THE ANALYSIS AND IMPLICATIONS OF THE WATER COLUMN DISTRIBUTION OF BROWN SHRIMP (PENAEUS AZTECUS) POSTLARVAE

A Senior Thesis

By

Amy Marie Graham

1996-97 University Undergraduate Research Fellow

Texas A&M University

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Amy Marie Graham

University Undergraduate Fellow, 1996-1997

Texas A&M University

Department of Oceanography

APPROVED

Fellows Advisor John H. Wormuth

Honors Director Susanna Finnell

ABSTRACT

Analysis and Implications of the Water Column Distribution of Brown Shrimp (*Penaeus Aztecus*) Postlarvae

Amy Marie Graham, Sponsored by Dr. John Wormuth

Oceanography, Texas A&M University

Three tows were taken at Galveston Bay, Tx on November 3rd and 4th, 1996 and were evaluated for abundance, with respect to the physical parameters: salinity, temperature, tide stage, and diel stage. These tows yielded a total abundance of zero for all net samples. The data analyzed is from twenty tows taken April 3rd and 4th, 1992. This data was collected by the same method and was evaluated against the same parameters. This analysis resulted in support for the theory that postlarval brown shrimp are less active at temperatures below 17 degrees Celsius. The analysis also showed a correlation between high surface abundance and daylight and high bottom abundance during the night. No conclusions could be drawn with respect to salinity or tide stage.

To all of my friends who make sacrifices for the things I have to do

ACKNOWLEDGMENTS

The author wishes at this time to profusely thank Dr. John Wormuth for giving of his time, resources, and especially his computer. This work would not have been completed without his assistance.

The author also wishes to thank Dr. Drew Vastano for pointing out the road that led here.

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INTRODUCTION

Background:

The coastal region of Texas, including its estuaries and offshore waters, yields a diverse commercial catch consisting of shrimp, oysters, crabs, and finfish. The annual ex-vessel value of shrimp alone amounts to about $250 million (Wormuth and Vastano, 1996). Successive years average about +/- 30% of the preceding years catch. That is, changes in a fishery's annual income can vary significantly without any assurance of low variance. The causes of this variability are unclear but appear to be more environmental than effort dependent.

To explore these environmental effects on shrimp harvesting, it is first necessary to understand the life cycle of the brown shrimp. Brown shrimp spawn offshore at depths greater than 14 meters. There are two periods of spawning, one in early spring (February to March) and one in late fall (September) (Lochman, 1990 p.187). Eggs quickly develop into free-swimming planktonic larvae through a series of molts (naupliar, protozoeal, and mysis) to a postlarval stage that is estuarine dependent for two-four months of additional development. At this stage, they become bottom-oriented and complete their life cycle as benthic juveniles and sub-adults. The process of the postlarvaes' migration from offshore to the estuaries is of great interest. If an accurate population size of postlarvae migrating into estuaries can be determined, then this number should accurately predict the shrimp harvest for the next season.

The earliest investigations into predicting commercial catches of penaeid shrimp from postlarval abundance began at the Bureau of Commercial Fisheries Laboratory at Galveston, Tx in November, 1959 (Christmas, J. Y. and T. N. van Devender, 1981 p.301). This study initially intended to contrast predictions based on juvenile populations verses postlarval populations. However, it soon became clear that the predictions based on postlarval populations were preferred since that data is available four to six weeks sooner. Although ultimately, these scientists concluded that the number of combinations of data that might be used to calculate an abundance index for postlarval shrimp is almost unlimited and the most appropriate method is open to question (Christmas, J. Y. and T. N. van Devender, 1981 p.303).

This was the first significant step in postlarval abundance predictions because these researchers immediately determined that it is impossible to account for every physical and environmental parameter that might effect postlarval migration.

Next, research began intensively in Barataria Bay, south of New Orleans. Here a random sampling technique was employed in an effort to decrease the variability brought on by continuous, short-term sampling. Temperatures and salinities were taken with each sample in order to determine which factors might control postlarval movements. These researchers concluded that time of arrival and condition of the environment appear[ed] to be the major factors affecting survival of postlarval shrimp on the nursery grounds (Christmas, J. Y. and T. N. van Devender, 1981 p.305). They also found that best growth and survival occurred at temperatures around 20 degrees Celsius and salinities over 10ppt.

This is significant because these researches narrowed the spectrum of physical characteristics to those that they perceived as important. However, the real question remains: what actually does effect postlarval migration?

Problem:

Do postlarval brown shrimp regulate their method of transport from offshore to estuary or is their migration due to physical processes alone? That is, do they instinctively make use of physical conditions (active migration) or are they carried along (passive migration)?

Usually, passive migrations refer to physical mechanisms of transport while active migrations refer to behaviorally-enhanced mechanisms of transport (Godwin, 1991 p.15). The assumption of this study is that postlarval shrimp utilize active migration. That is, there is more to postlarval migration than the postlarvae simply being swept into estuaries by highly variable currents. However, by adjusting themselves vertically in the water column, postlarvae may make instinctive use of water currents.

Among the penaeids, the magnitude of the vertical migration seems to be dependent on the developmental stage. Postlarvae stages tend to migrate deeper in the water column during the day than the protozoeal or mysis stages. The more pronounced vertical migrations of the postlarvae probably allow this stage to utilize specific currents to a greater degree than the younger stages...but there is no consensus on which signals the postlarvae specifically respond to within a current (Mathews, 1992 p.178).

If the postlarvae do specifically respond to environmental factors, then this temporally selective activity in the presence of different environmental signals attests to the plasticity of a postlarva's response to environmental signals and provides a mechanism for estuarine immigration. The presence of a response hierarchy to environmental signals may also help account for the ability of postlarval penaeids to immigrate into estuaries with different hydroperiods and salinity regimes (Mathews, 1992 p. 177).

Responses to temperature and salinity were already mentioned. Other environmental cues include light, whether it is day or night (diel stage). A diel rhythmic behavior allows postlarvae to limit their exposure to swimming, visual predators by entering the water column only when the light levels are low enough to minimize detection (Mathews, 1992 p.178).

Tide stage is another factor with the potential to help immigrating postlarvae by regulating their position in the water column so as to be near the surface on a flood tide and near the bottom during an ebb tide. This type of migration would assure the postlarvae the most positive horizontal advection toward to estuary.

With this in mind, the objective of this study was clear.

Objective:

To collect postlarval brown shrimp samples from the Gulf of Mexico and evaluate and analyze their water column distribution with respect to temperature, salinity, diel stage, and tide stage.

LITERATURE REVIEW

Salinity:

The importance of salinity levels in postlarval shrimp migration is a controversial point. Some researchers claim that salinity levels are one of the most important factors, and others report them to be wholly unrelated. Both sides have supportive data for their respective cases. However, even among those who avow the necessity of acceptable salinity regimes, the range of those regimes vary from experiment to experiment. Various investigators have reported high abundance and optimal growth and survival of young brown shrimp in water in which salinity exceeded 10 ppt. However, the occurrence of brown shrimp at salinities below 1 ppt was reported by Gunter and Shell (1958), Gunter and Hall (1963), Parker (1970), Henke (1971), Crowe (1975), and Barrett et. al. in 1978 (Herke, 1987 p9).

Other variations in salinity ranges have been suggested by many other scientists. For instance, White and Boudreaux (1977) wrote that dense populations of brown shrimp have been noted in salinities below 5 ppt, and they detail one instance in which good production occurred in salinities below 1-3 ppt (Herke, 1987 p.9-10). Sliding the scale a little more upward, Gunter et. al. (1964) observed that young brown shrimp were most abundant within a salinity range of 10-30 ppt and that 0.80 ppt was the lower salinity limit of brown shrimp on the northwestern coast of the Gulf of Mexico (Herke, 1987 p.20). Then, on the other side, in laboratory studies, Zein-Eldin (1963) concluded that salinities of 2-40 ppt had no appreciable effect on survival or growth of postlarval brown shrimp (Herke, 1987 p.10).

Reasons for these differences in these ranges are as plentiful as the ranges themselves. However, possible explanations may be that some scientists perform field experiments and some perform laboratory experiments with postlarval brown shrimp. Therefore, the type of experiment is fundamentally different, so, too, then are the results of these experiments.

Another reason may be that some researchers sample the postlarval shrimp in the middle of the estuary, upon arrival of the shrimp, some sample them at the mouths of estuaries, when they are in transit from offshore to estuary, and some sample the shrimp offshore as they make their way toward the estuaries. Obviously, sea water will be more saline than estuary water. So, the problem of no uniform method of sampling and reporting makes interpreting results from different studies an extremely difficult task.

As another example, Venkataramish et. al. (1974)...suggested that disagreement over salinity limits in the literature may be attributed to the fact that shrimp populations are changing: white shrimp (*P. setiferus*) may be losing part of their lower salinity territory to brown shrimp. Thus, selection of a particular salinity regime may not be influenced exclusively by physiological limits (Herke, 1987 p.10).

Temperature:

Water temperature is also a parameter of interest and debate with respect to its effects on postlarval shrimp migration. Although, in the literature presented here, it was found that the existence of an acceptable temperature regime is more widely accepted. Or at least, it is more widely accepted that water temperature is a factor of influence in postlarval shrimp migration.

It is important to note here that postlarval shrimp migrate to the estuaries to grow and leave as juveniles. Therefore, some research is focused on the apparent growth of brown shrimp at different water temperatures. This is used as a tool to estimate the ranges of temperature to which they are most likely to migrate. Herke (1987) found in their study that the growth of brown shrimp seemed to be affected more by water temperature than by salinity. Compared with other growth estimates in the literature, growth rates of [their] shrimp appeared to respond in the "normal" manner to changes in temperature (Herke, 1987 p.21). In other field studies, Christmas et. al. (1966) and St. Amant et. al. (1966) noted an inhibitory effect of water temperatures below 18 degrees Celsius on the presence and growth of postlarval penaeids (Herke, 1987 p.10). Also of interest, Herke (1987) found that [their] data indicated a relation between temperature and apparent growth in estuarine nursery areas, but no such relation was found between growth and salinity (Herke, 1987 p. 24).

Temperature and Salinity:

To determine if salinity and temperature could affect postlarval migration together, many scientists have constructed experiments to observe the relationship between the two parameters, if any. For example, a laboratory study by Zein-Eldin and Aldrich (1965) indicated that combinations of low temperature and low salinity were detrimental to the survival of postlarval and juvenile brown shrimp...Postlarvae survived temperatures as low as 11 degrees Celsius for one month at salinities above 15 ppt, but significant growth did not occur until water temperatures reached the interval between 11 and 18 degrees Celsius (Herke, 1987 p.21). In other laboratory work (Zein-Eldin and Griffith 1969), brown shrimp postlarvae grew equally well at water temperatures of 24.5-26 degrees Celsius and salinities of 2-40 ppt. St. Amant et. al. at (1966) prescribed water temperatures of 20 degrees Celsius and salinities greater that 15 ppt (Herke, 1987 p. 24). Therefore, although there may not be a consensus as to why temperature and salinity affect growth, the possibility that they could together create a regime of maximum postlarval growth is very real.

Tide Stage:

Bioregulation with respect to tide stage is a physical factor that researchers still debate but want most to believe. Since postlarval brown shrimp do end up in estuaries and are not washed away immediately upon arrival, it makes sense that they have some innate internal mechanism that would aid them in estuary retention. The reasons why postlarvae are abundant on flood tides is simply because they are recruiting from their offshore spawning grounds to the estuary. The reasons why they are usually not abundant on ebb tides is less clear. Postlarvae may be less abundant on ebb tides because a relatively high percentage of them, which had arrived on the previous flood tide, were diffused throughout the bay during the subsequent slack tide. However, it is also possible that postlarvae swim to the bottom to become associated with the substrate after a flood tide, as suggested by Staples and Vance (1985) and thus avoid being flushed from the inlet (Godwin, 1991 p.85). In concordance with this, Godwin, 1991 found that abundances on the flood tide definitely exceeded the abundances on the ebb tide (Godwin, 1991 p.80-85). It is good to note here that brown shrimp postlarvae are capable of rapid swimming. Zein-Eldin and Renaud (1986) reported a swimming speed of 4.8 cm/s *P. aztecus* postlarvae (Godwin, 1991 p.89). Therefore, if they do not regulate themselves in the water column to the substrate to avoid the ebb tide, it is possible that they could swim out of range during the ebb tide.

Diel Stage:

Another possible physical parameter affecting migration is diel stage (whether it is day or night/light or dark). On the ocean, diel stage is one thing that is constant. Temperatures and salinities may be affected by meteorological or human events, but day and night always occur and at fairly regular intervals. Therefore, bioregulation with respect to diel stage is common among many oceanic organisms and can be measured with respect to other physical factors. Mathews (1992) observed diel stage regulation with respect to salinity and found that during dark/nocturnal conditions, the postlarvae respond[ed] to salinity increases and light level decreases by increasing swimming activity.

The postlarvae decrease[d] swimming activity in response to decreases in salinity and increases in light (Mathews, 1992 p.177). Copeland and Truitt (1966) found greatest abundances of *P. aztecus* postlarvae in Aransas Pass during night time flood tides. St. Amant et. al. (1966) found the same results in their study in Louisiana (Lochman, 1990 p.189)

In a more purely diel stage sense, Temple and Fisher (1965) found that brown shrimp postlarvae...tended to move to the surface layer just before dark when the water column was density stratified (Lochman, 1990 p.188). However, Lochman (1990) found that *Penaeus aztecus* postlarvae did not show a response to light levels as was reported for brown shrimp postlarvae offshore by Temple and Fisher (1965) (Lochman, 1990 p. 242). Therefore, it seems that if postlarval brown shrimp do use diel stage as a cue for migration, they respond to a change from light to dark.

MATERIALS AND METHODS

This section will discuss the reasons for the sampling site chosen, sampling design, equipment, method of acquisition, and the field and laboratory procedures used to analyze the data.

The sampling site chosen for this experiment was Galveston Bay. Galveston Bay is one of the most important bays of the Gulf of Mexico in terms of amount of shrimp harvested, and is generally representative of other large bays of the western Gulf (George, 1983 p. 42). Also, the pass between Galveston Bay and The Intercoastal Waterway serves as a transitional site from offshore to estuary. This study traveled to the east of Galveston to the vicinity of Heald Bank for offshore samples.

The data was obtained by sampling the vertical distribution of the postlarval shrimp in the water column verses the physical parameters: salinity, temperature, tide stage, and diel stage at the time of the sample. The postlarvaes' vertical distribution was determined through the use of MOCNESS (Multiple Opening-Closing Net Environmental Sensing System) tows. Three tows were taken approximately 3 hours apart. A MOCNESS is a large metal frame with nets spaced at depth intervals of choice (for this experiment, they were spaced 2 meters apart). It was lowered into the water by a wench at the back of the boat. Its sensors reported to a computer in the ship's laboratory. Once the MOCNESS was in the water, the boat proceeded forward and gradually increased speed until the monster device was at about a 45 degree angle. This speed was maintained for the duration of the tow. When the first net was opened, the monitor in the laboratory showed the volume of water filtered by that net. When 50 cubic meters had been filtered by the first net, a switch was flipped in the laboratory to close the first net and then open the second one. This process was repeated for all the nets. When the tow was completed, the boat slowed to a stop and the wench hauled it out of the water. Samples were collected in "cod ends" (cylindrical containers attached to the nets) for each net. The biomass in the these cod ends was then put in sample containers for examination in the University's laboratory.

