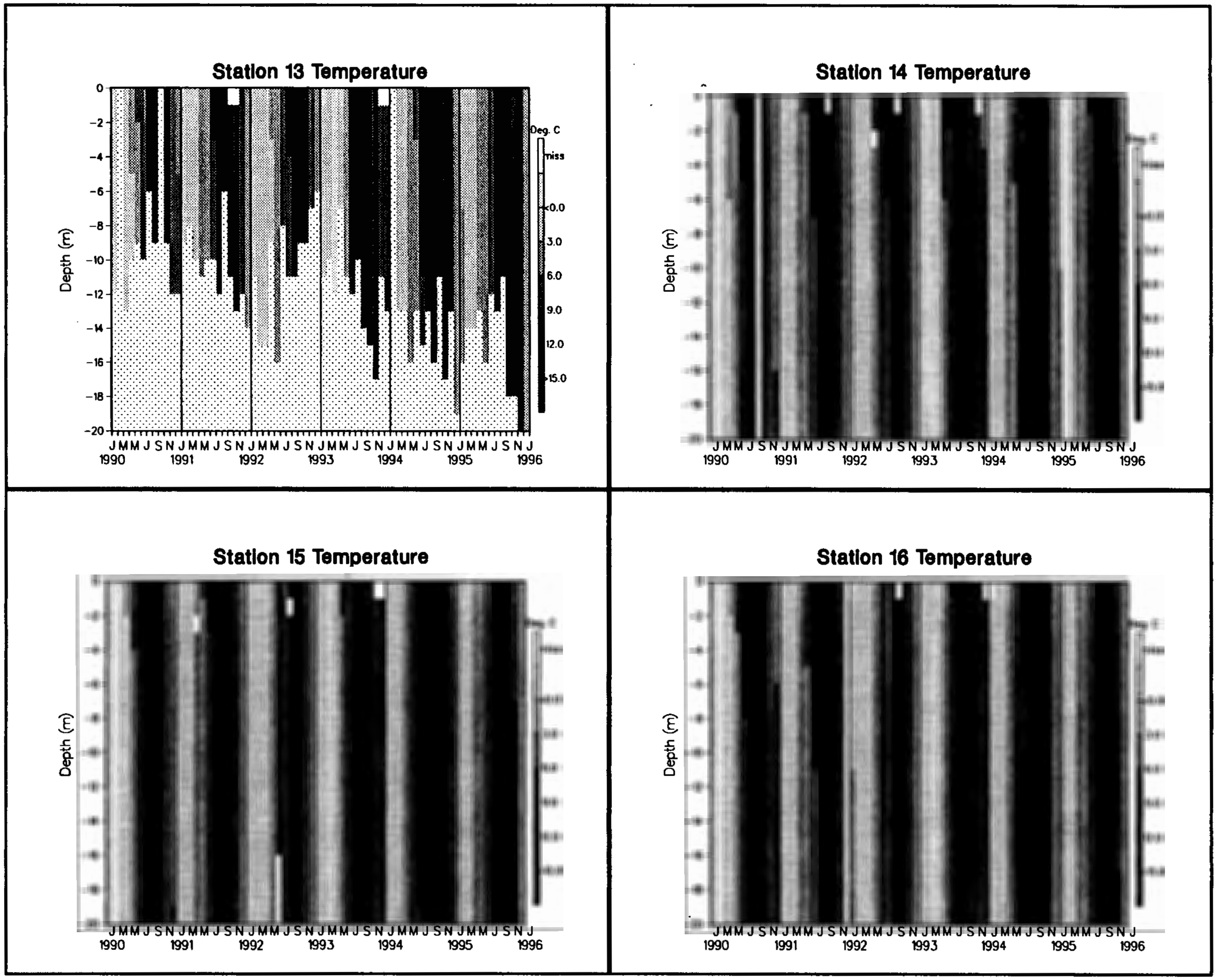

Figure 3a: continued

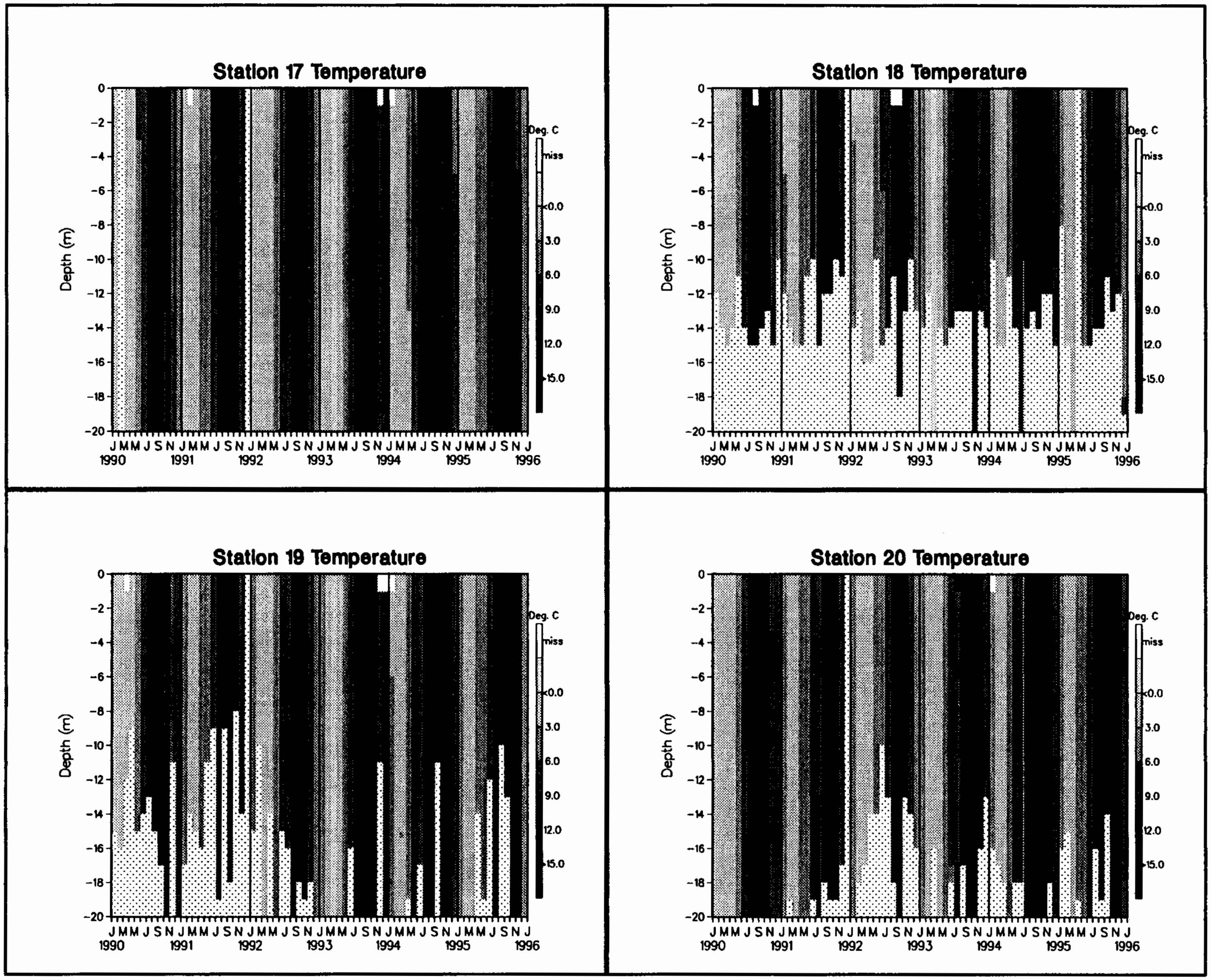

Figure 3a: continued

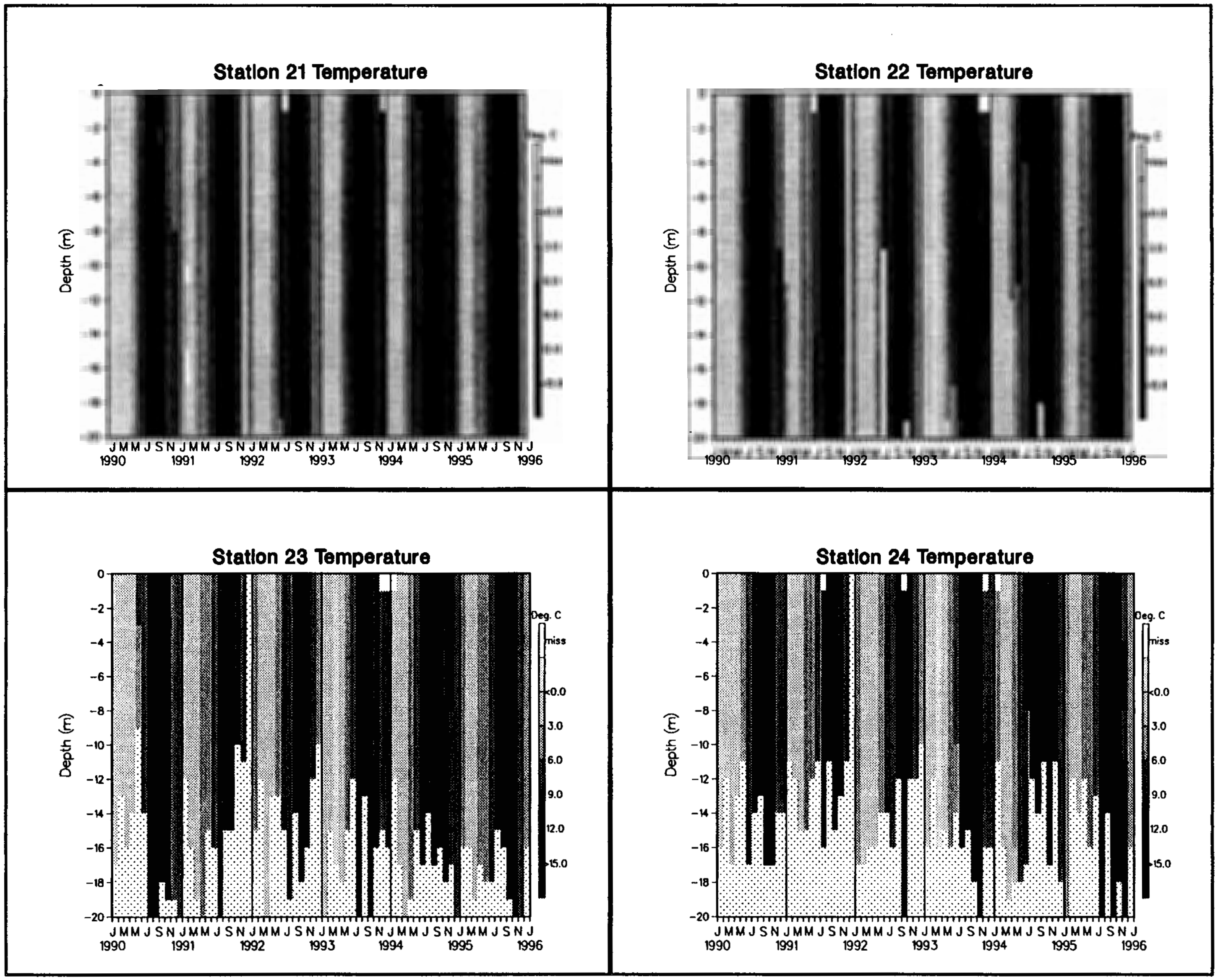

Figure 3a: continued

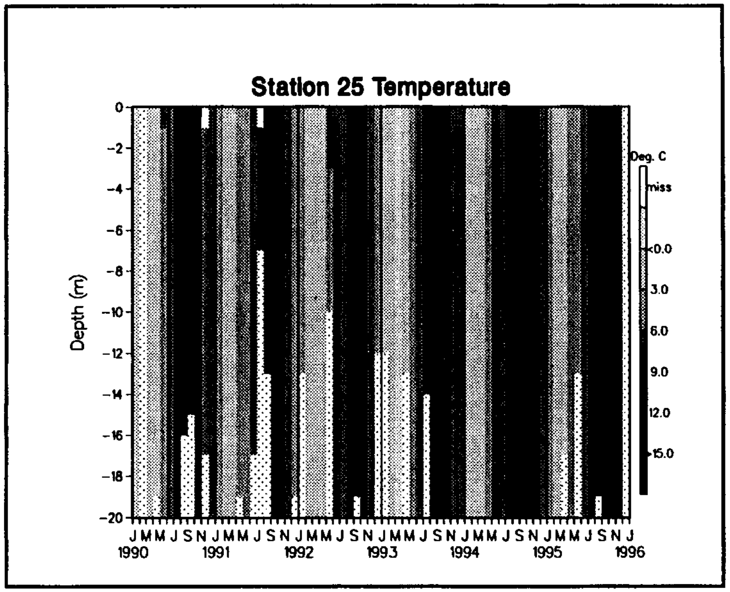

Figure 3a: continued

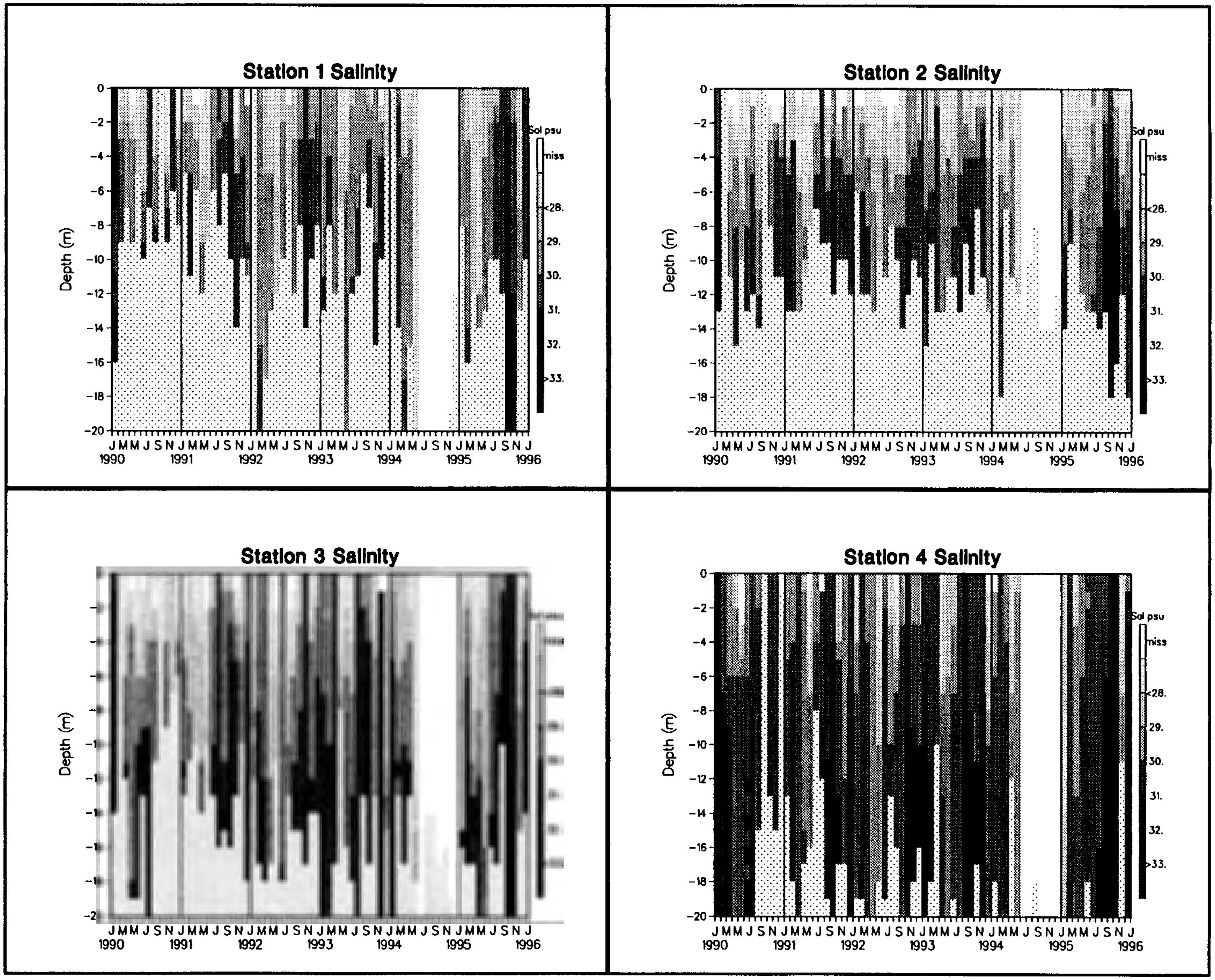

Figure 3b: Time series of depth binned salinities for stations 1–25. The data are binned into 1m intervals. The dotted area represents the bottom and when the bottom extends to surface it indicates no data was taken. A white area represents missing data in the profile.