The physical parameters were recorded at the time of sampling. Temperature was one of the parameters that the MOCNESS reported back to the laboratory, providing temperatures for every depth interval. Salinity was obtained on board, but it was rechecked in the laboratory on land. When recorded on the ship, the salinity was measured through the use of a refractometer. A refractometer bears a resemblance to a kaleidoscope with a panel on the outside. A drop of water from a sample was placed on the refractometer. Then, a look through the eyehole revealed a scale of salinities with white shading on the top and blue shading on the bottom. The line where the blue and white sections met was measured against the scale and yielded the salinity. This process was repeated on board for only a few of the samples. Refractometers are very precise instruments. However, in case of instrument breakage or miscalibration, the salinity of all the samples was redetermined in the lab. Tide stage was known even before the ship left port, and diel stage was obvious, as it is determined by the time of day.

Once back in the laboratory, the samples were separated into finer and finer parts until brown shrimp postlarvae could or should be observed. They were then counted and their number recorded. Thus, their abundance is the final, and most crucial, piece of data needed to begin analysis

DATA AND RESULTS

The site of this experiment, as was mentioned, was Galveston Bay. Of the three tows that were taken during November 3rd and 4th, 1996 (referred to as tows 199-201 in the data), not one sample yielded any brown shrimp postlarvae. Although, salinity and temperature measurements were taken. These results are not atypical, while November is not within the two seasonal peaks for recruitment. Therefore, because no more cruises were scheduled for the spring, the data analyzed in this study is data from the Oceanography department that was yet to be examined. It was given to this study to be published as an example of a more successful experiment. It was conducted in exactly the same manner, although during April 3rd-4th, 1992 and at Aransas Pass, near Corpus Christi. This cruise consisted of 20 tows (referred to in the data as tows 1-20), and the exact same measurements were taken.

Figures 1-44 represent temperature and salinity values with respect to depth for each tow. These figures are arranged to display the measurements for each tow in order, although salinity and temperature values are evaluated separately.

Fig. 1, Fig. 3, and Fig. 5 represent the salinity values for tows 199-201. For tow 199, salinity values ranged from 21.0 ppt to 27.0 ppt which were distributed, unusually, across each depth interval. The salinity values for tow 200 varied between 24.0 ppt to 27.6 ppt with the most variation in the upper half of the water column. In tow 201, the salinity values ranged from 22.0 ppt to 32.5 ppt with the most variation in the lower half of the water column.

Fig. 2, Fig.4, and Fig. 6 represent the temperature values for tows 199-201. The temperature values for tow 199 ranged from 20.5 to 23.3 degrees Celsius with the upper half of the water column centered near to 21.5 degrees Celsius. For tow 200, the temperature values varied between 21.4 to 22.9 degrees Celsius. The upper half of the water column was most centered at 21.5 degrees Celsius, while the bottom half was most centered around 22.7 degrees Celsius. In tow 201, the temperature values ranged from 20.0 to 22.5 degrees Celsius. Although, most of the water column represented 22.3 degrees Celsius.

Figures 7-43 (odd) represent the salinity values for tows 1-20. Salinity values for tow 1 (Fig. 7) ranged from 22.9 ppt to 28.2 ppt, but the distribution suggests that either not every net sample of the tow was measured for salinity or the instrument used to measure salinity malfunctioned. For tow 2 (Fig. 9), salinity values ranged from 21.4 ppt to 28.5 ppt, with the majority of the water column centered around 27.0 ppt. In tow 3 (Fig 11), values varied between 20.4 ppt to 28.0 ppt, with the water column mostly consisting of salinities near 27.5 ppt. There was only one salinity value recorded for tow 4 (Fig. 13), that of 25.8 ppt, which suggests another example of equipment malfunction. The salinity values for tow 5 (Fig. 15) ranged from 24.2 ppt to 27.8 ppt, with the water column most centered around 27 ppt. For tow 6 (Fig 17), the salinities varied between 20.2 ppt and 26.7 ppt, with most of the values scattered around 24.5 ppt. In tow 7 (Fig 19), the salinities ranged from 20.2 ppt to 31.8 ppt, with the values highly variable near the surface, but narrowing to 27.4 ppt near the bottom. The salinity values for tow 8 (Fig. 21) ranged from 20.2 ppt to 31.2 ppt, also with high variability near the surface and narrowing to 27.0 ppt near the bottom. Salinity data for tow 9 was not available.

For tow 10 (Fig. 23), the values varied between 20.2 ppt and 31.3 ppt, again with high variability near the surface but centered around 21.0 ppt near the bottom. For tow 11 (Fig. 25), the salinities ranged from 20.2 ppt to 27.3 ppt, with high variability near the surface but centering at 27.0 ppt. Tow 12 (Fig. 27) was fairly tightly distributed with salinities ranging from 21.9 ppt to 26.7 ppt, and with the majority of the water column having a salinity value centered around 26.5 ppt. In tow 13 (Fig. 29), the salinity values were also more tightly distributed, varying between 25.5 ppt and 27.6 ppt and centered at 27.0 ppt. The values for tow 14 (Fig. 31), too, were fairly tightly distributed, ranging from 21.7 ppt to 29.8 ppt and centered around 26.5 ppt. For tow 15 (Fig. 33), the data ranged only slightly, between 24.0 ppt and 28.2 ppt, and concentrated around 26.5 ppt. In tow 16 (Fig. 35), the salinity values were almost linear, varying between 20.8 ppt to 26.9 ppt, with all the data points except one clustered around 26.6 ppt. The salinity values for tow 17 (Fig. 37) ranged from 20.3 ppt to 26.7 ppt with highly variable distribution. Tow 18 (Fig. 39) experienced values ranging from 21.4 ppt to 27.2 ppt, with high variability near the surface but became centered around 26.8 ppt near the bottom. For tow 19 (Fig. 41), the salinity values varied between 21.0 ppt and 27.8 ppt, also with high variability near the top but centering at 27.2 ppt near the bottom. The values for tow 20 (Fig. 43)

Fig. 1 Tow 199 SvZ

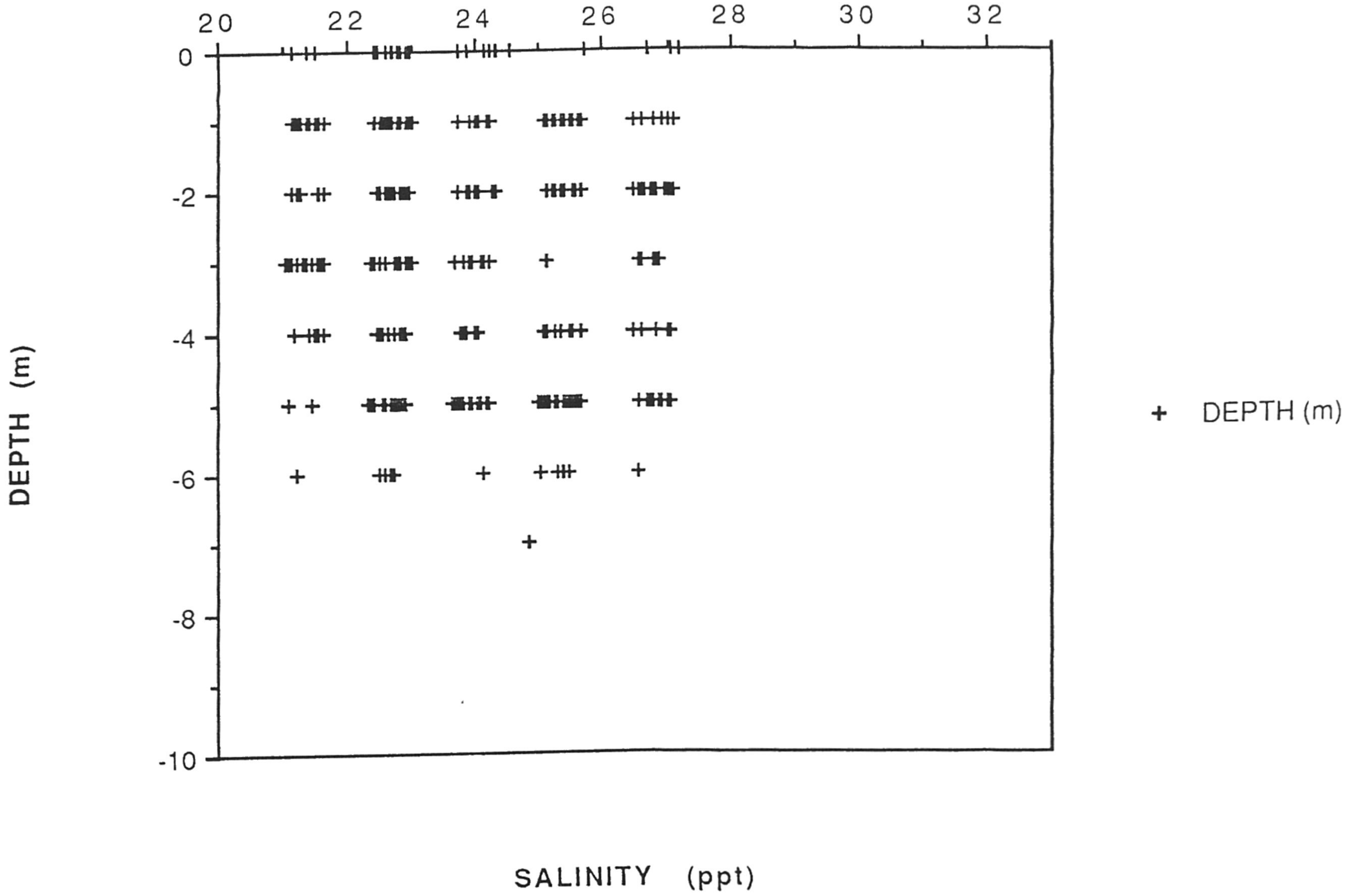


Fig. 2 Tow 199 TvZ

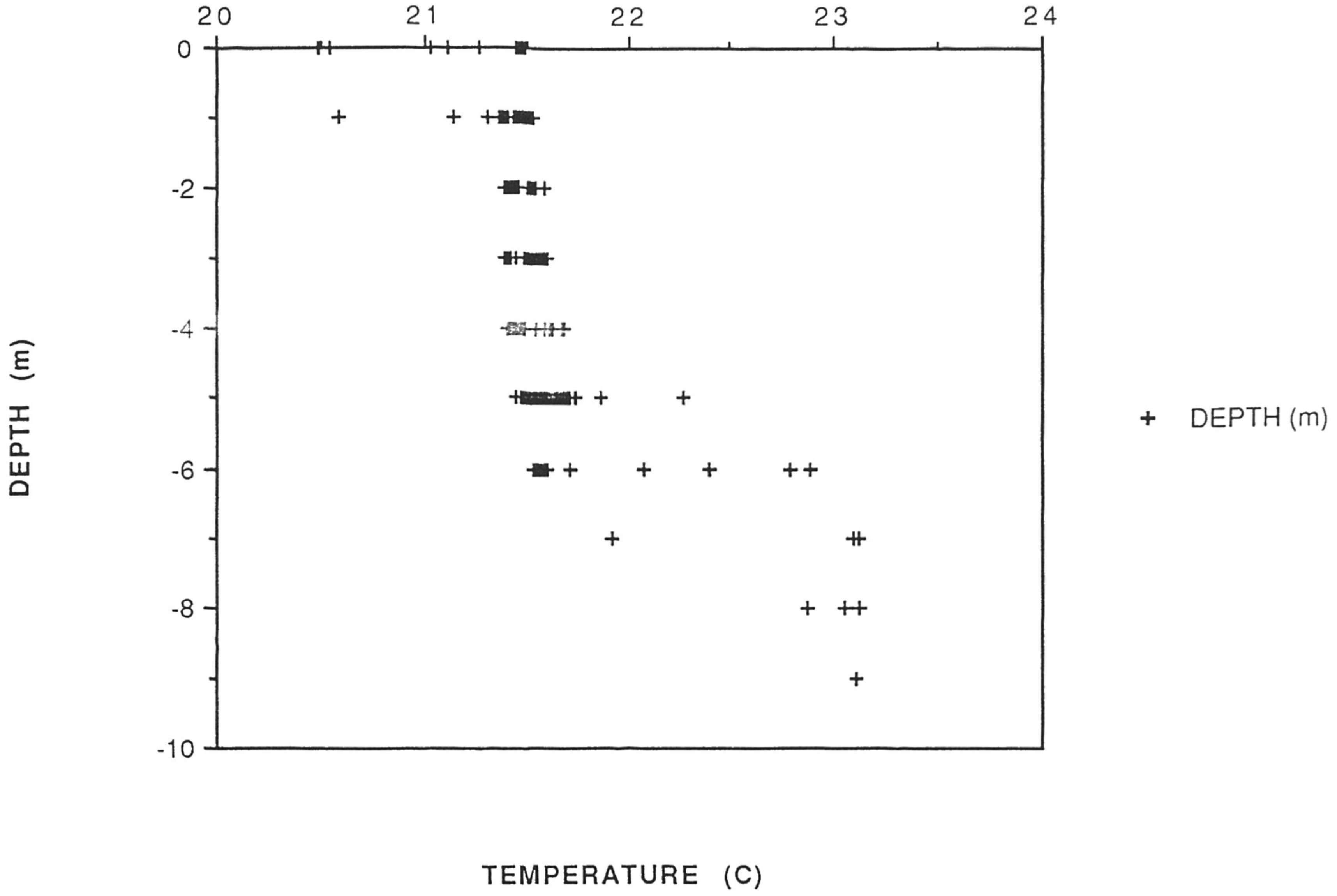


Fig. 3 Tow 200 SvZ

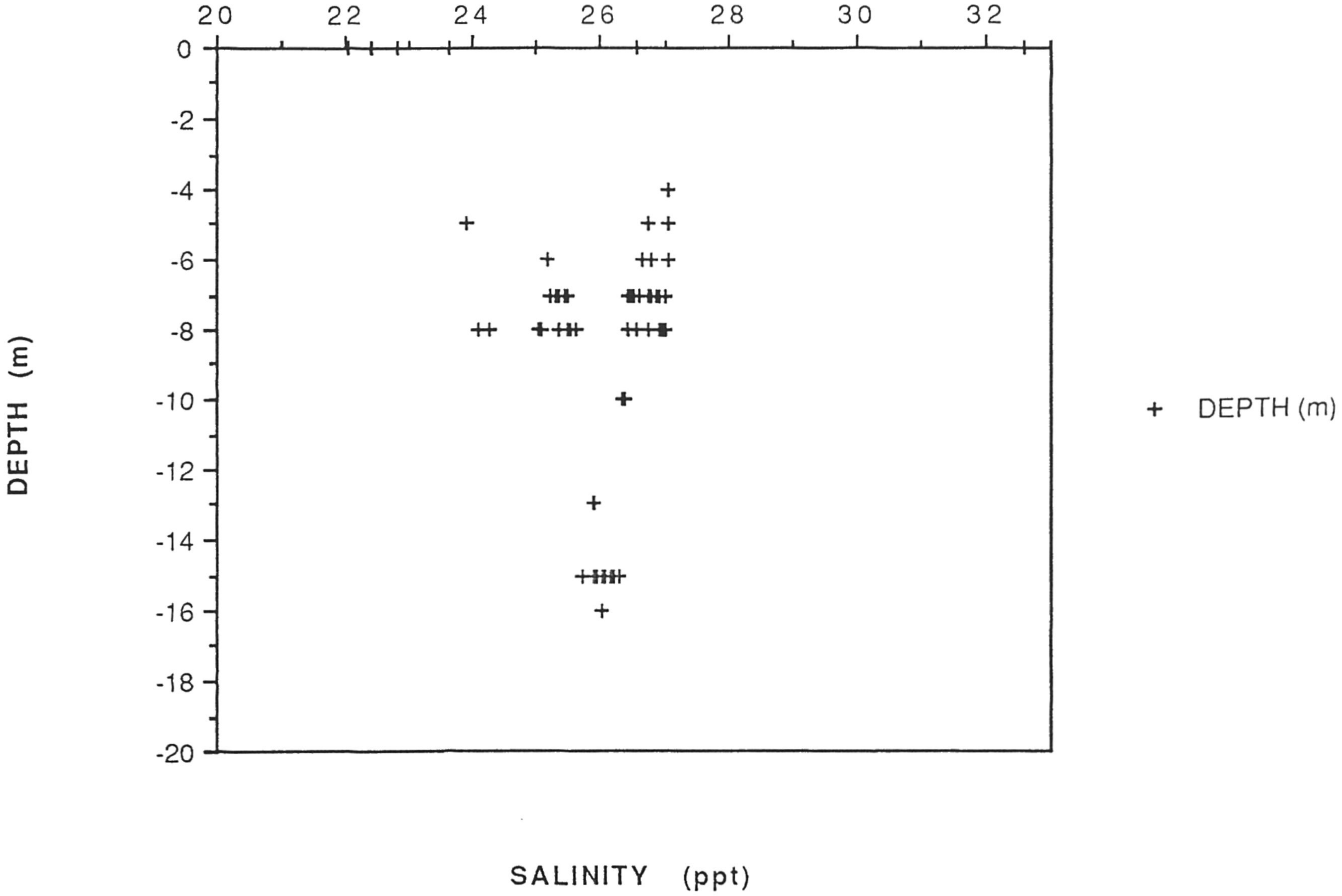


Fig. 4 Tow 200 TvZ

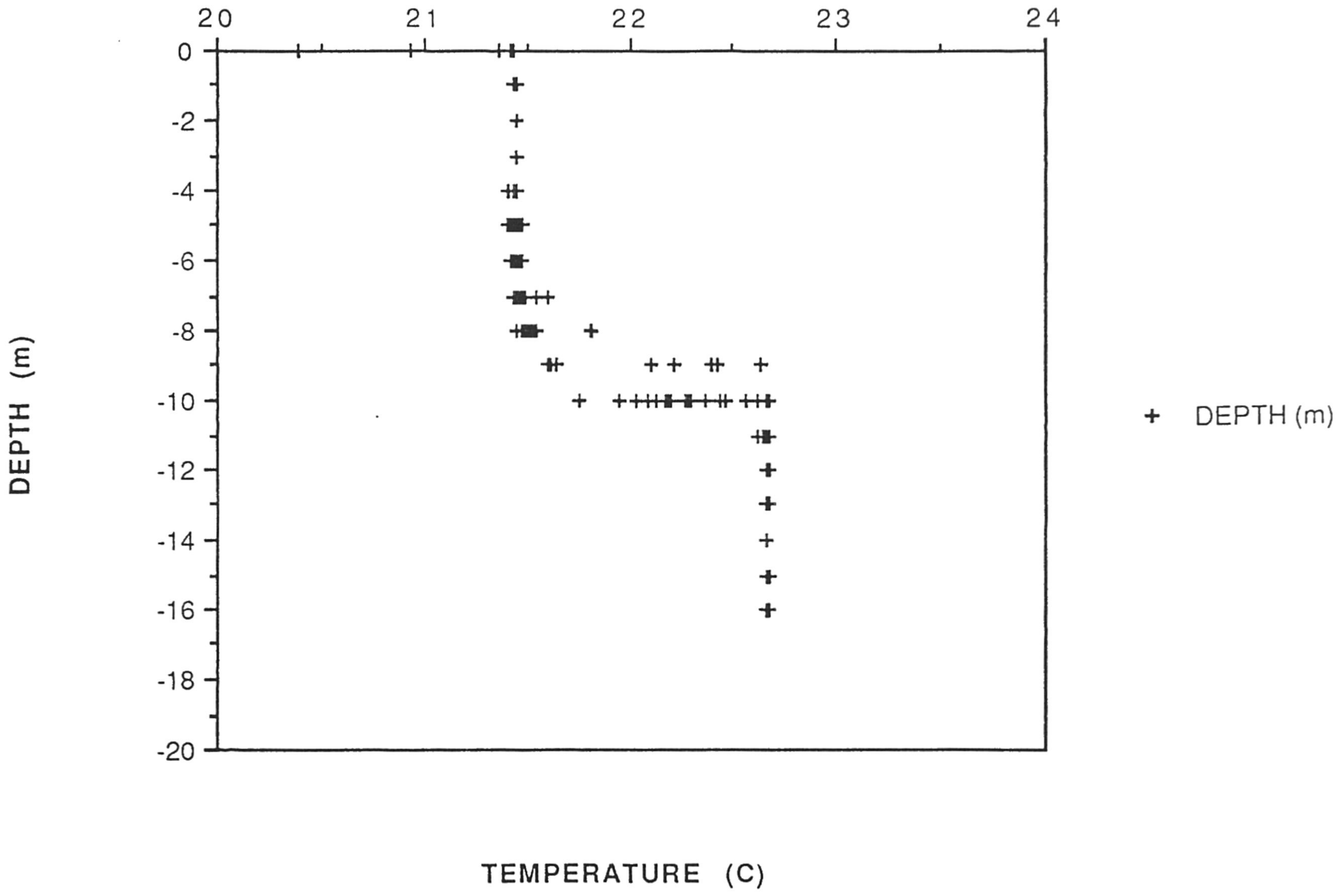


Fig. 5 Tow 201 SvZ

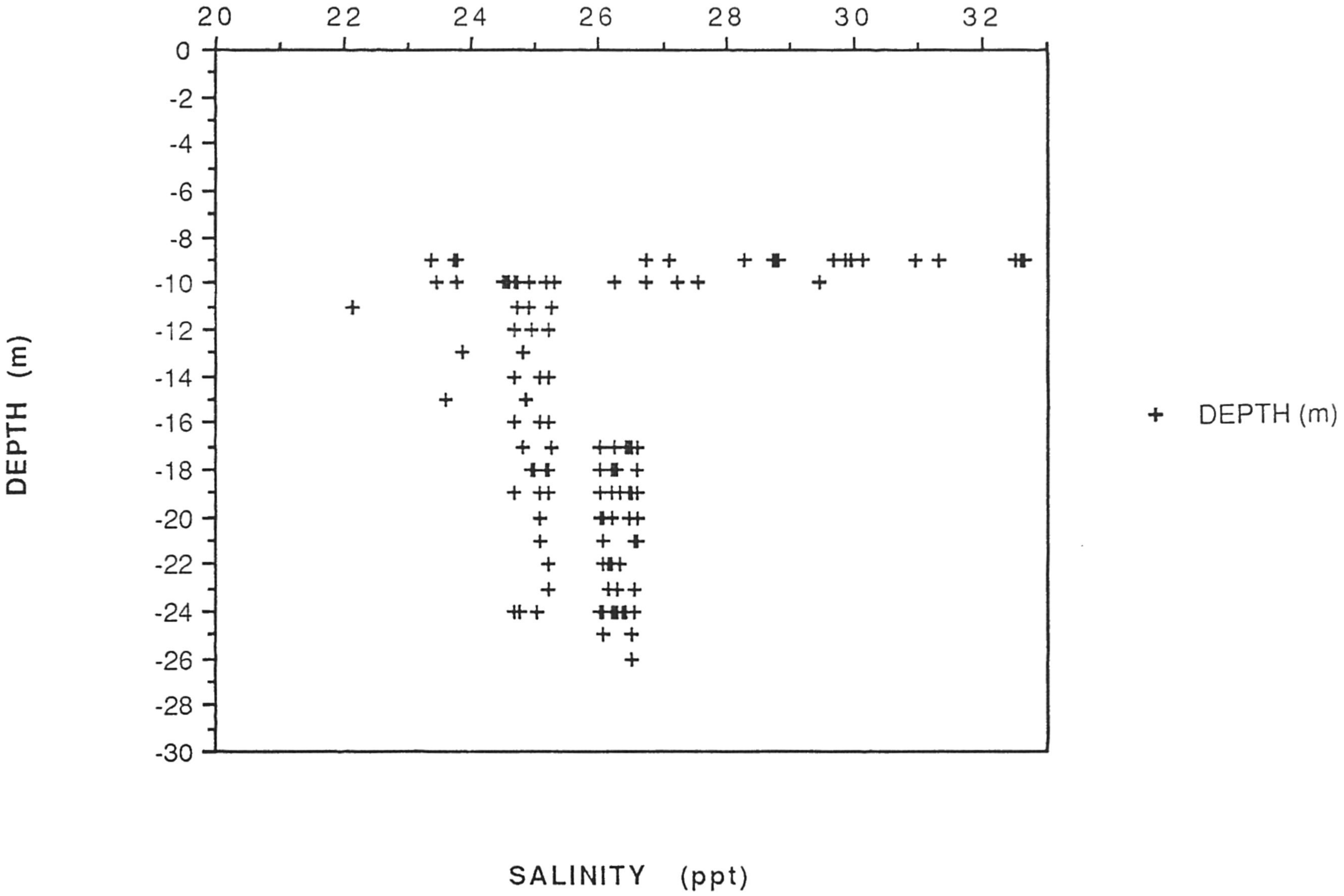
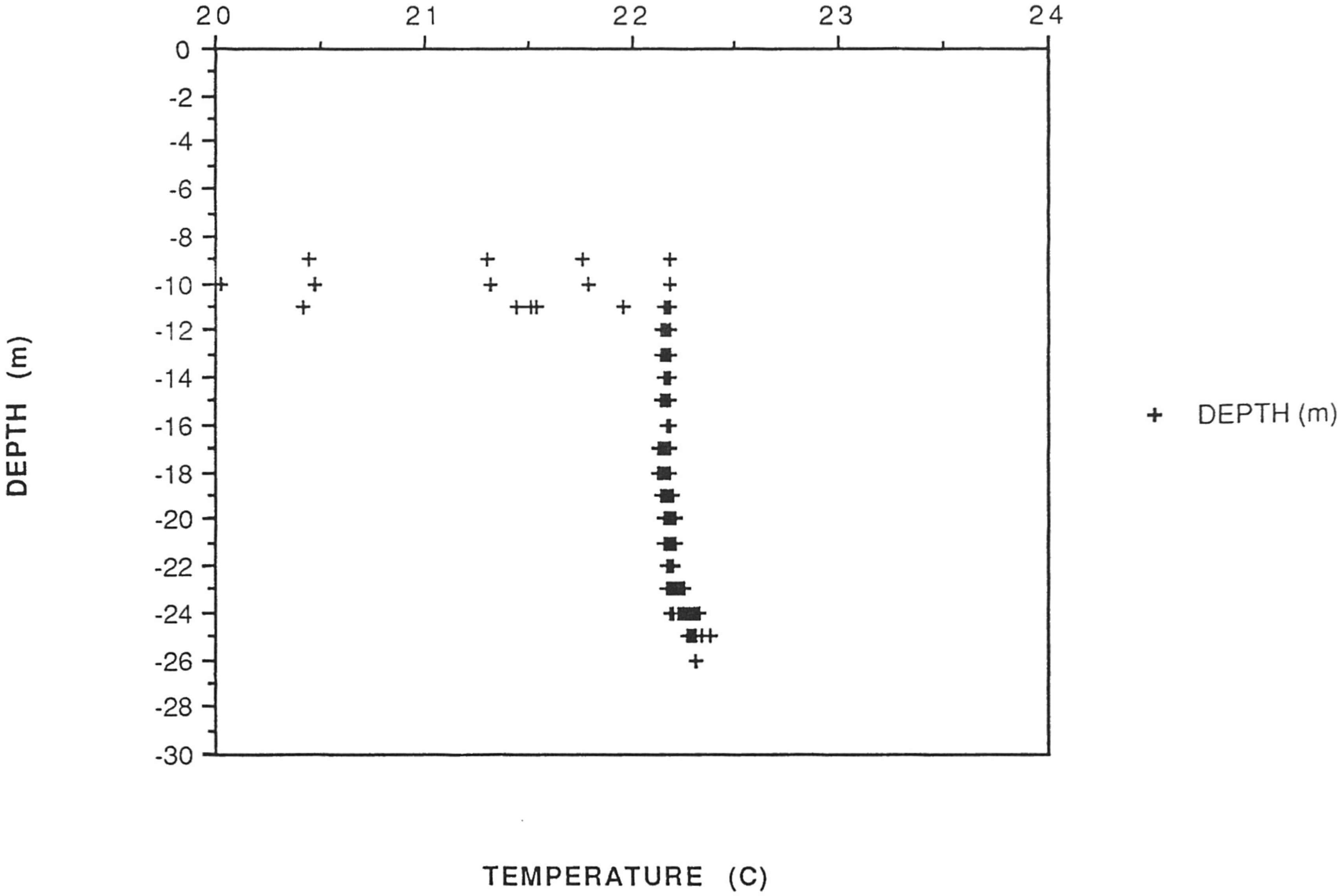


Fig. 6 Tow 201 TvZ



were wildly distributed between 20.0 ppt and 31.9 ppt with high variability, suggesting instrumentation malfunction.

Figures 8-44 (even) represent the temperature values for tows 1-20. For tow 1 (Fig. 8) the temperatures were tightly distributed and ranged from 16.7 degrees Celsius to 17.8 degrees Celsius, centered around 16.9 degrees Celsius. Tow 2 (Fig. 10) was also fairly tightly distributed, ranging from 16.5 degrees Celsius to 17. 3 degrees Celsius. Most of the data was centered at 17.2 degrees Celsius. In tow 3 (Fig. 12), the data was tightly distributed around 17.1 degrees Celsius, varying between 16.1 degrees Celsius to 17.3 degrees Celsius. For tow 4 (Fig. 14), the values ranged from 16.2 degrees Celsius to 18.3 degrees Celsius, with high variability near the surface but then centering around 18.0 degrees Celsius. The data for tow 6 (Fig. 16) was tightly distributed, centered at 18.2 degrees Celsius, and ranged from 16.9 degrees Celsius to 18.3 degrees Celsius. In tow 6 (Fig. 18), the temperature values varied between 16.5 degrees Celsius to 18.2 degrees Celsius, with high variability near the surface and narrowing to around 18.0 degrees Celsius. For tow 7 (Fig. 20), the data ranged from 16.9 degrees Celsius to 18.7 degrees Celsius, centered at 18.4 degrees Celsius. The values for tow 8 (Fig. 22) ranged from 16.5 degrees Celsius to 18.3 degrees Celsius and centered at 18.0 degrees Celsius. No temperature data was available for tow 9.