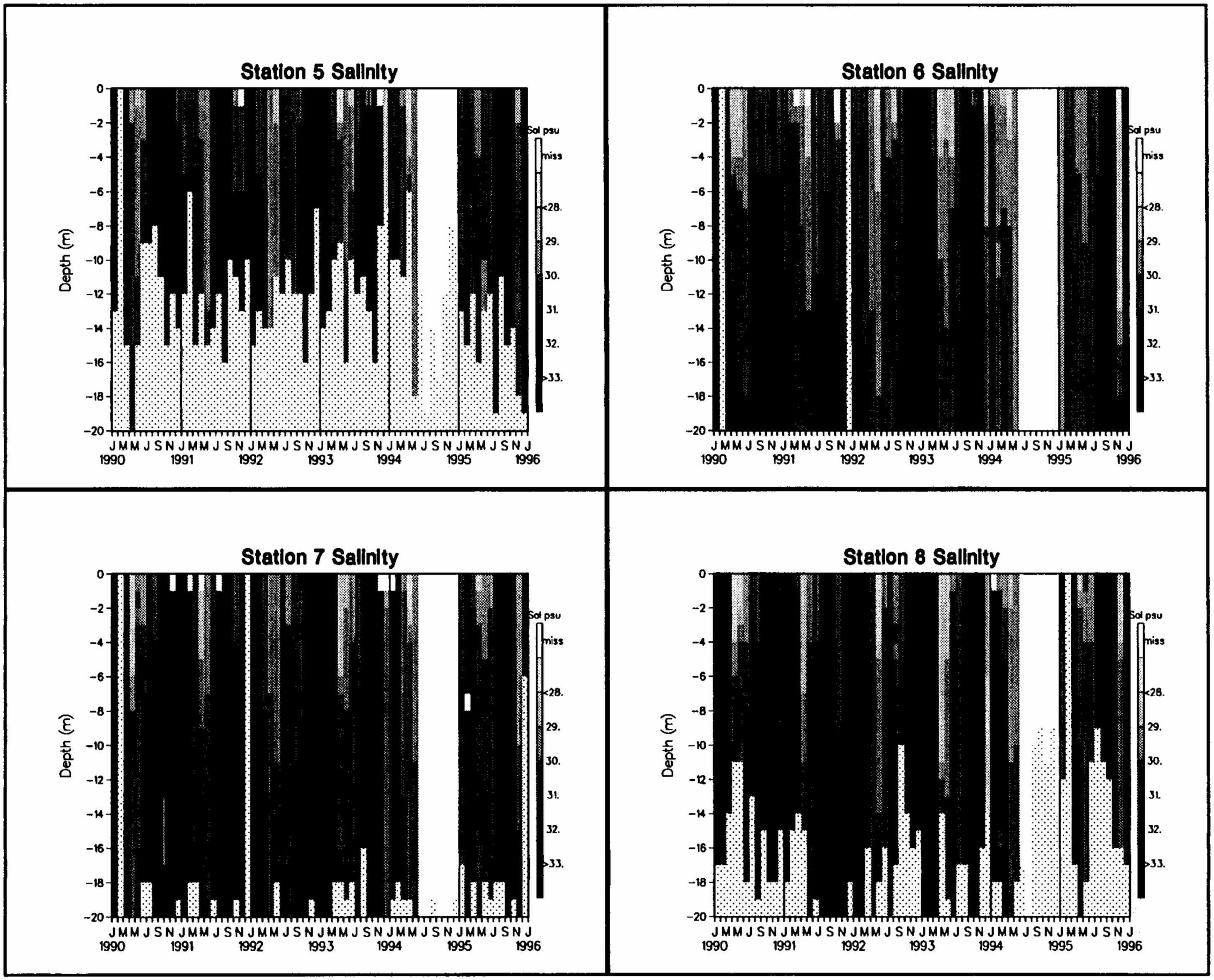

Figure 3b: continued

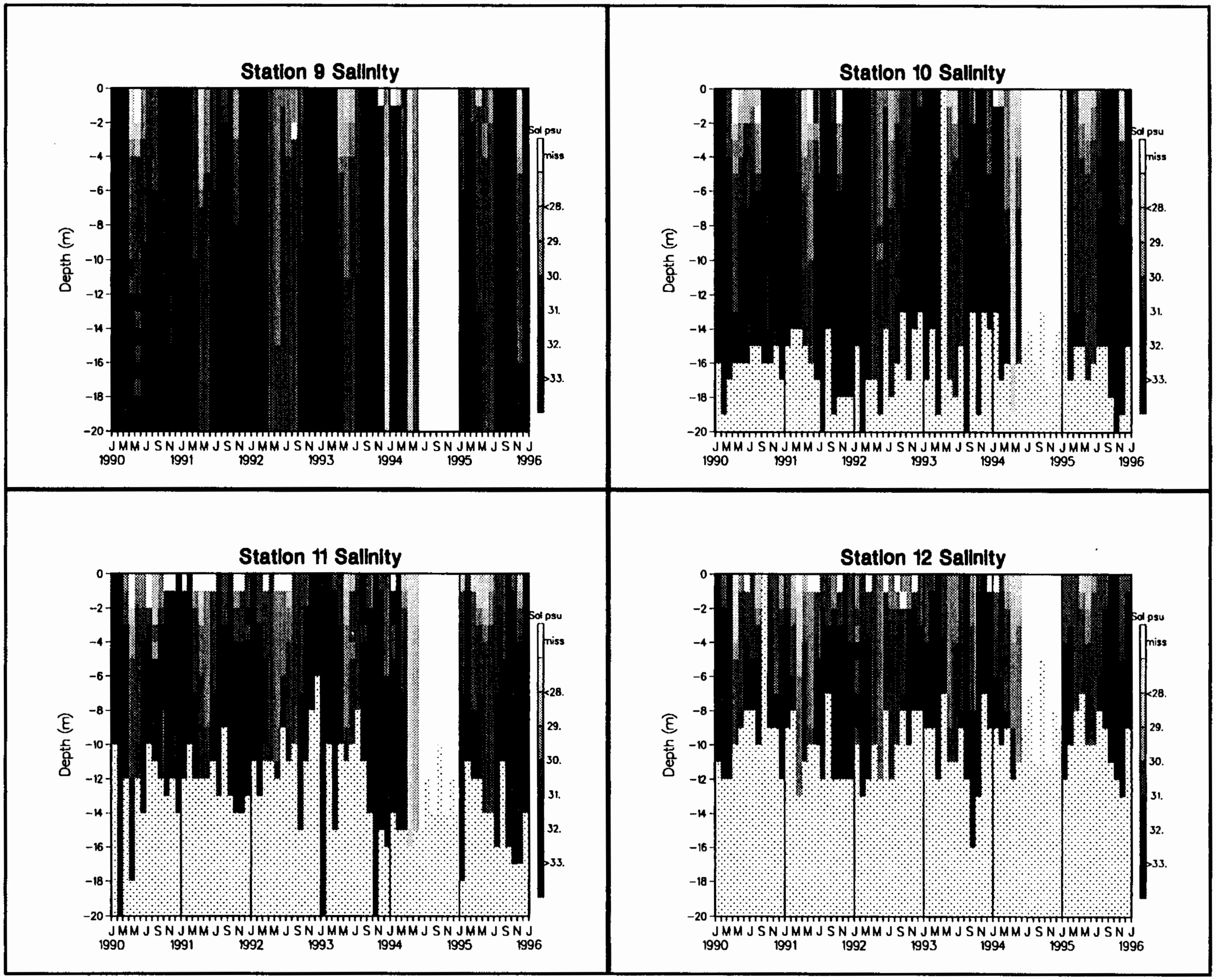

Figure 3b: continued

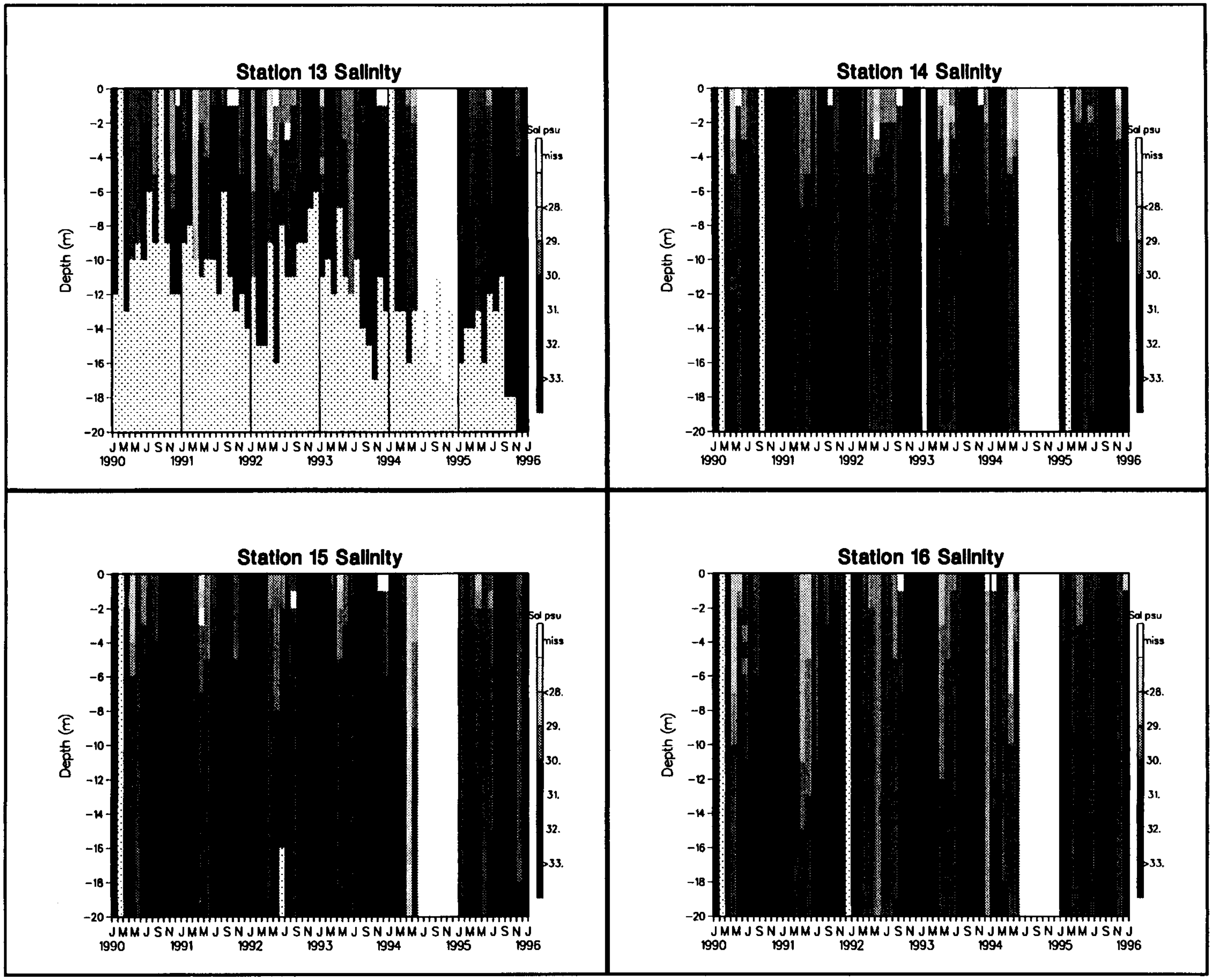

Figure 3b: continued

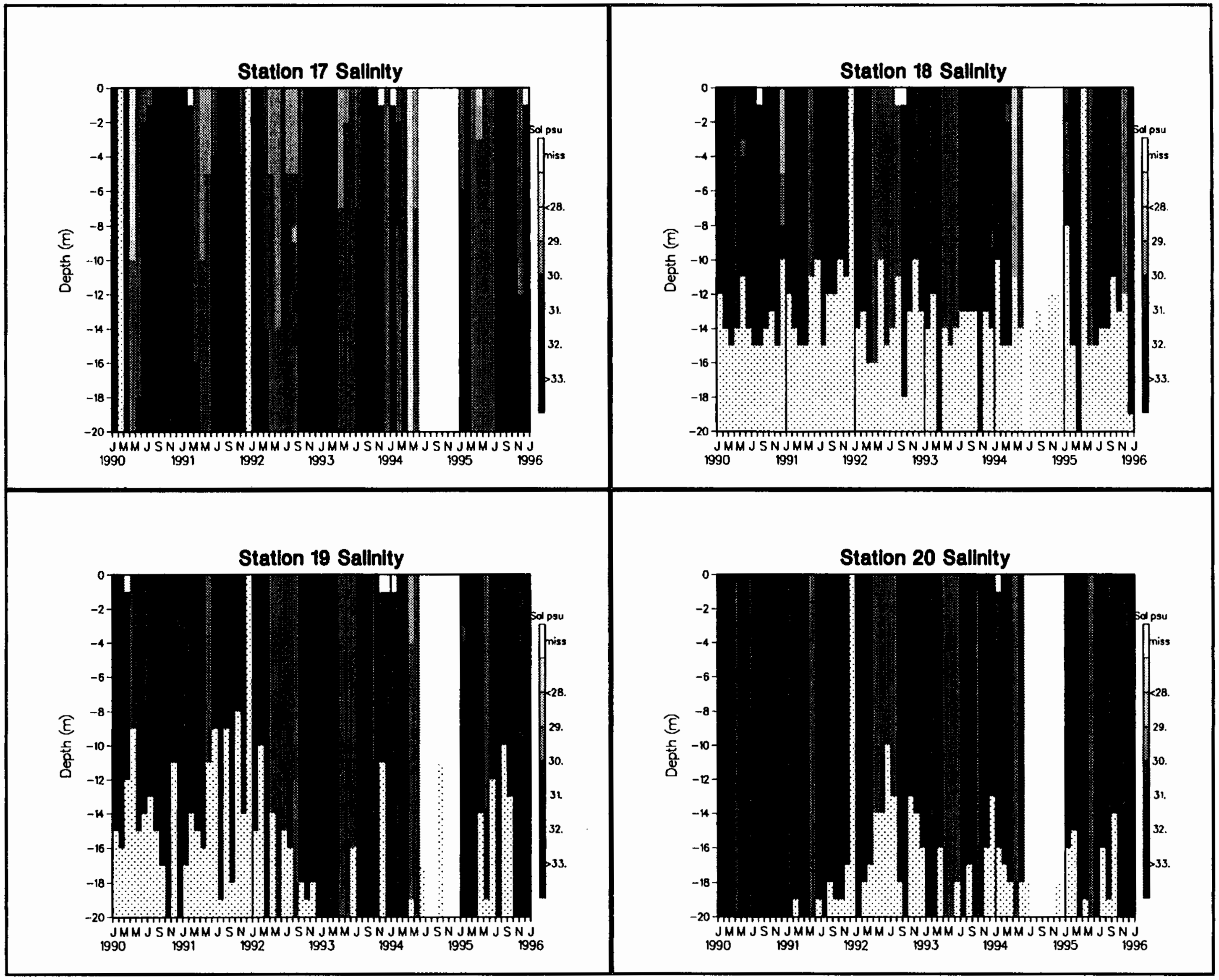

Figure 3b: continued

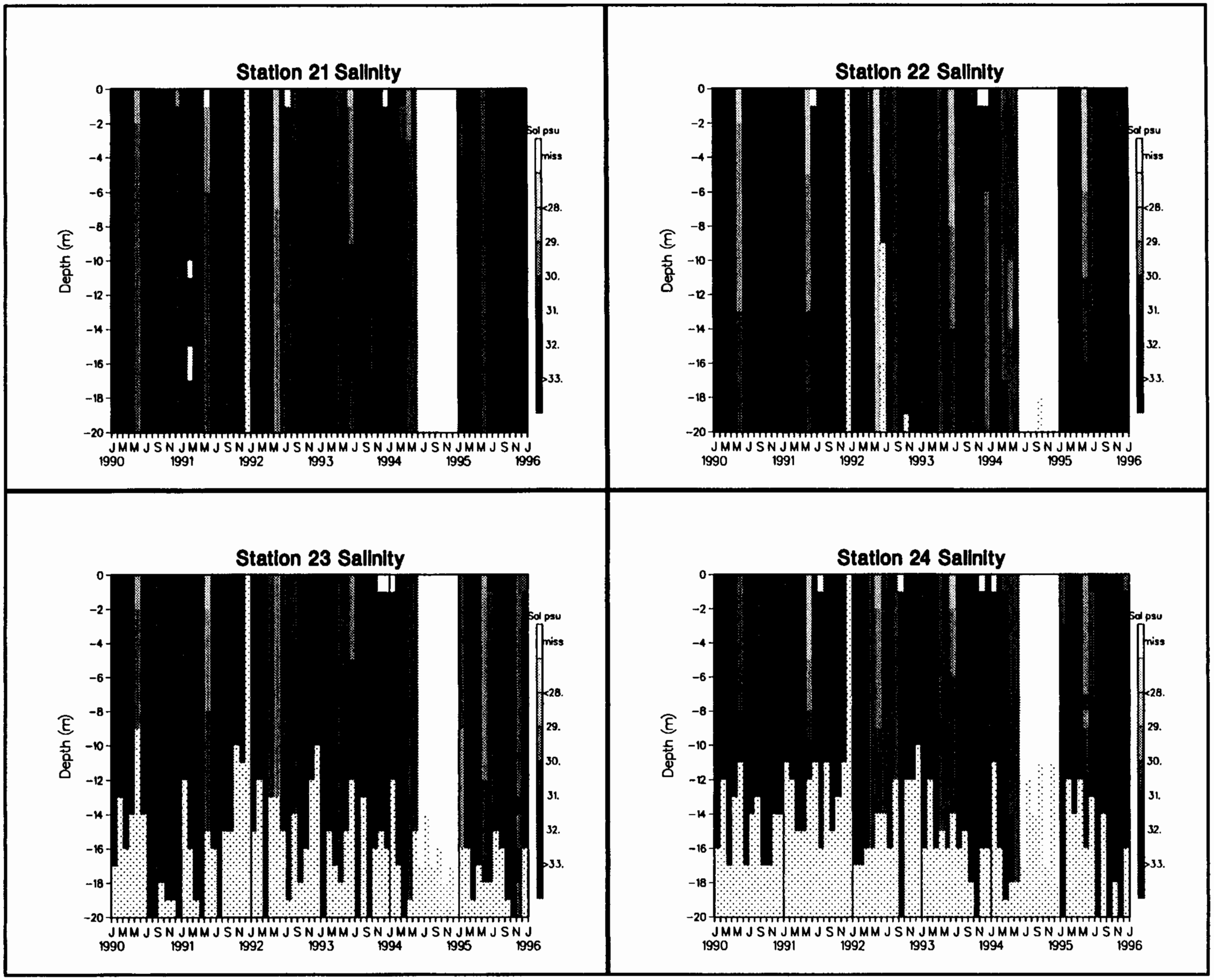

Figure 3b: continued

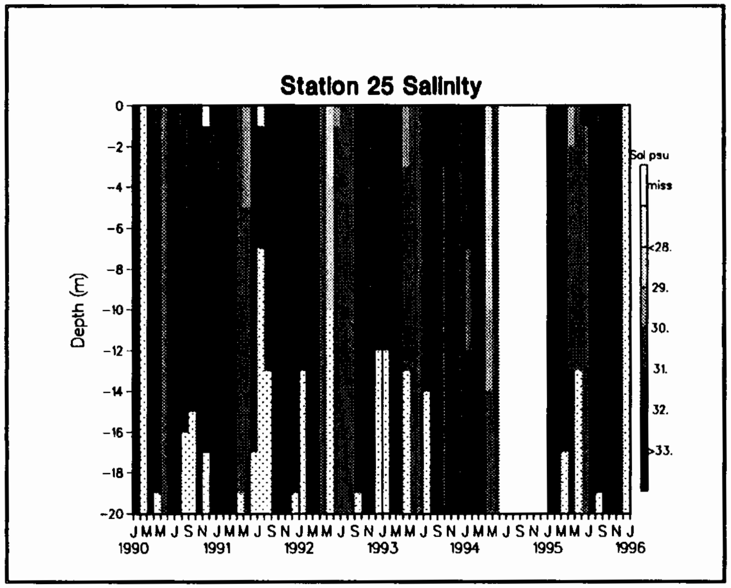

Figure 3b: continued

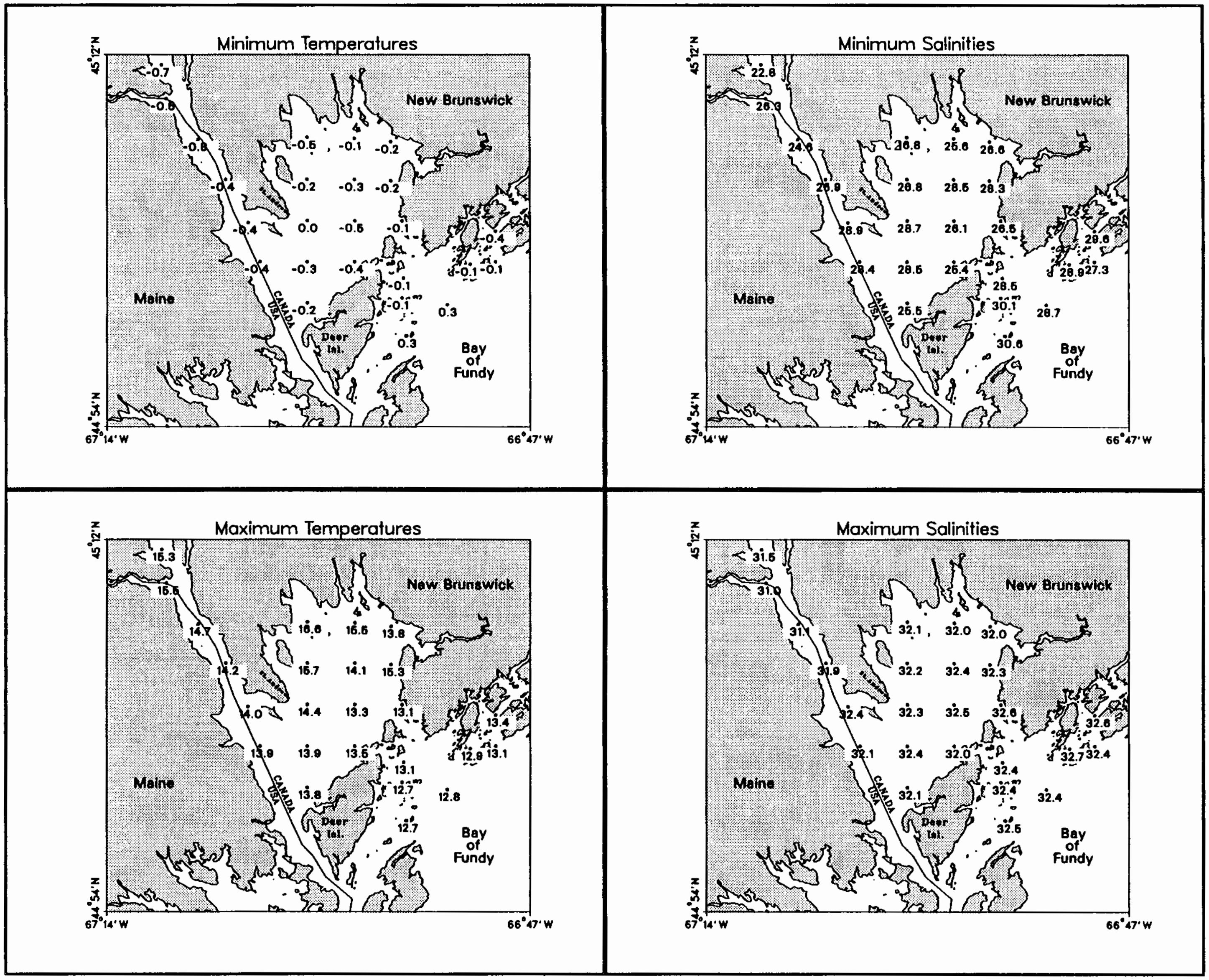

Figure 4a–d: Minimum and maximum temperatures and salinities by station at a depth of 5 m over the period January 1990 to December 1995.