In tow 10 (Fig, 24), the temperature values varied between 16.6 degrees Celsius to 18.5 degrees Celsius, centered around 18.3 degrees Celsius. For tow 11 (Fig. 26), the data ranged from 16.8 degrees Celsius to 18.4 degrees Celsius, centered at 18.1 degrees

Celsius. The values for tow 12 (Fig.28) were tightly distributed around 18.1 degrees Celsius and ranged from 17.0 degrees Celsius to 18.2 degrees Celsius. In tow 13 (Fig. 30), the data was also tightly distributed, centered at 18.3 degrees Celsius, and varying between 17.5 degrees Celsius to 18.4 degrees Celsius. Tow 14 (Fig. 32) experienced more variability, ranging from 17.1 degrees Celsius to 18.3 degrees Celsius, and somewhat centered at 17.9 degrees Celsius. For tow 15 (Fig. 34), the data was tightly distributed around 18.0 degrees Celsius and ranged from 16.3 degrees Celsius to 18.4 degrees Celsius. The temperature values for tow 16 (Fig. 36) were very tightly distributed around 18.2 degrees Celsius and varied between 16.1 degrees Celsius and 18.4 degrees Celsius. Tow 17 (Fig. 38) also was tightly distributed, centered around 18.0 degrees Celsius, and ranged from 17.2 degrees Celsius to 18.2 degrees Celsius. For tow 18 (Fig. 40), the data experienced a little more variability, ranging from 16.5 degrees Celsius to 18.7 degrees Celsius and somewhat centered at 18.3 degrees Celsius. In tow 19 (Fig. 42), the values ranged from 16.8 degrees Celsius to 18.7 degrees Celsius and centered around 18.4 degrees Celsius. The temperature data for tow 20 (Fig.44) ranged from 17.0 degrees Celsius to 18.4 degrees Celsius, with high variability near the surface but narrowed to around 17.7 degrees Celsius.