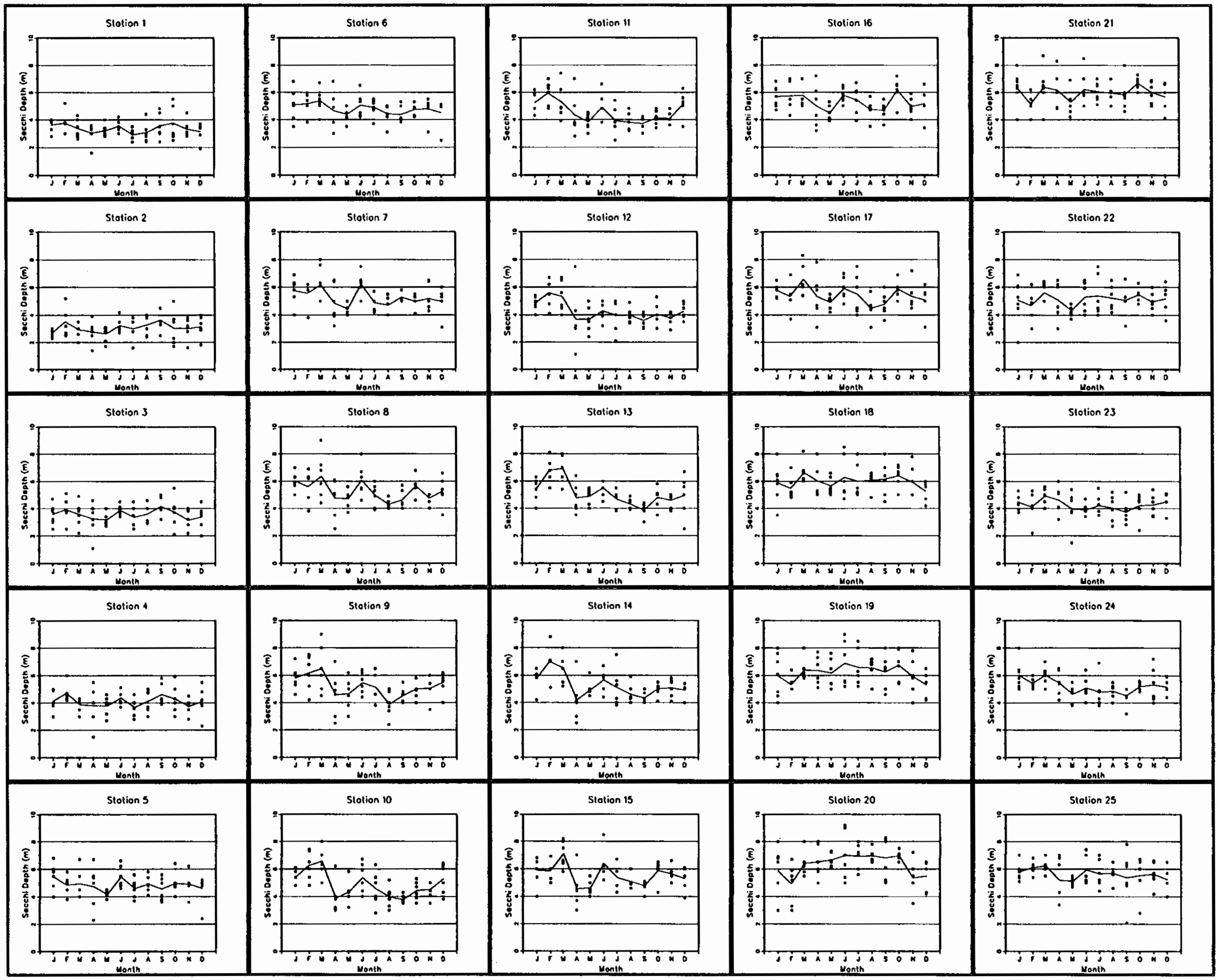

Figure 5: Monthly secchi disk readings by sampling station taken during 1990 to 1995. The open symbols represent a single record. The solid curve through the points joins the 1990 to 1995 monthly means.

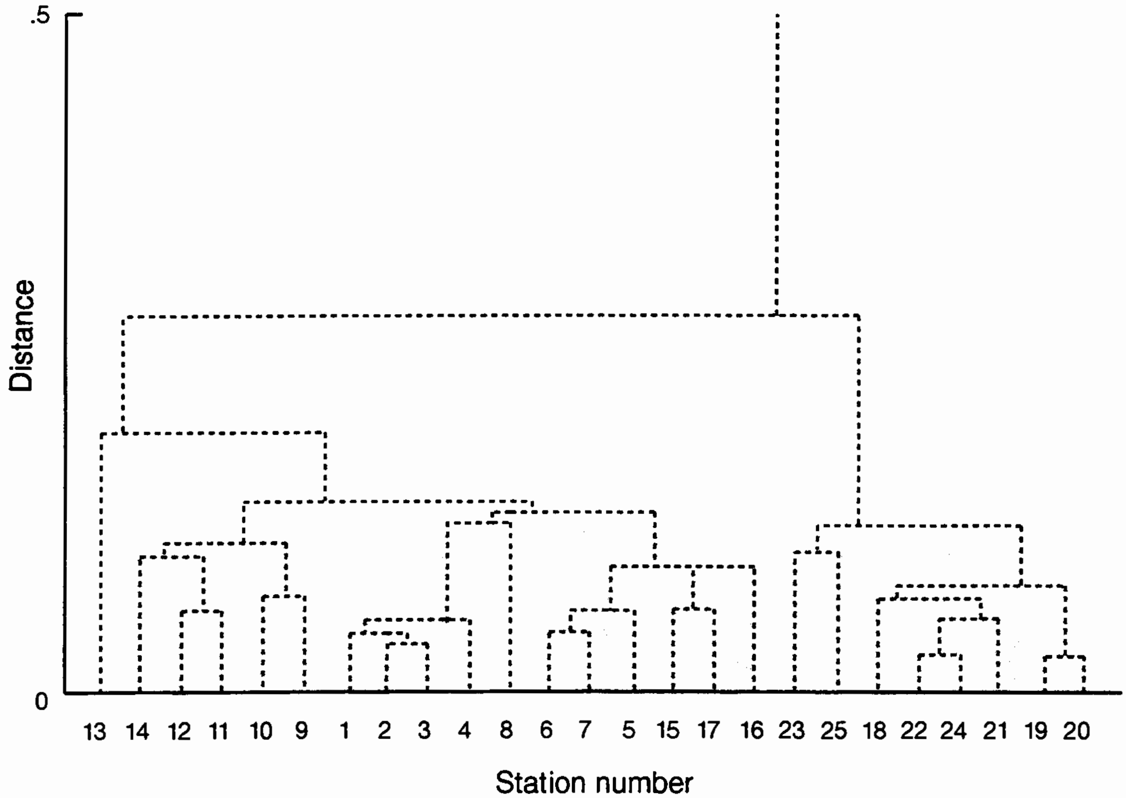

Figure 6. Euclidean distance dendrogram of station locations based on temperature time series at a depth of 5 m.

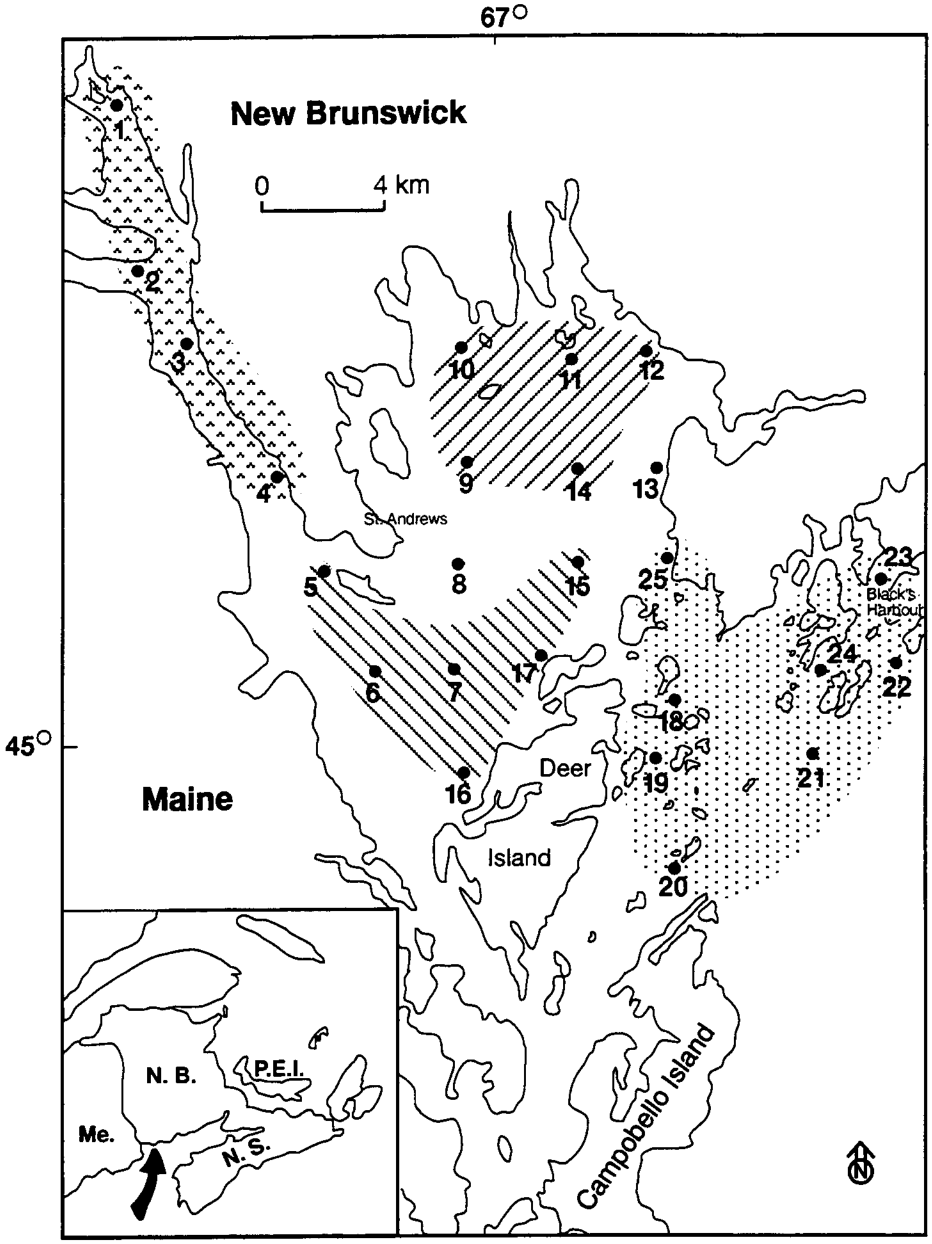

Figure 7. Map showing clustering of stations based on temperature at a depth of 5 m.