Chart 1 represents the rest of the physical data for each tow number. Of importance are: #PL/m^3 (the number of postlarvae per cubic meter, i.e. abundance), depth, tide stage, and day/night. Within the day/night column, some entries are listed as "T". This stands for twilight, and these tows were not included in the diel stage analysis.

Fig. 7 Tow 1 SvZ

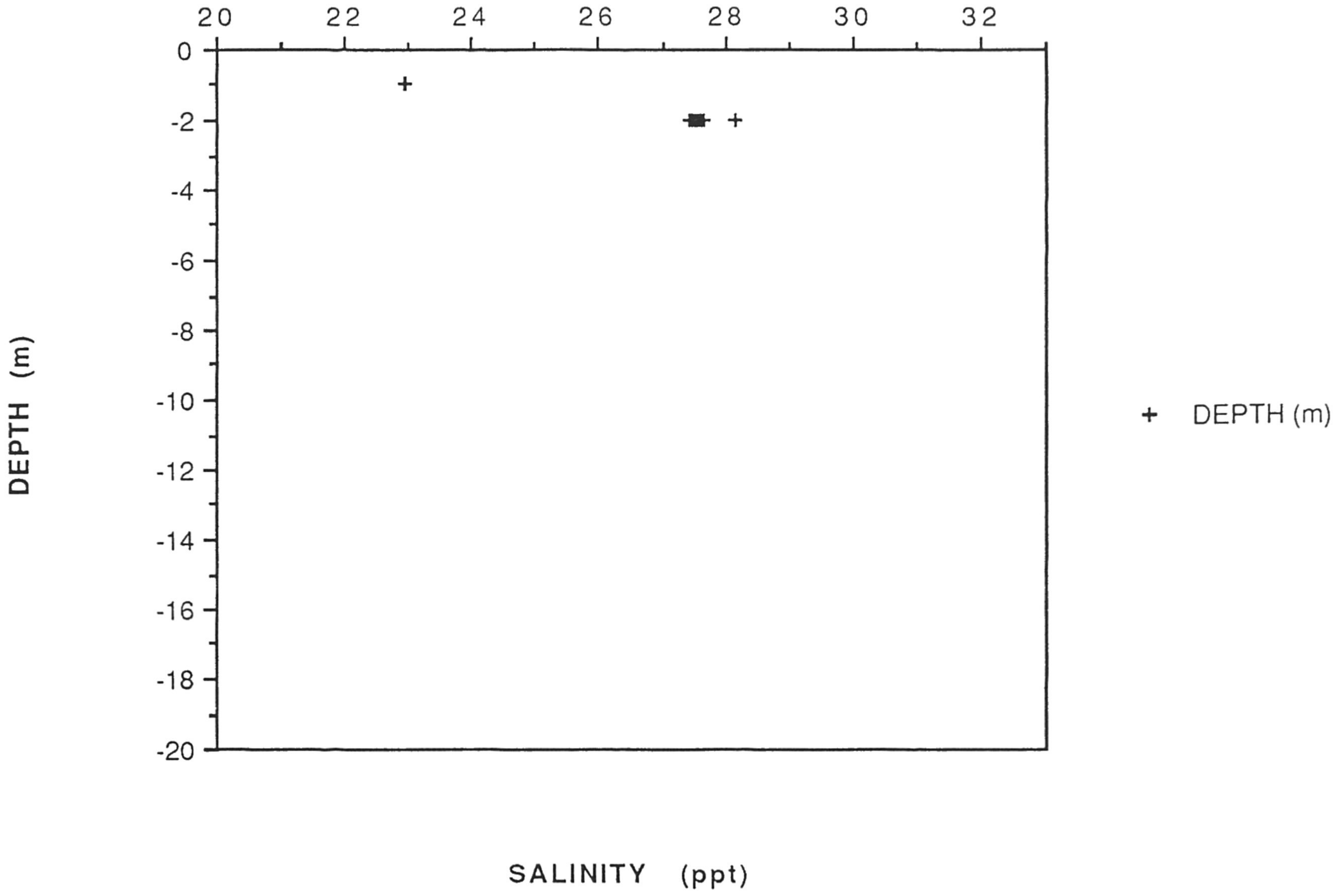


Fig. 8 Tow 1 TvZ

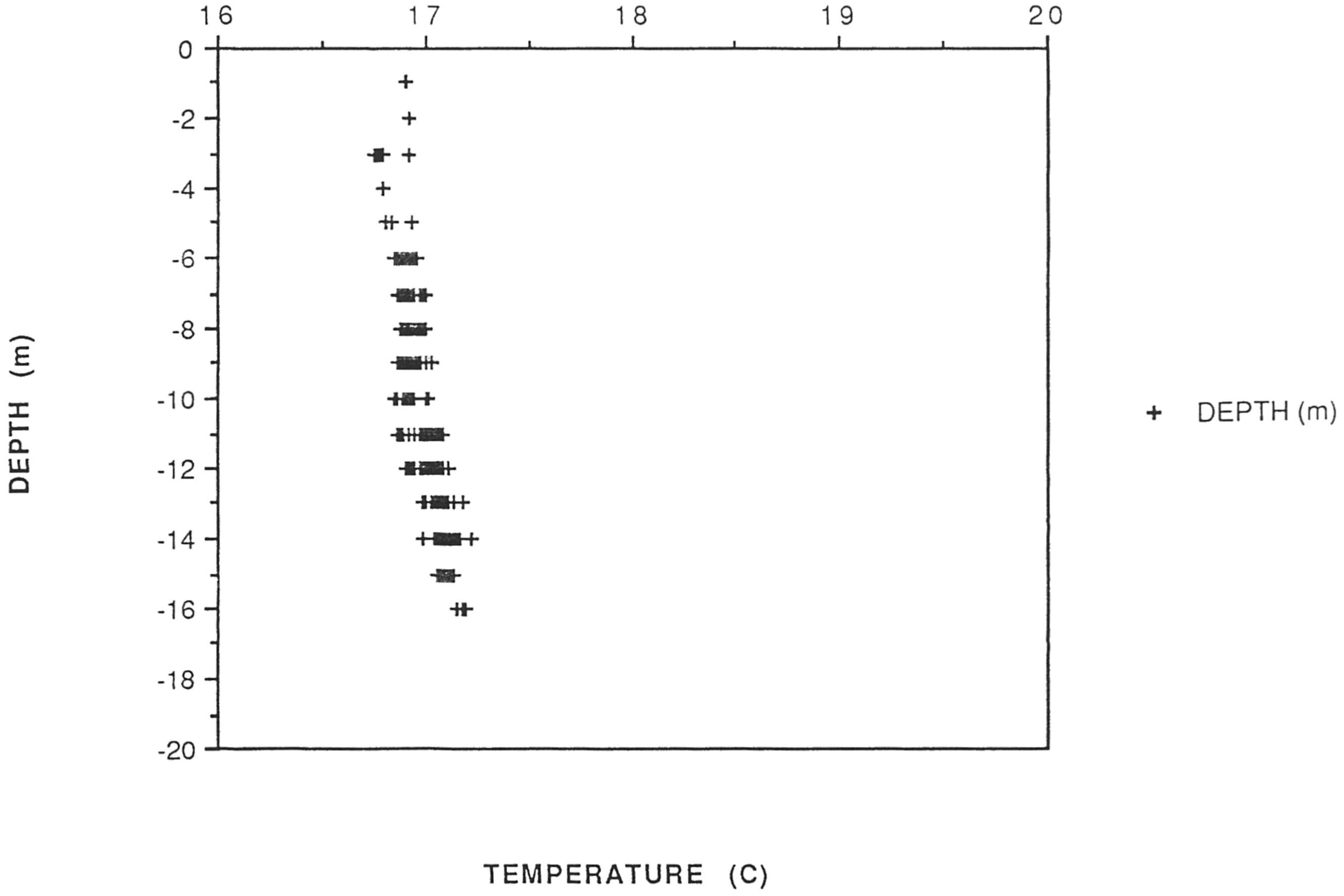