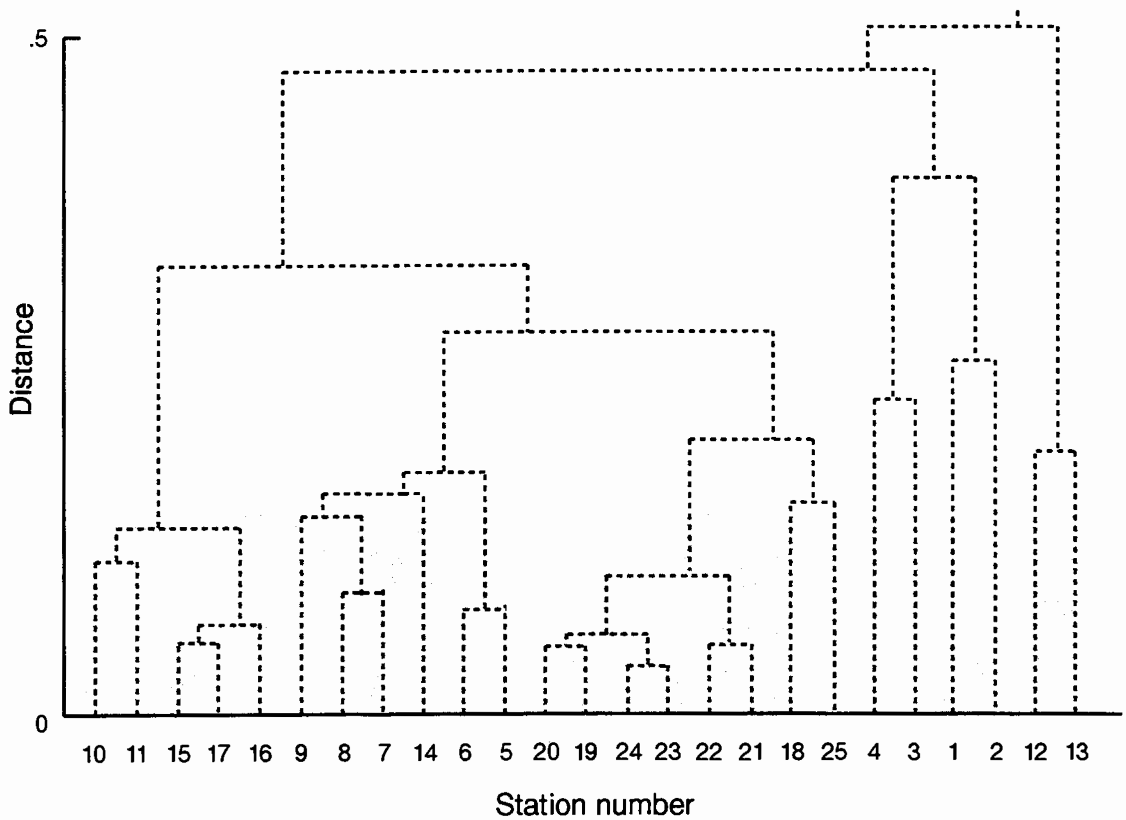

Figure 8. Euclidean distance dendrogram of station locations based on salinity time series at a depth of 5 m.

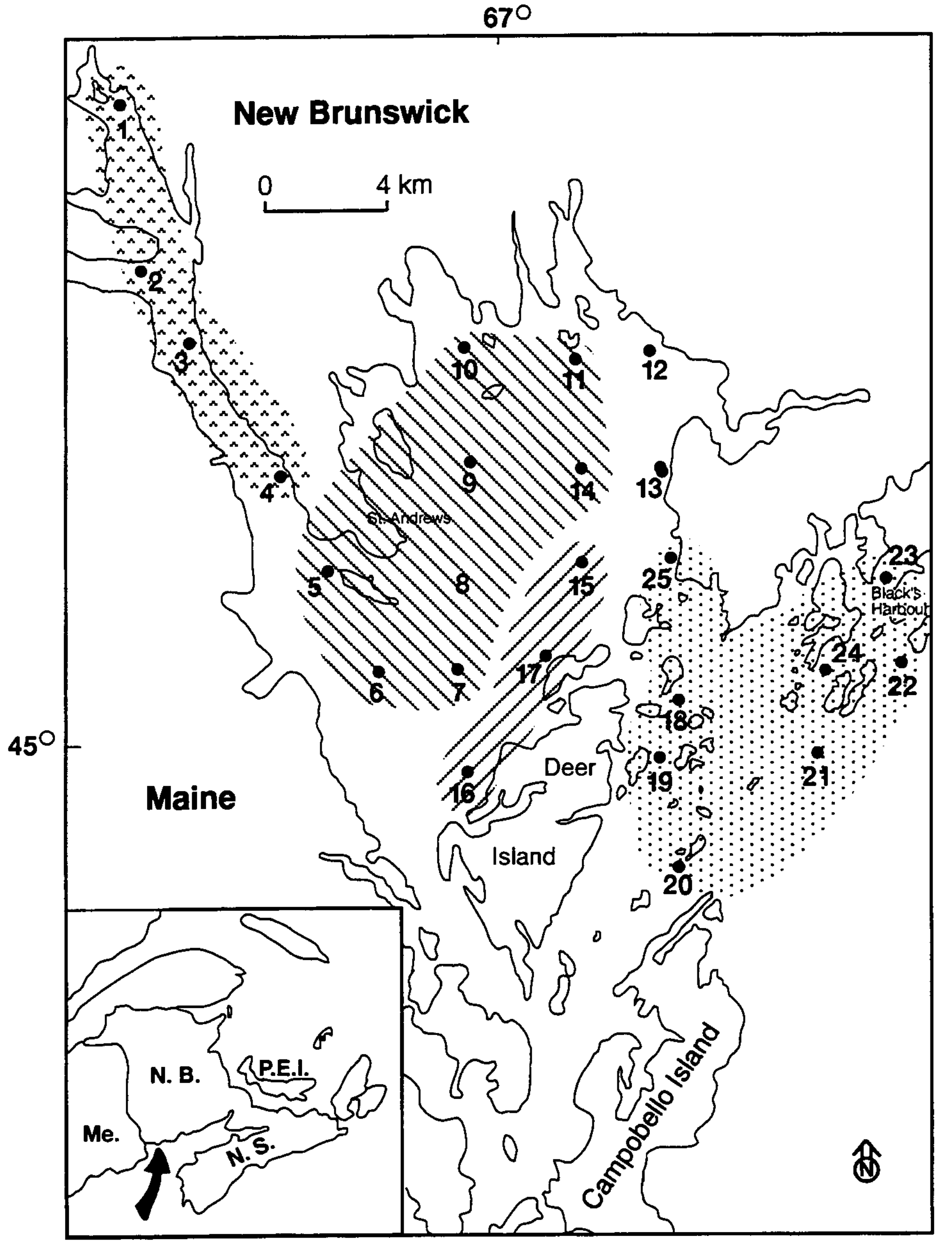

Figure 9. Map showing clustering of stations based on salinity at a depth of 5 m.

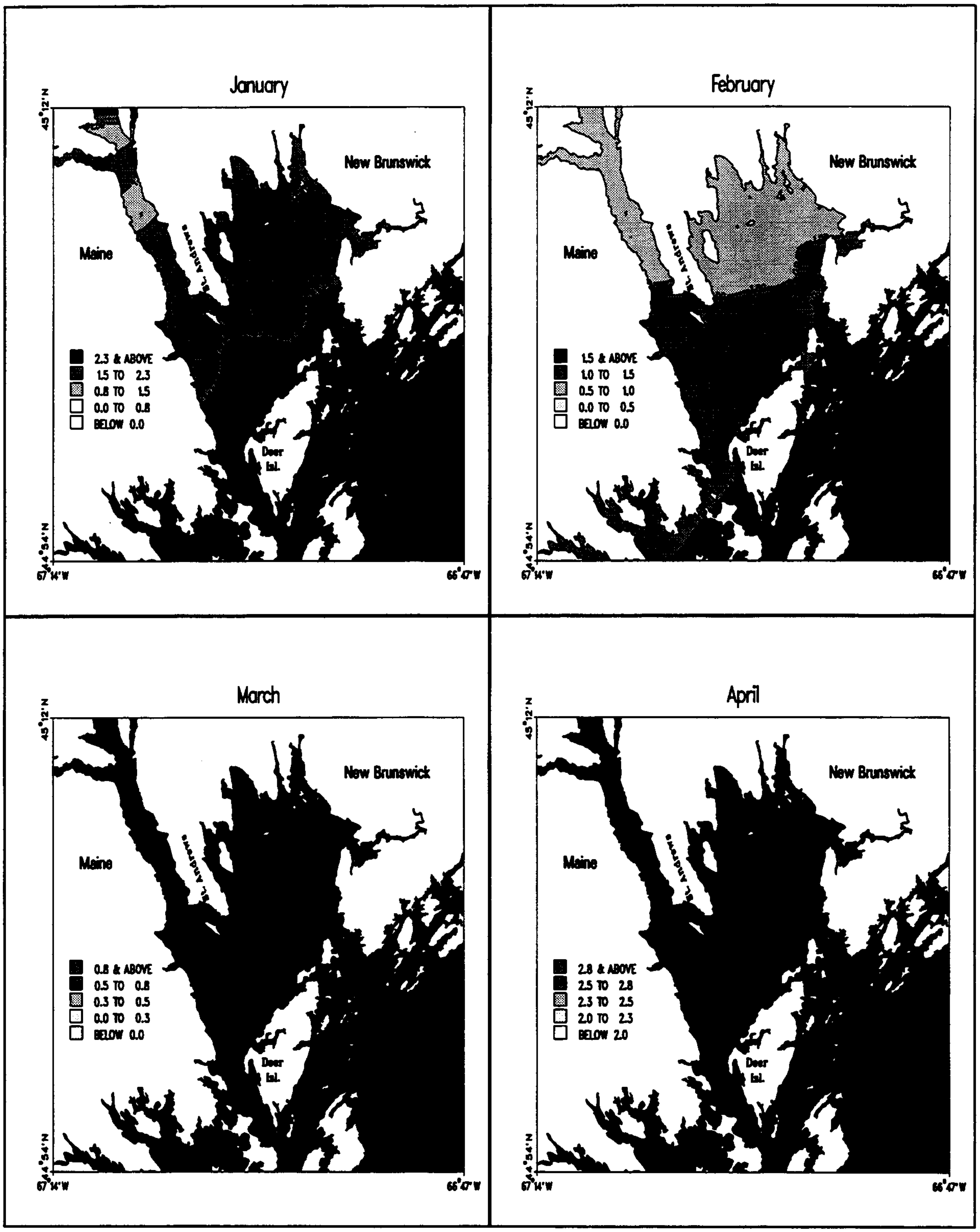

Figure 10: Contour plots of mean water temperatures (C.) by month from 1990–1995 at 5m depth.