Fig. 9 Tow 2 SvZ

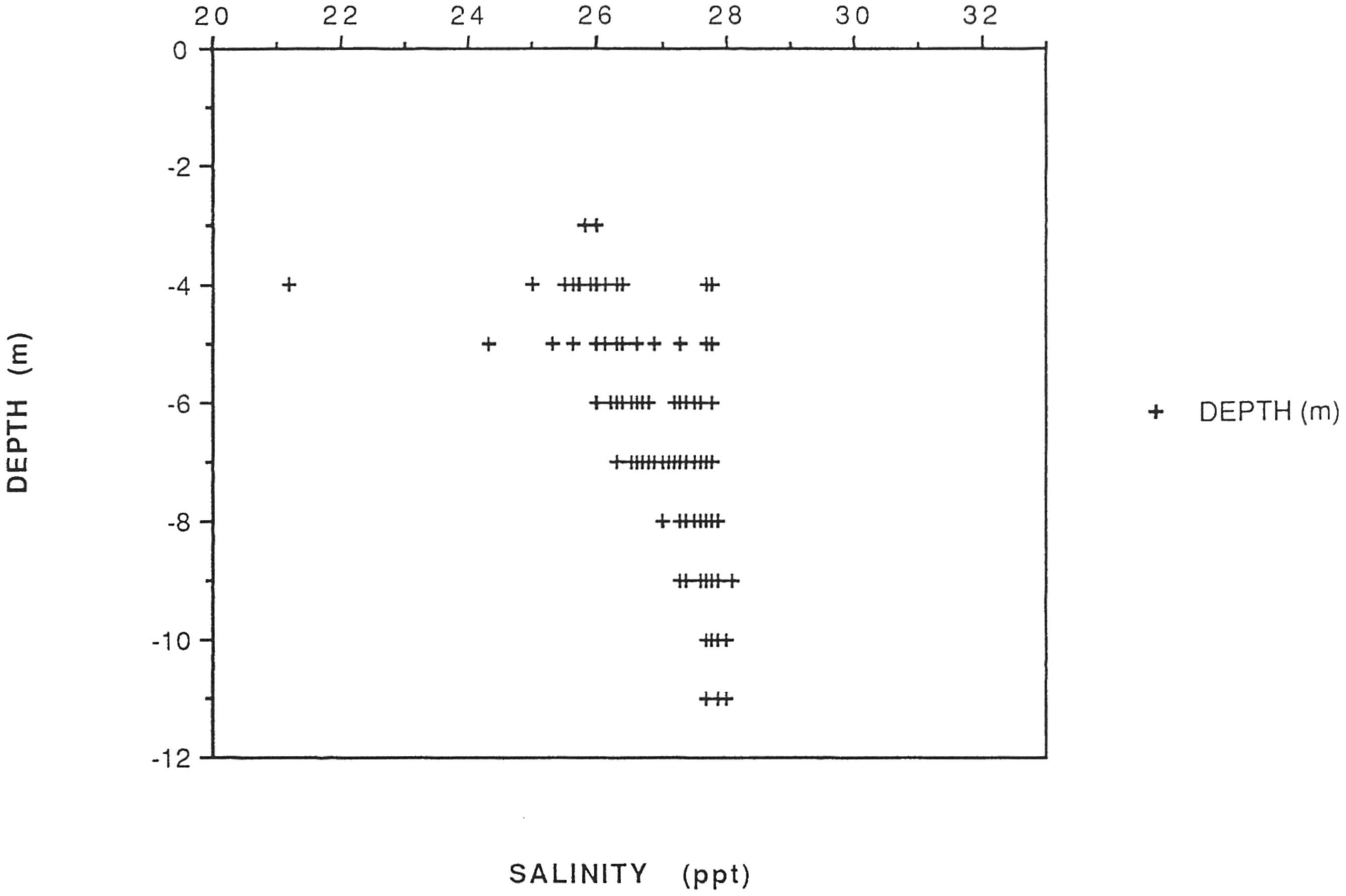


Fig. 10 Tow 2 TvZ

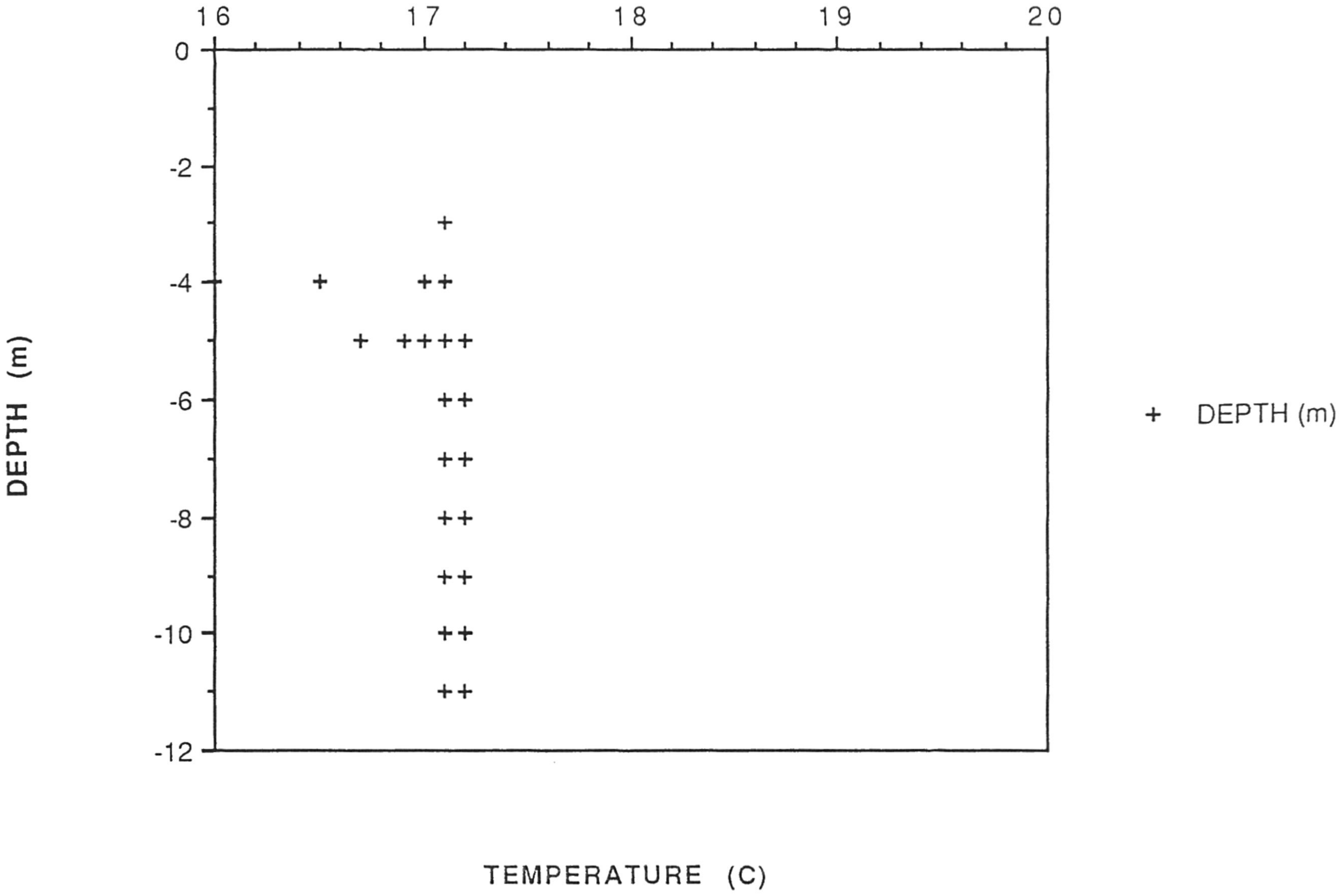


Fig. 11 Tow 3 SvZ

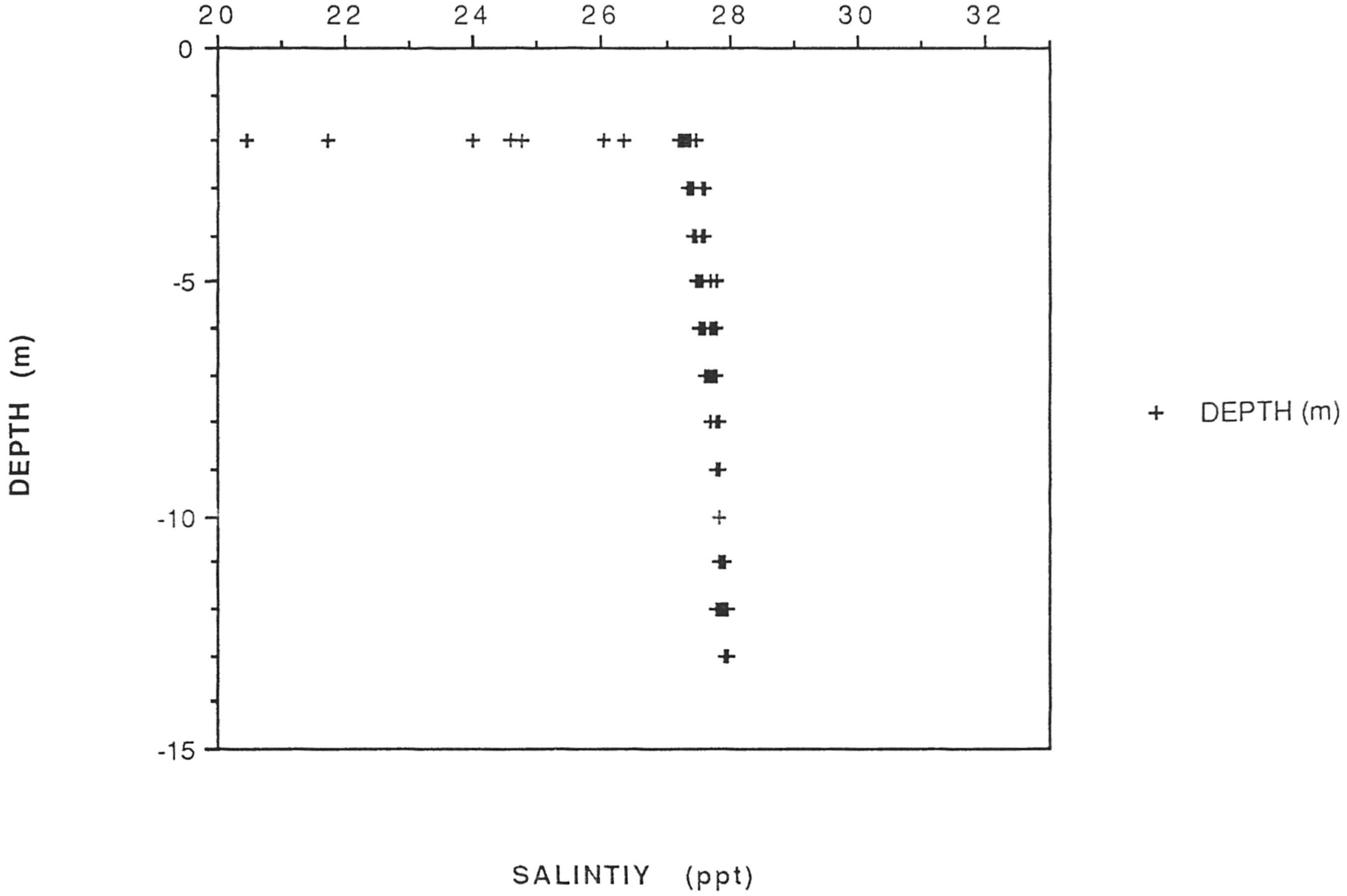


Fig. 12 Tow 3 TvZ

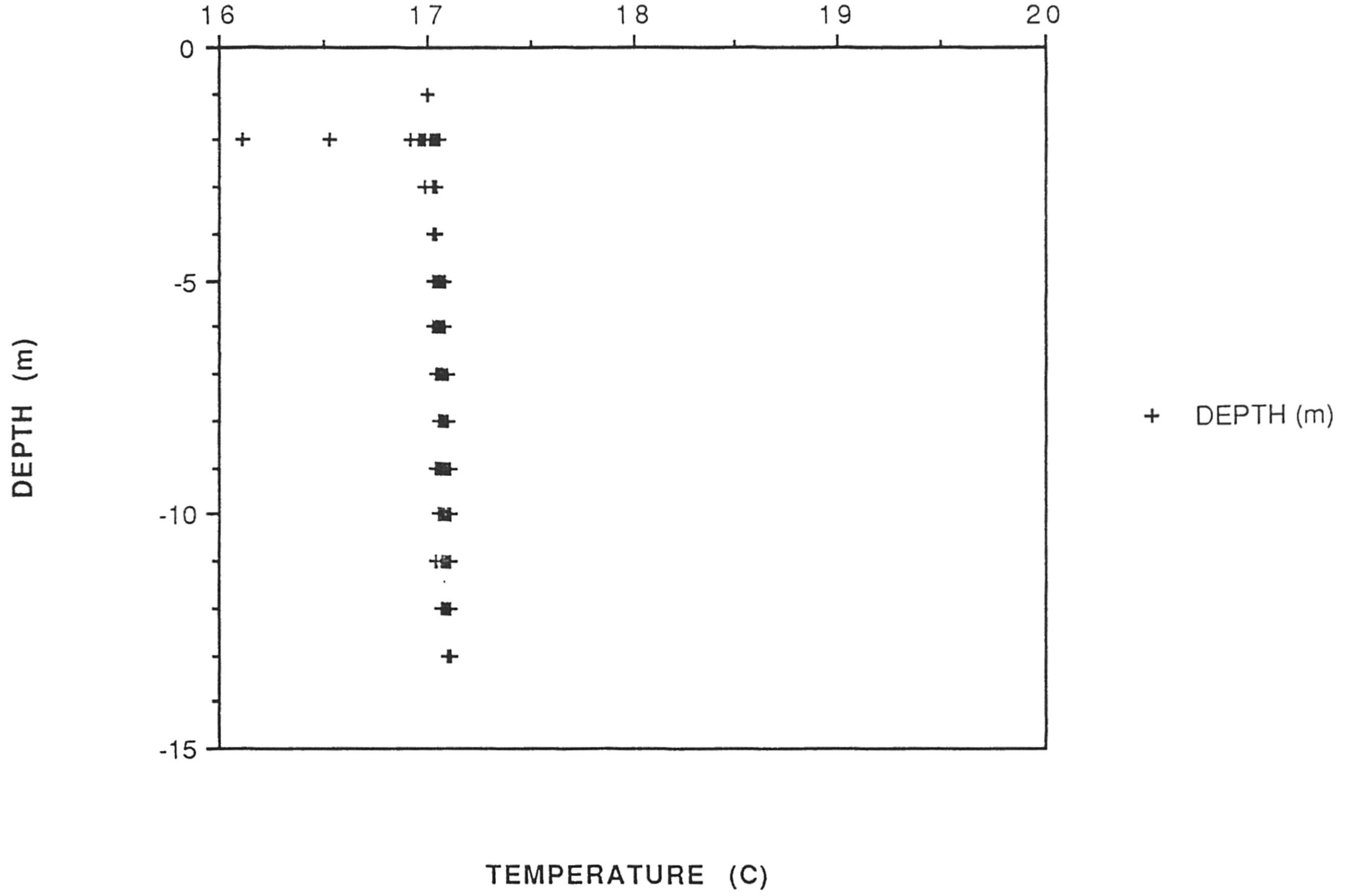


Fig. 13 Tow 4 Svz

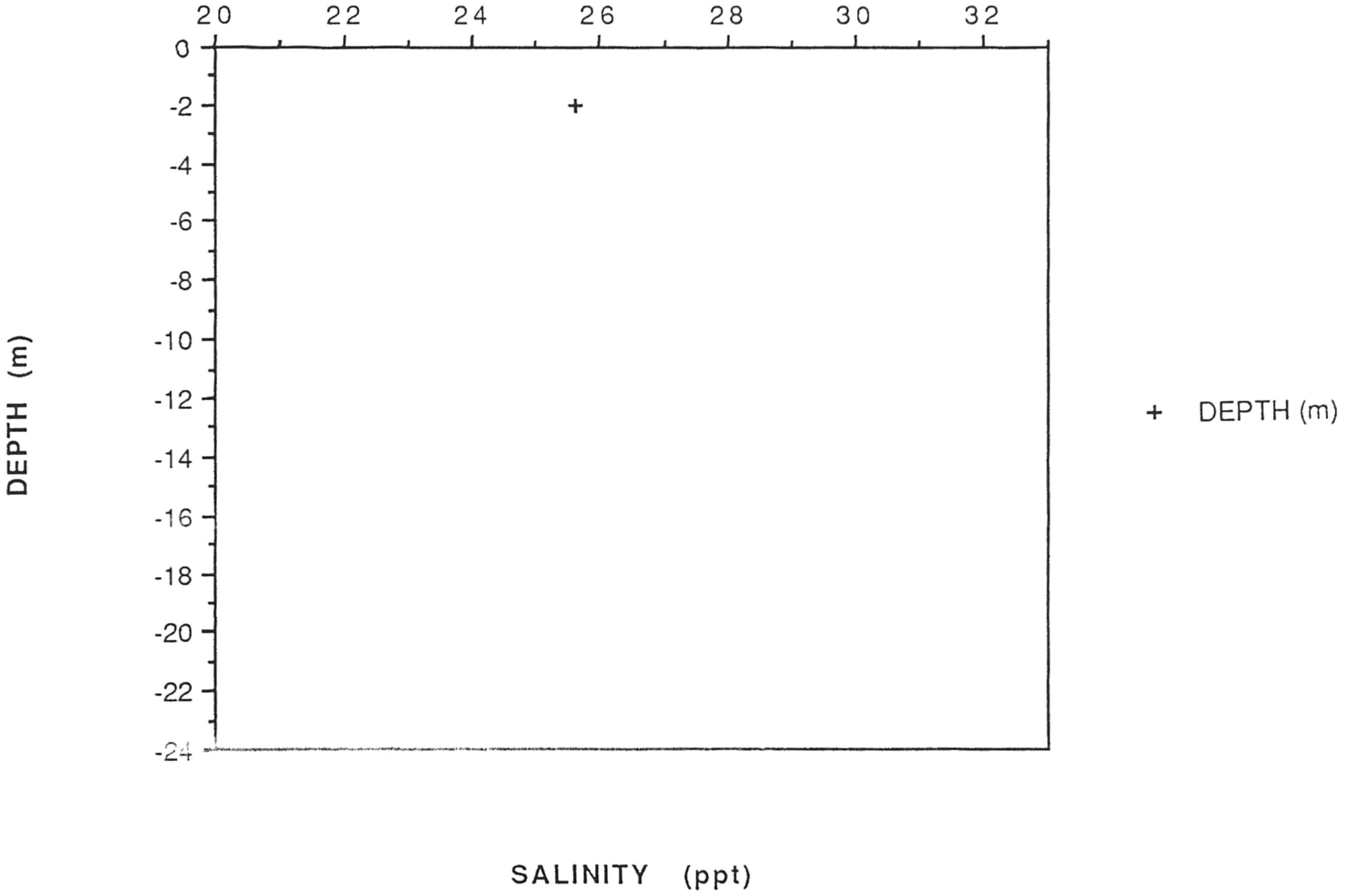


Fig. 14 Tow 4 TvZ

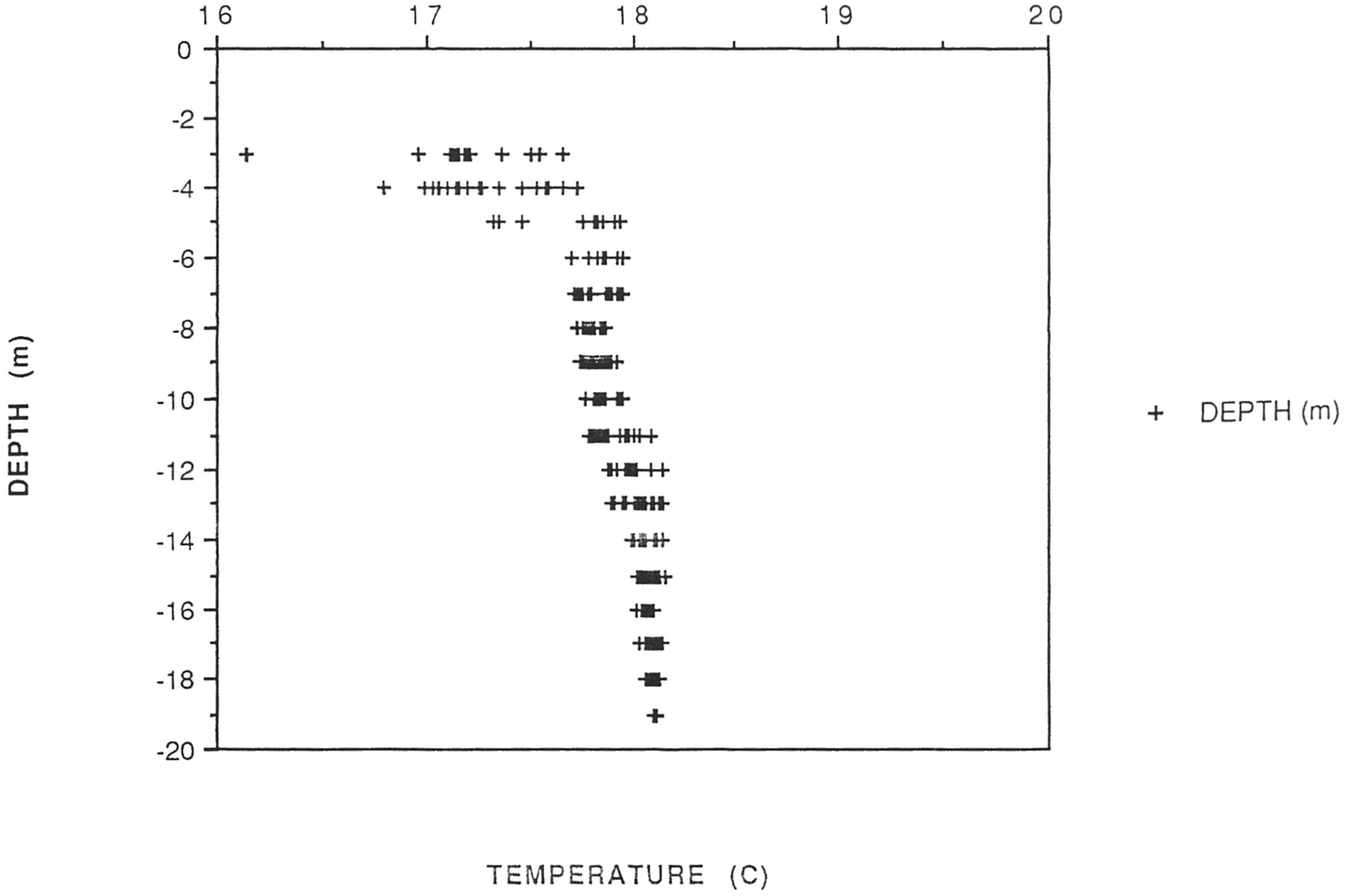


Fig. 15 Tow 5 SvZ

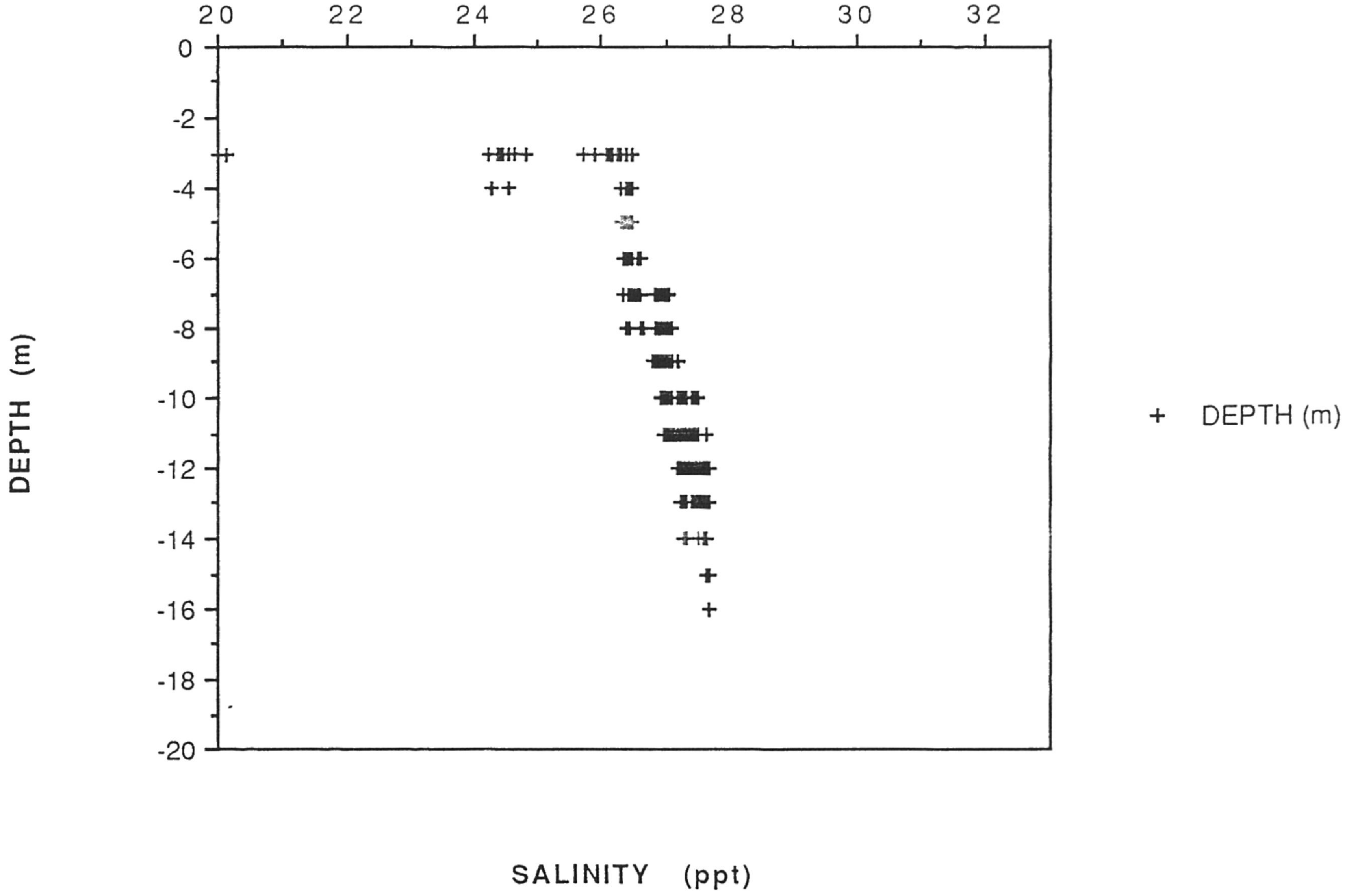
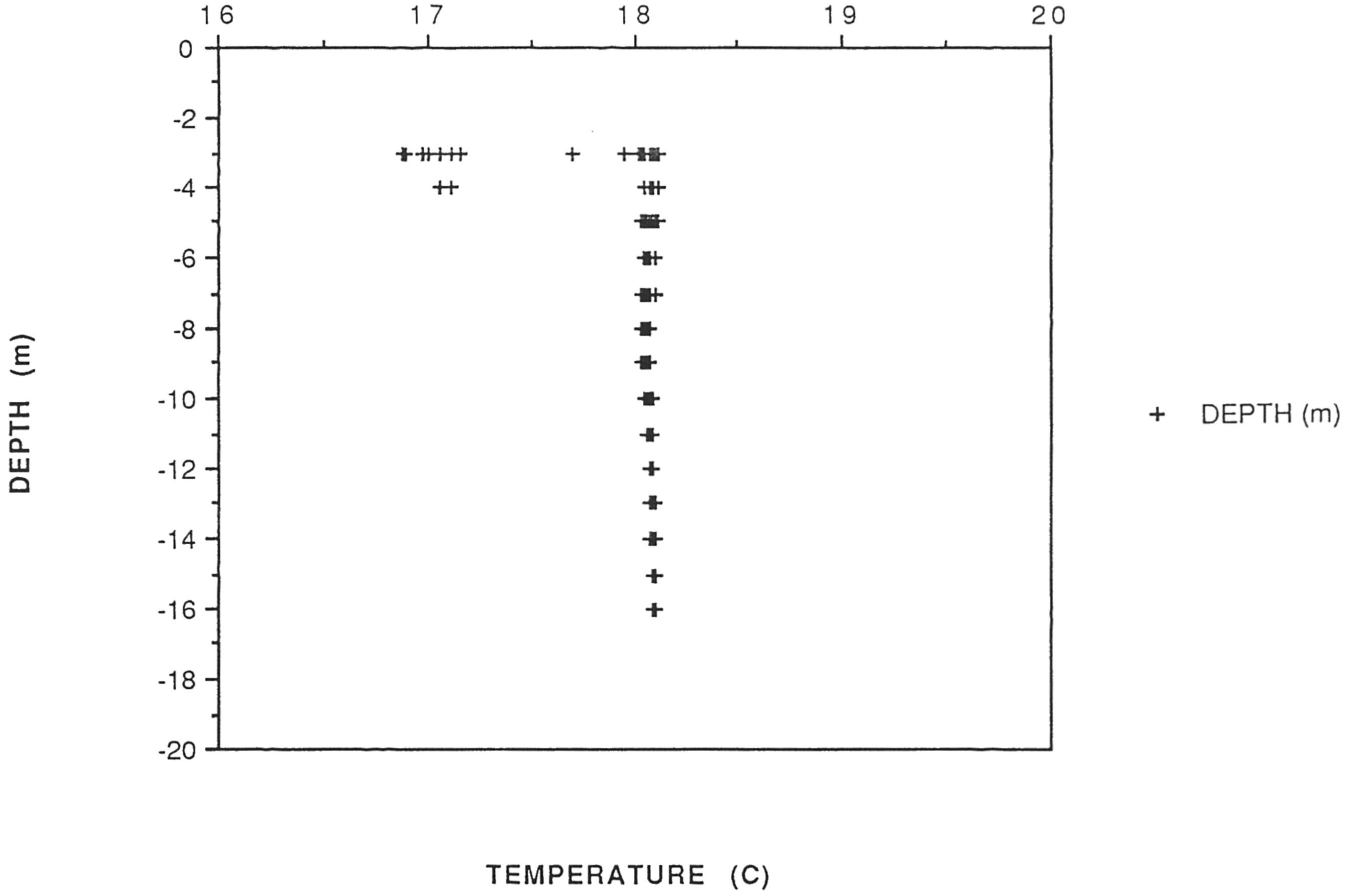