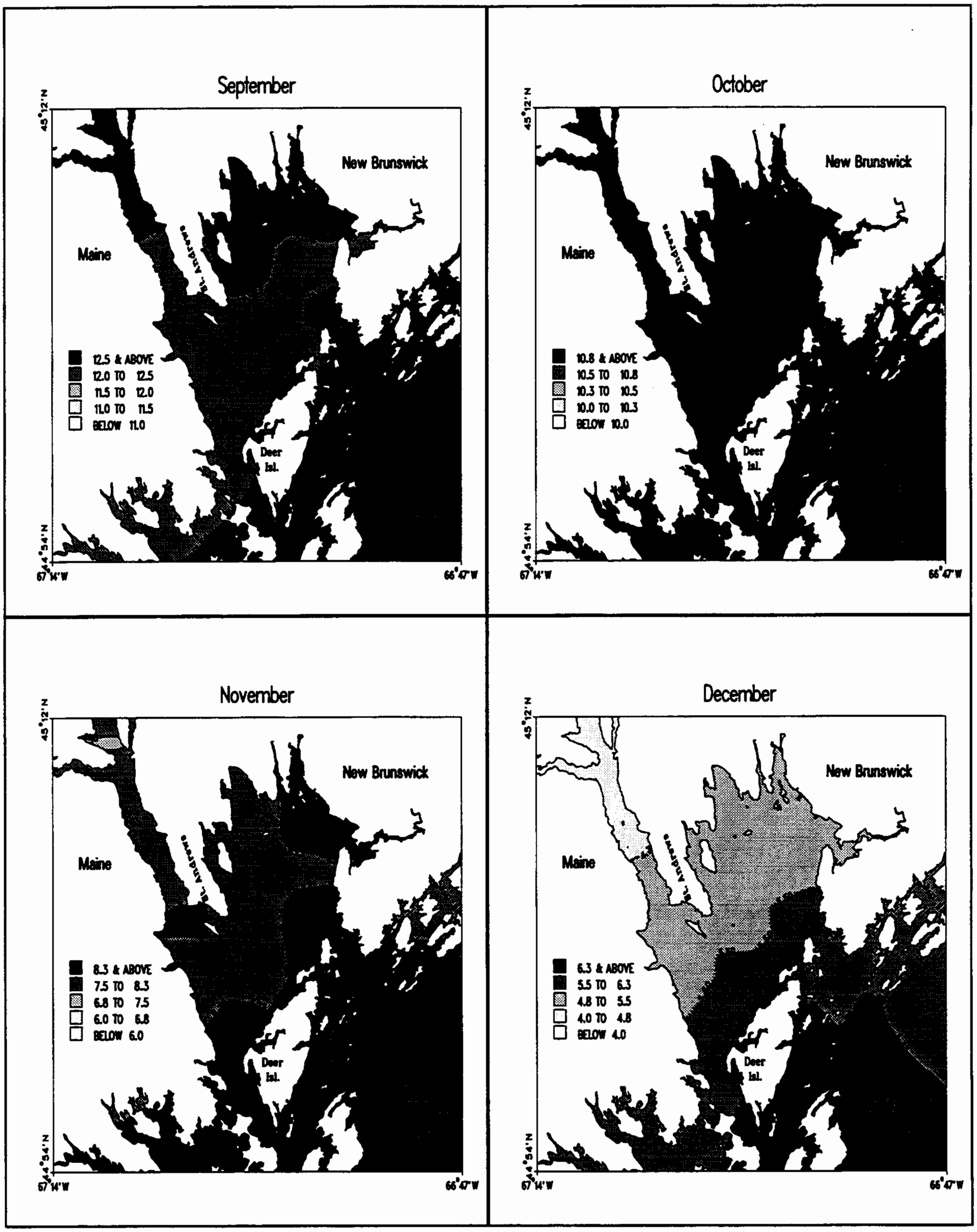

Figure 10: continued

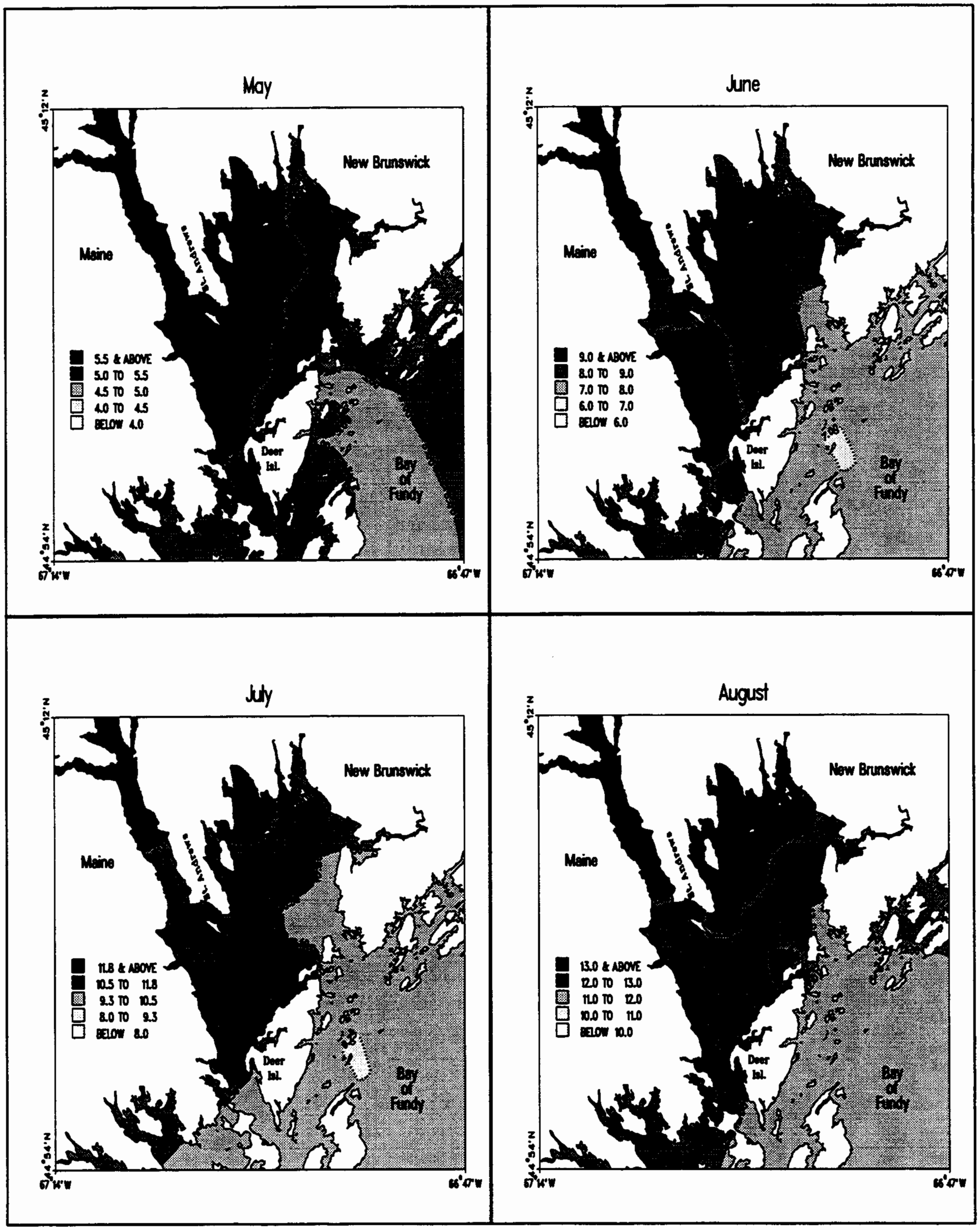

Figure 10: continued

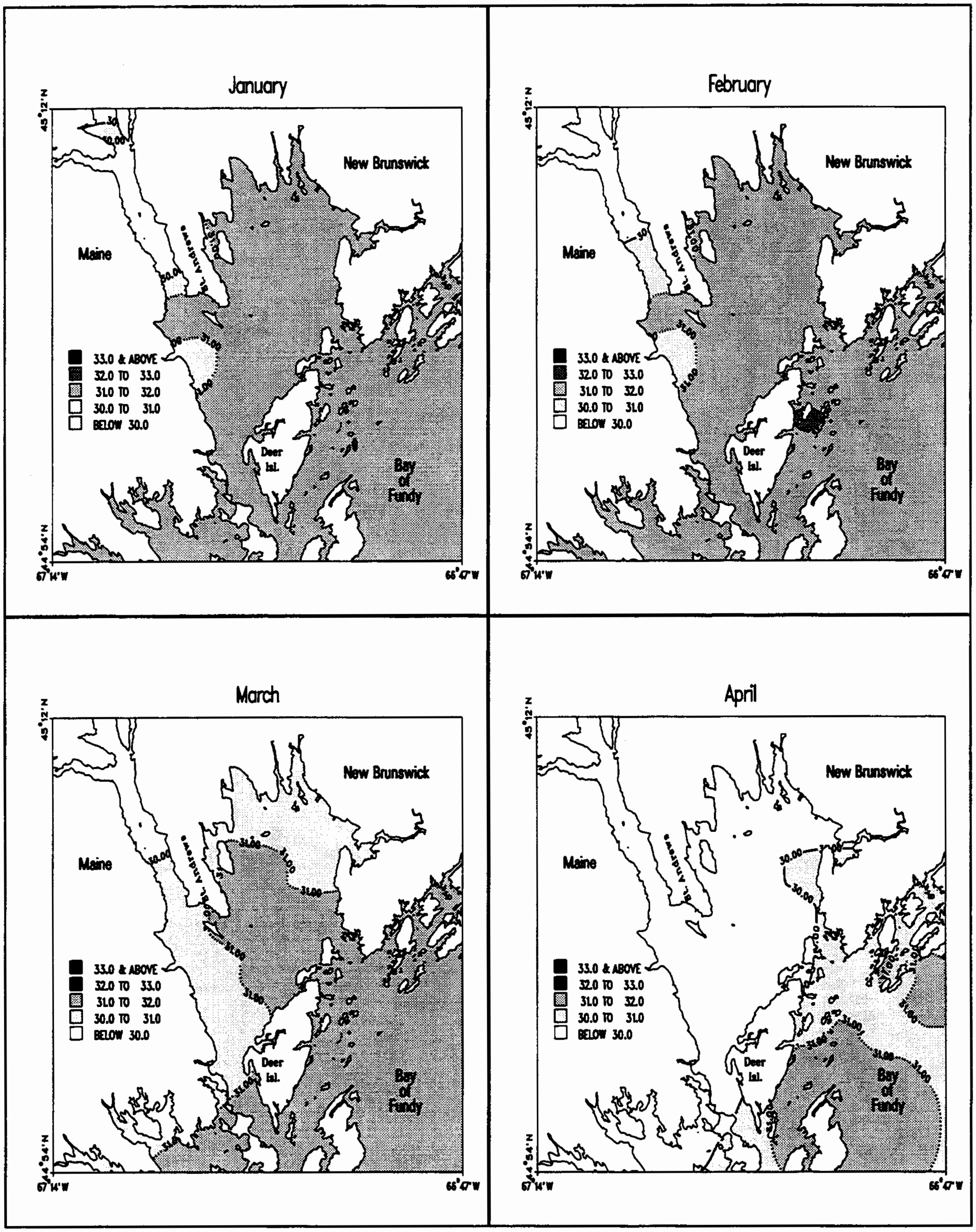