Fig. 16 Tow 5 TvZ



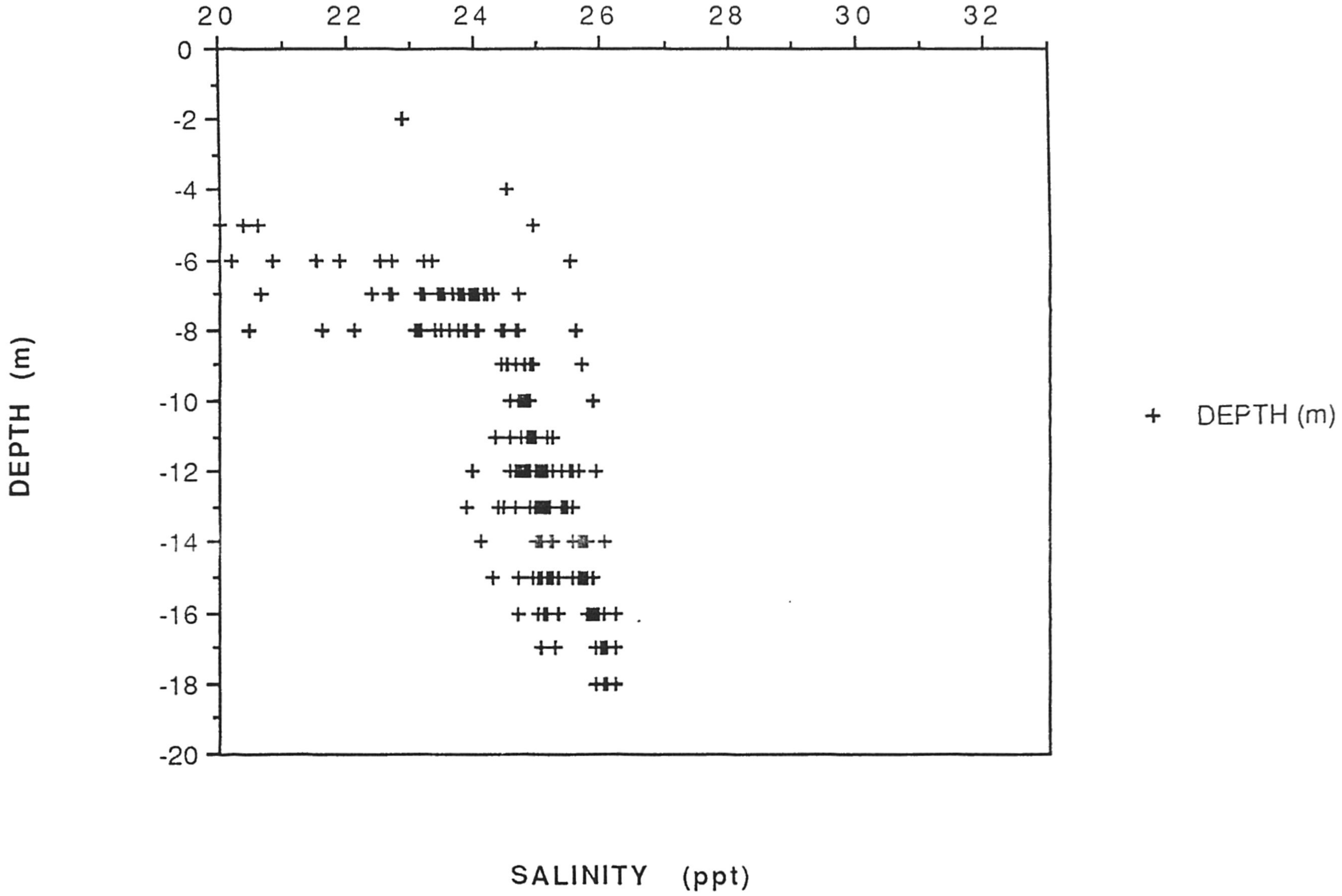


Fig. 17 Tow 6 SvZ

Fig. 18 Tow 6 TvZ

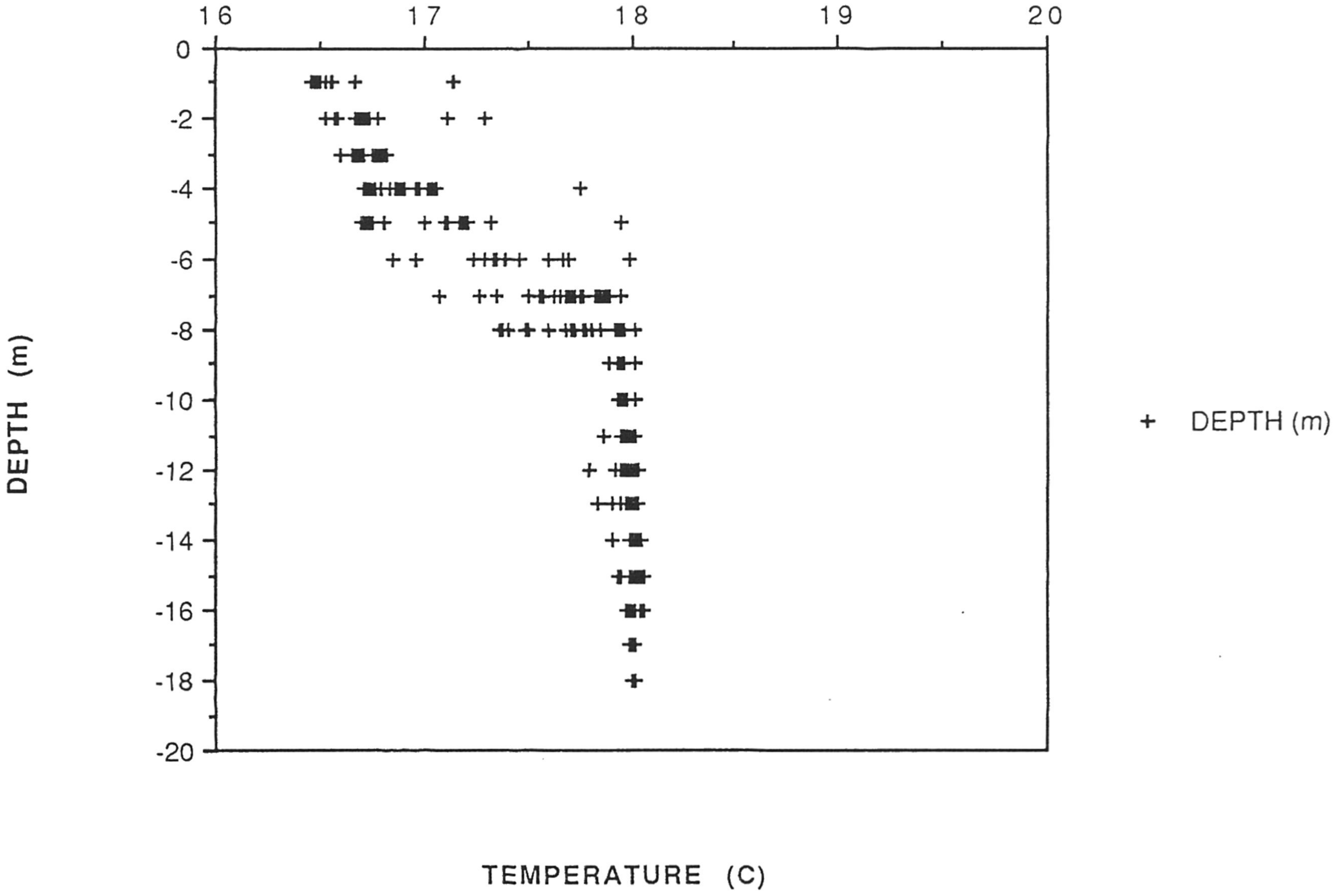


Fig. 19 Tow 7 SvZ

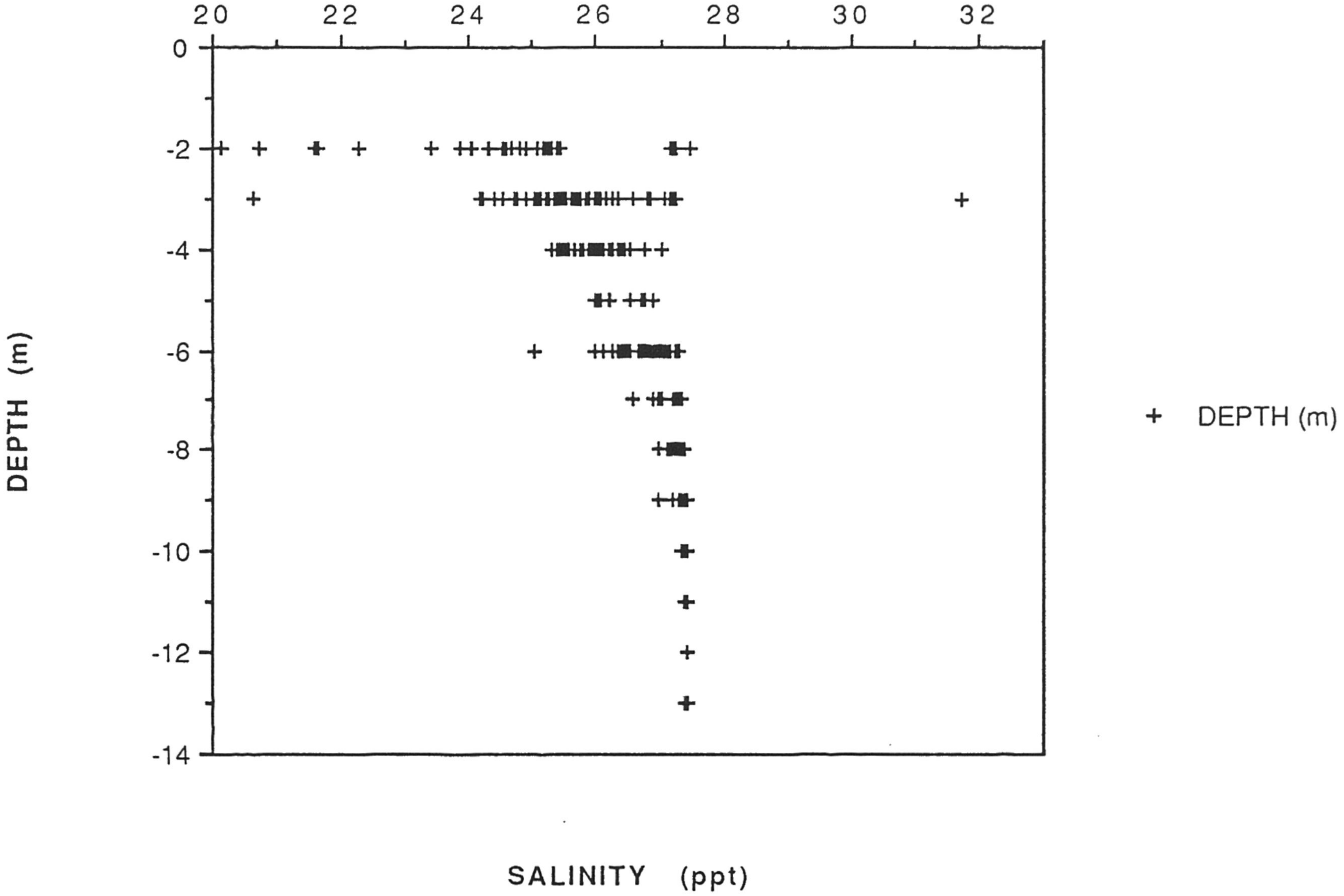


Fig. 20 Tow 7 TvZ

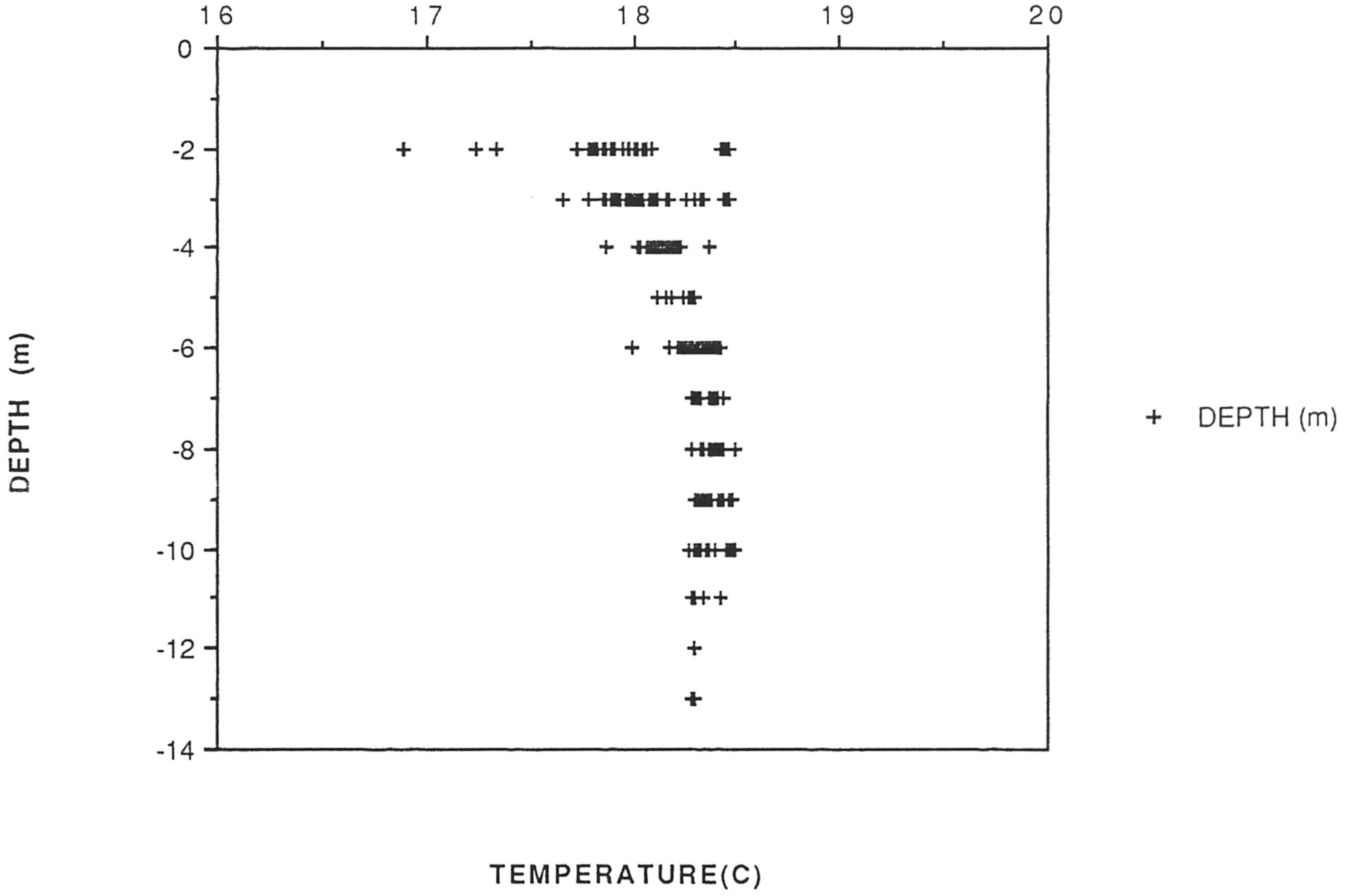


Fig. 21 Tow 8 SvZ

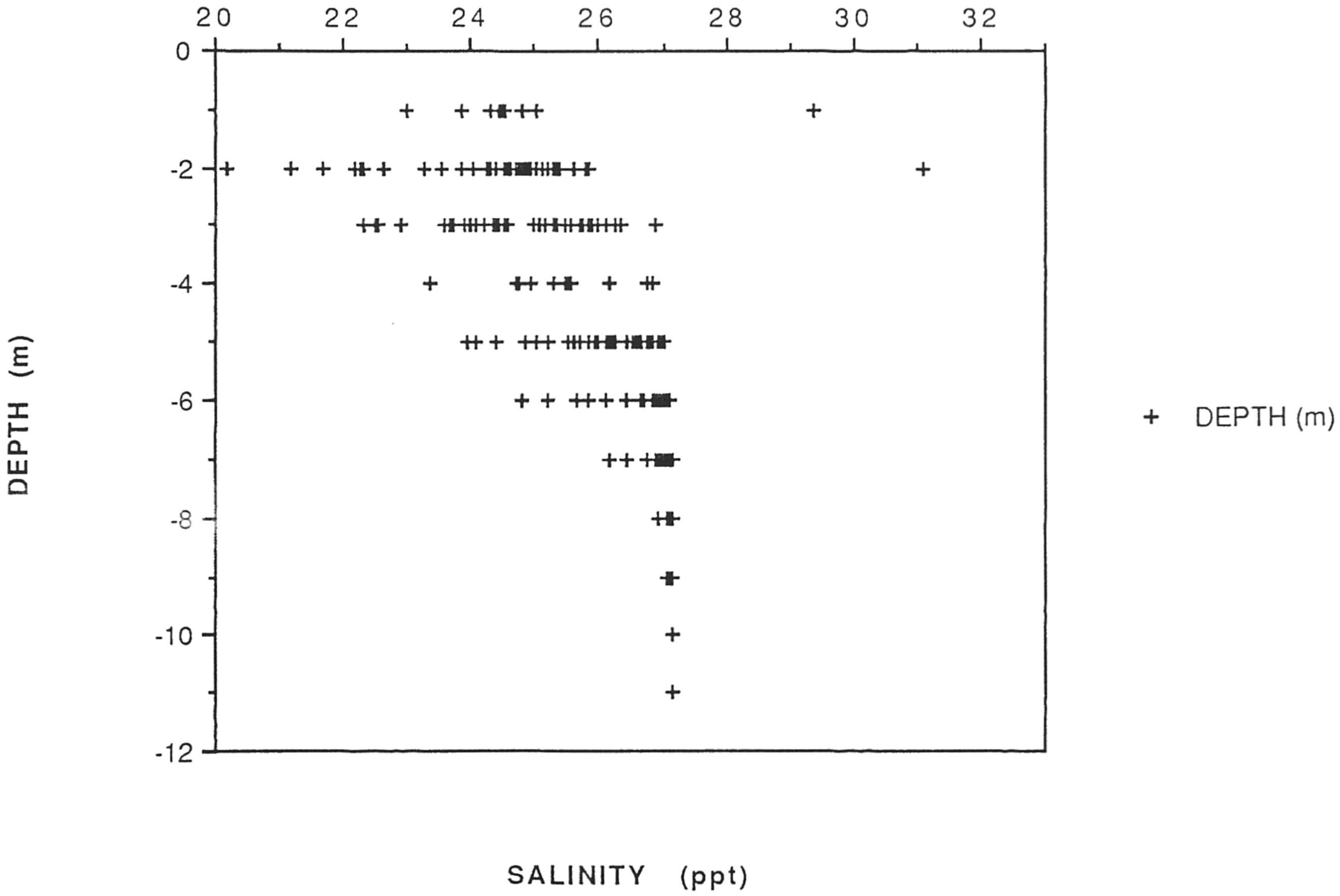