Figure 11: Contour plots of mean salinities (psu) by month from 1990–1995 at 5m depth.

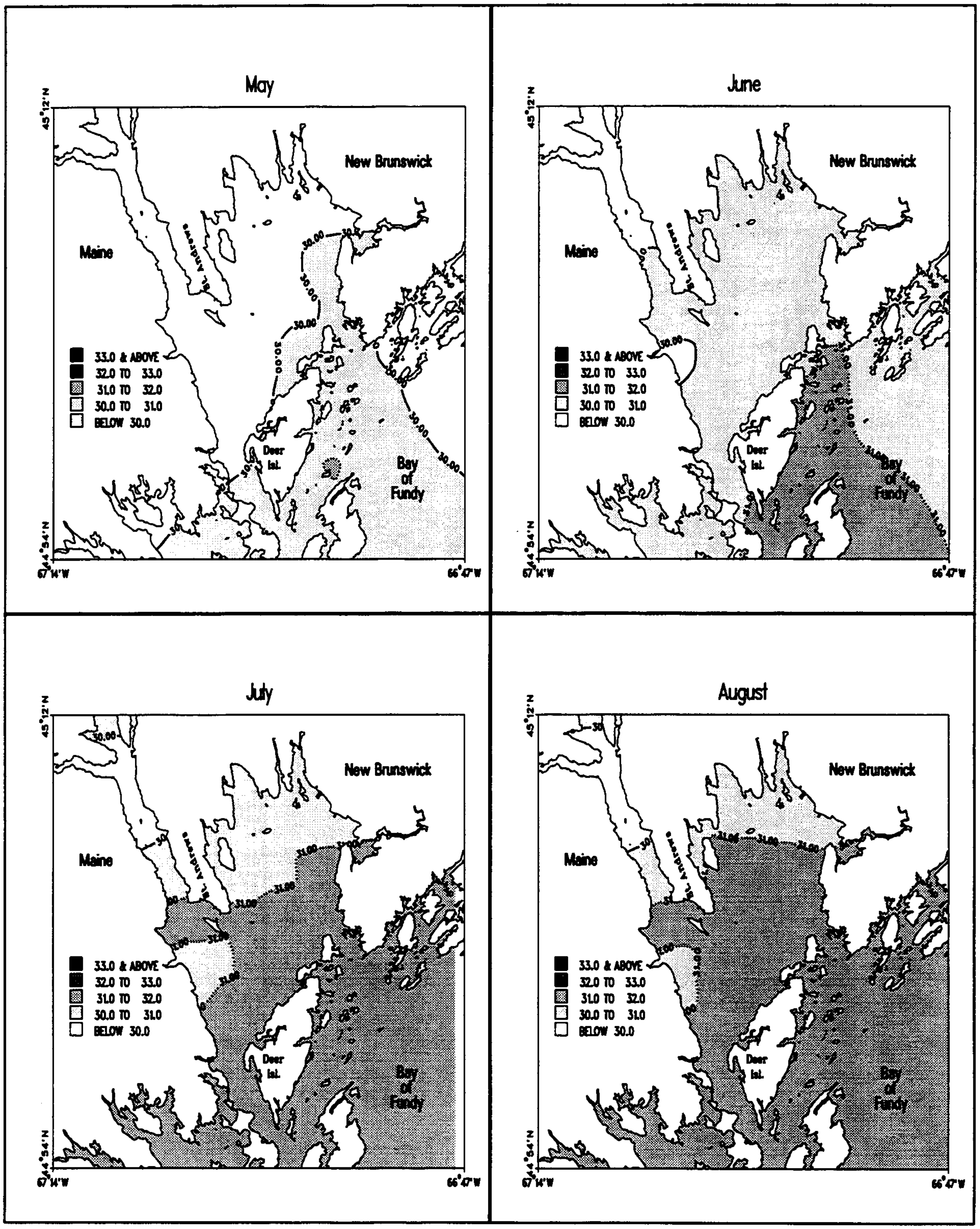

Figure 11: continued

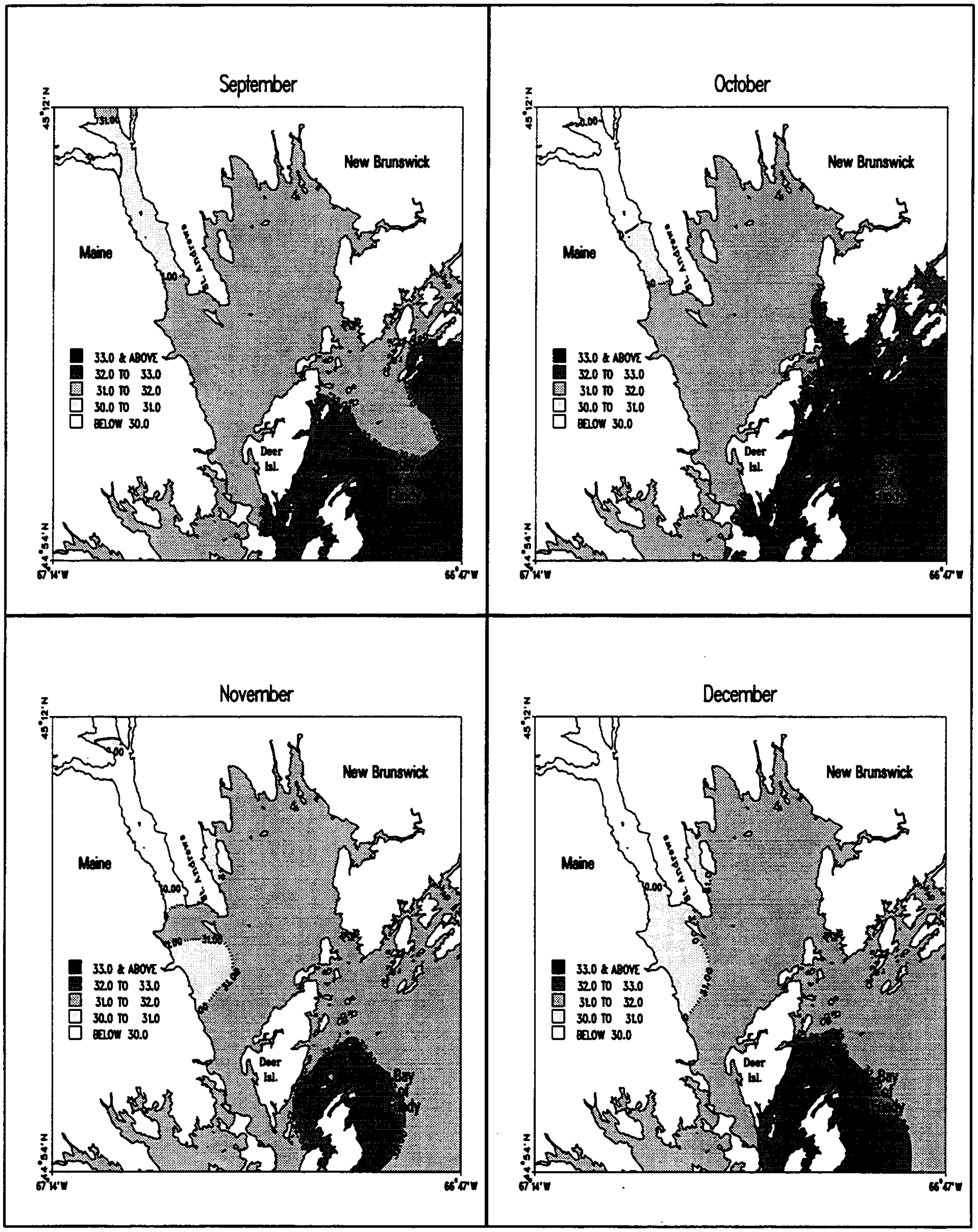

Figure 11: continued