Fig. 22 Tow 8 TvZ

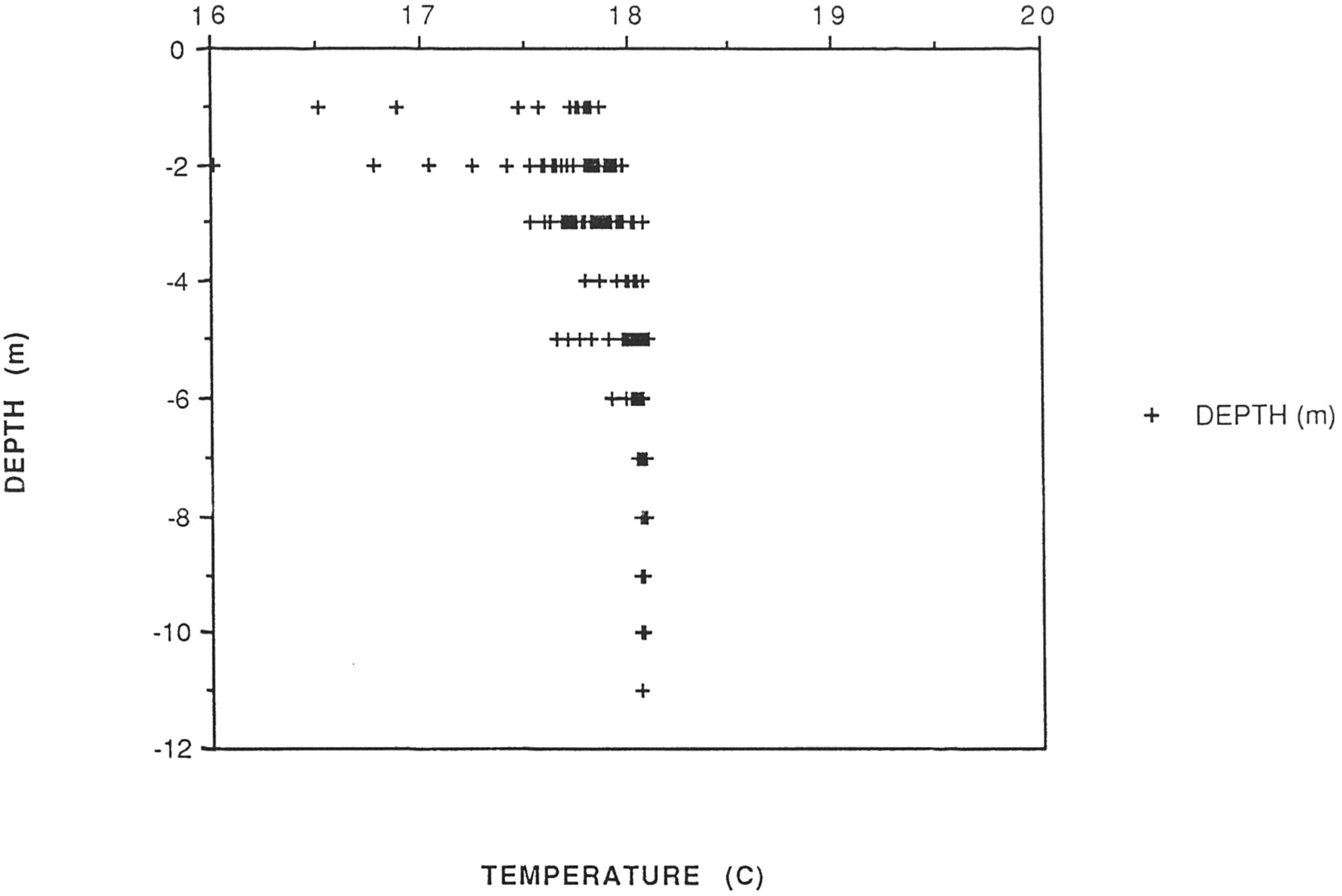


Fig. 23 Tow 10 SvZ

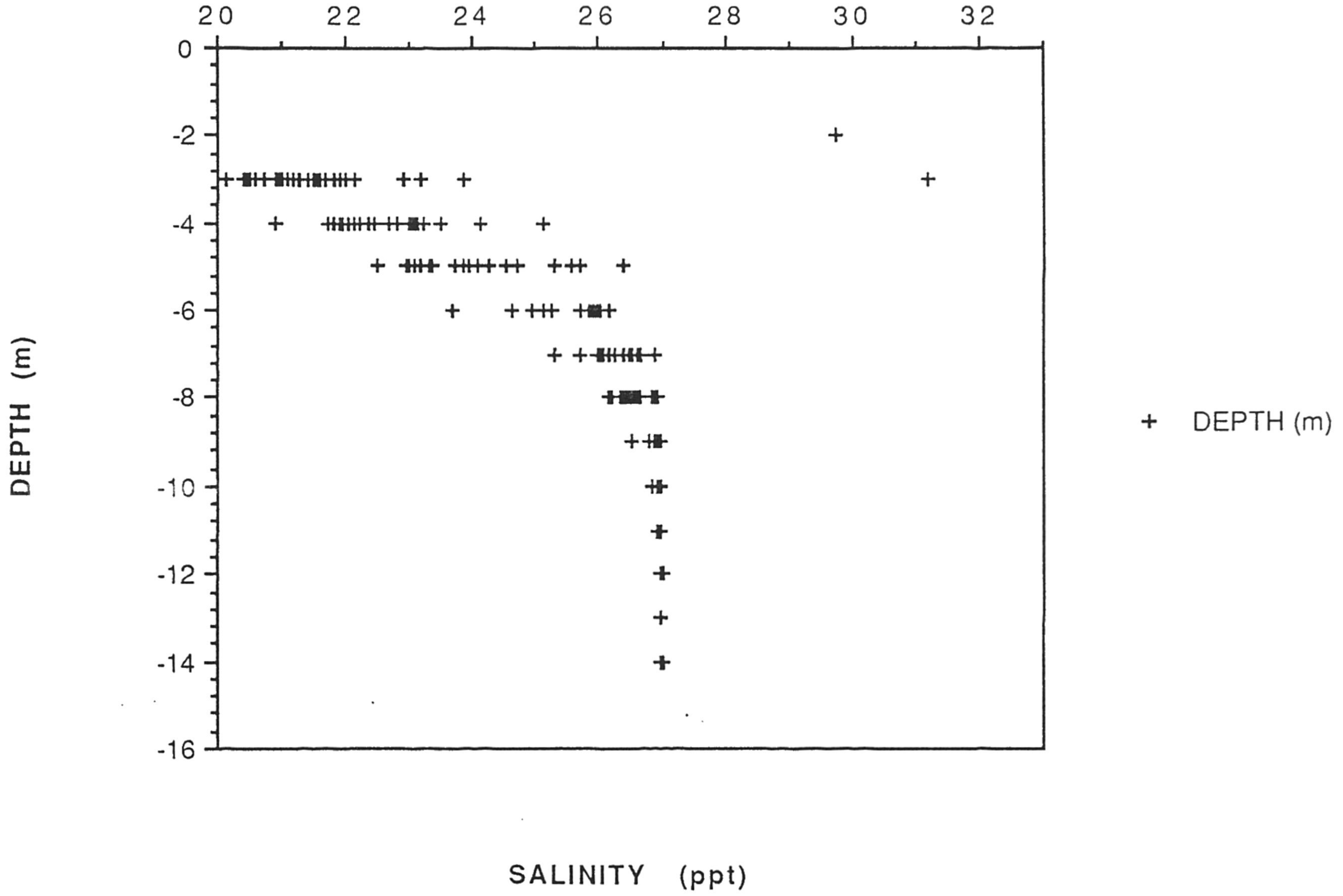


Fig. 24 Tow 10 TvZ

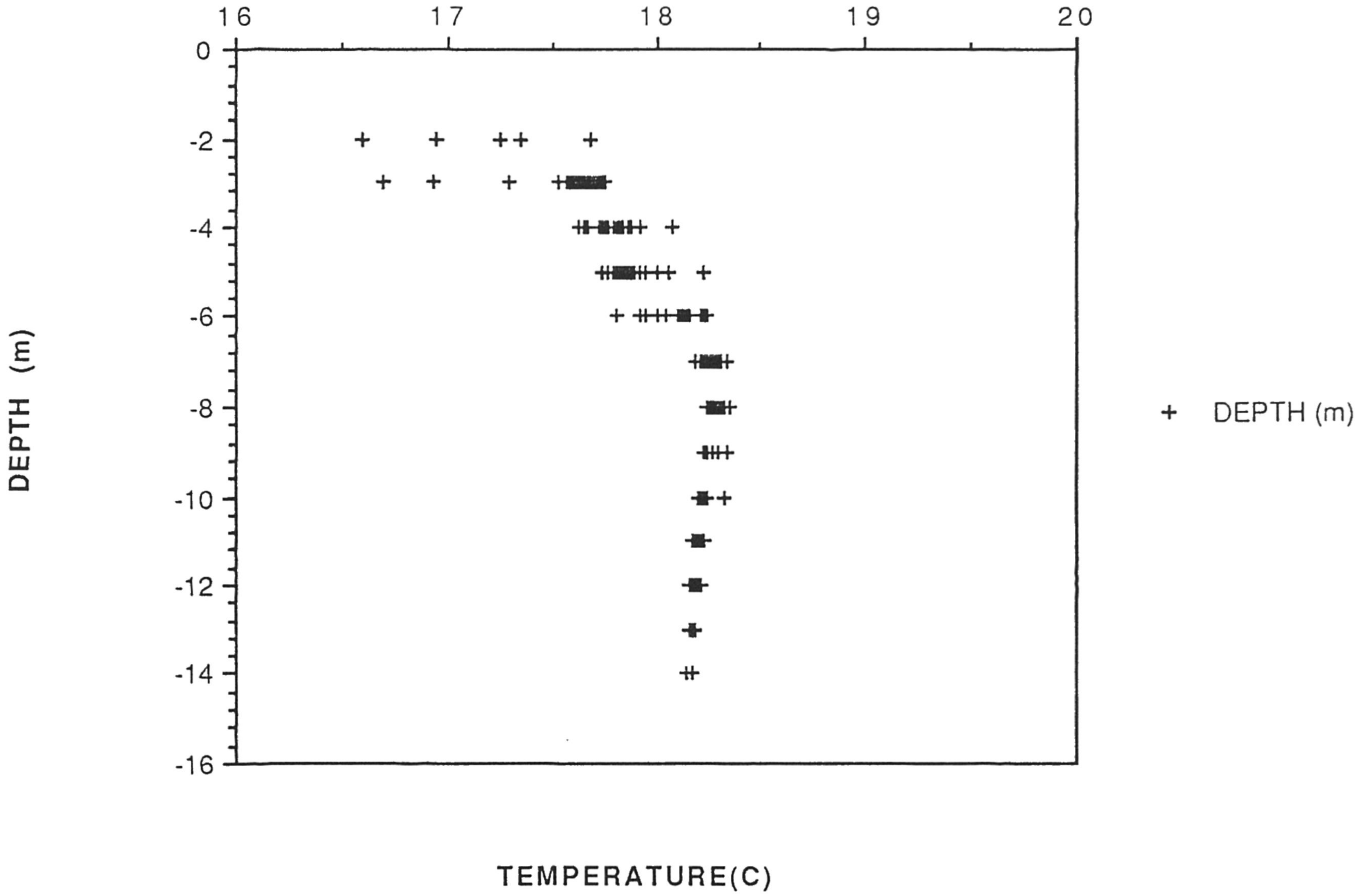


Fig. 25 Tow 11 SvZ

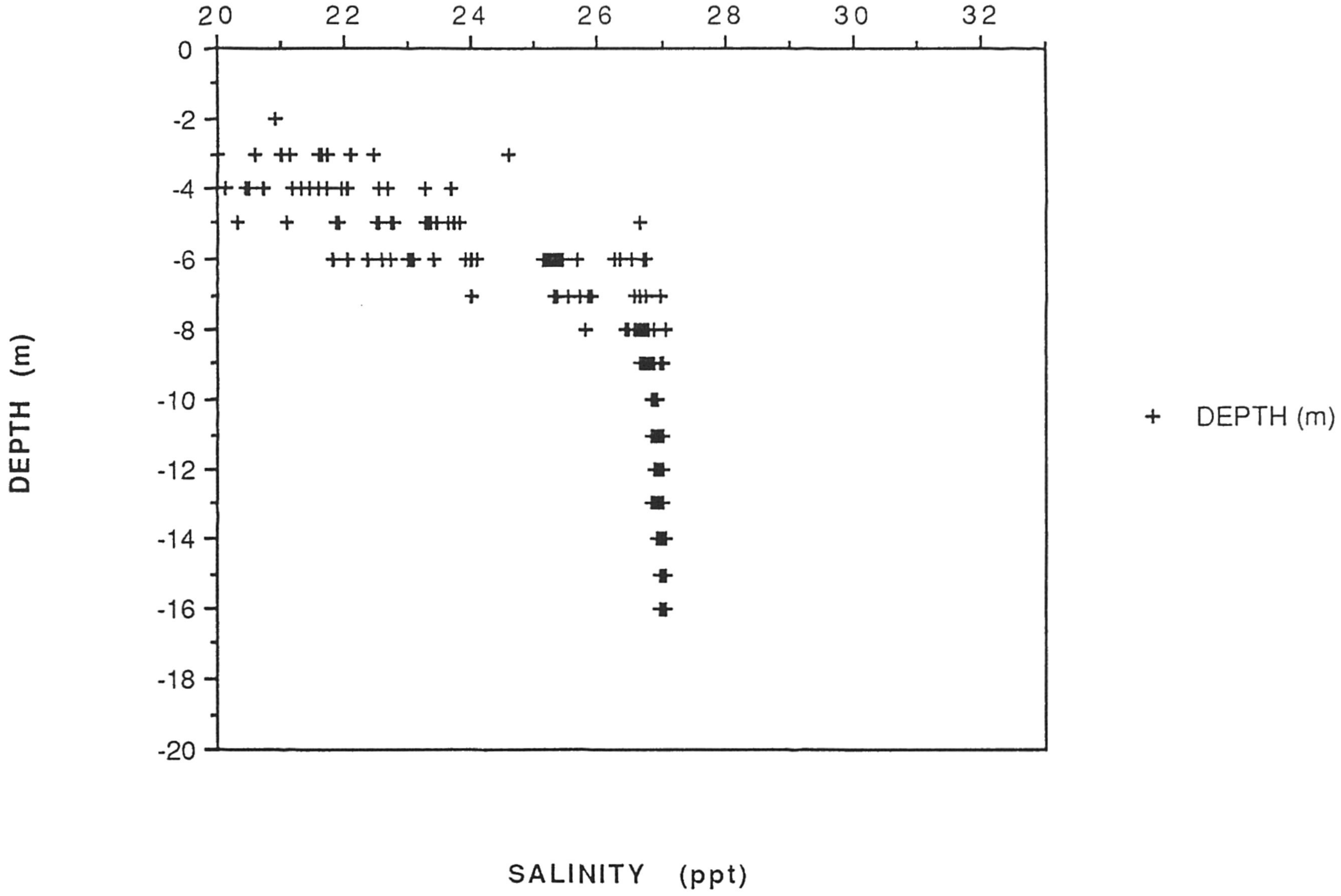


Fig. 26 Tow 11 TvZ

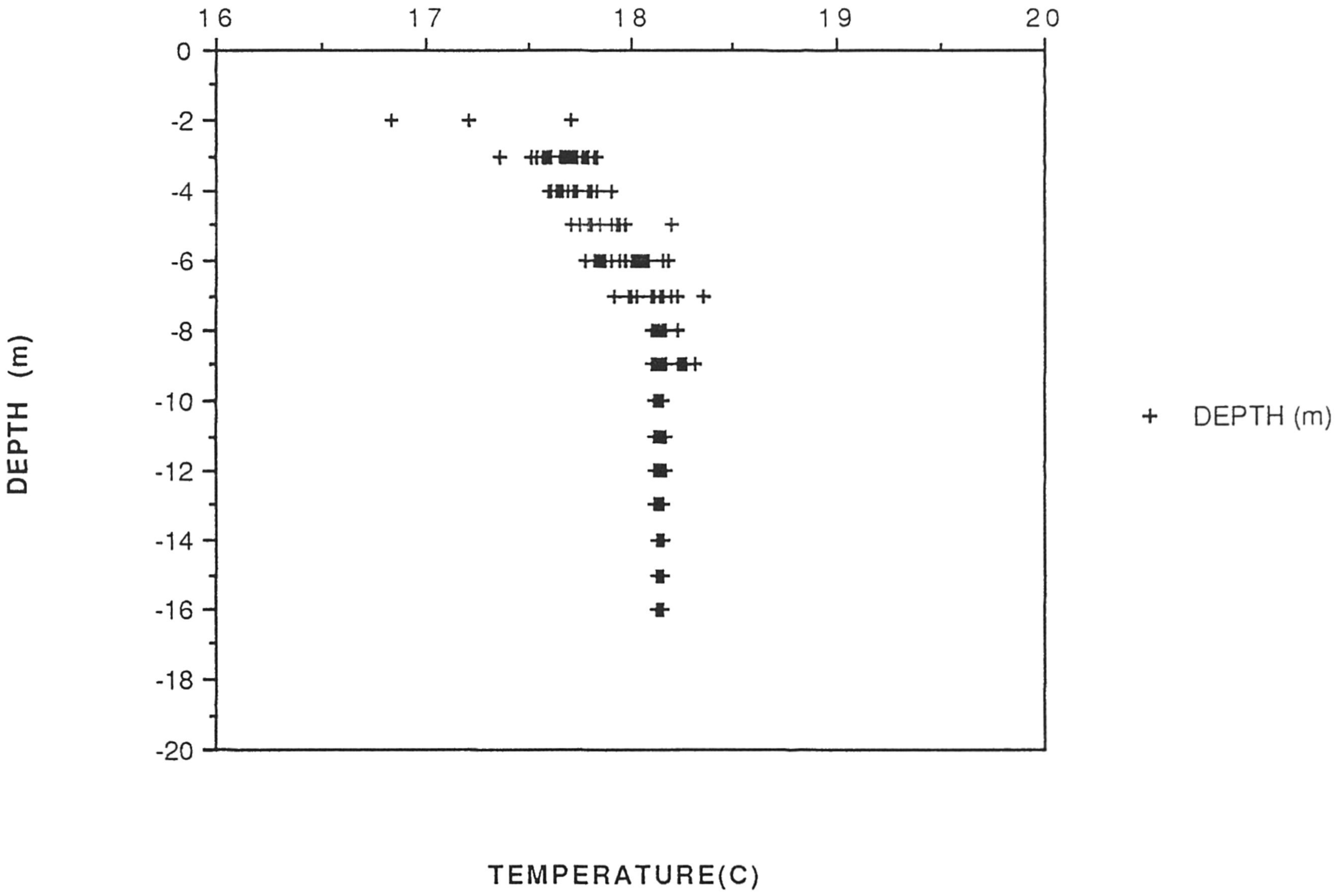


Fig. 27 Tow 12 SvZ

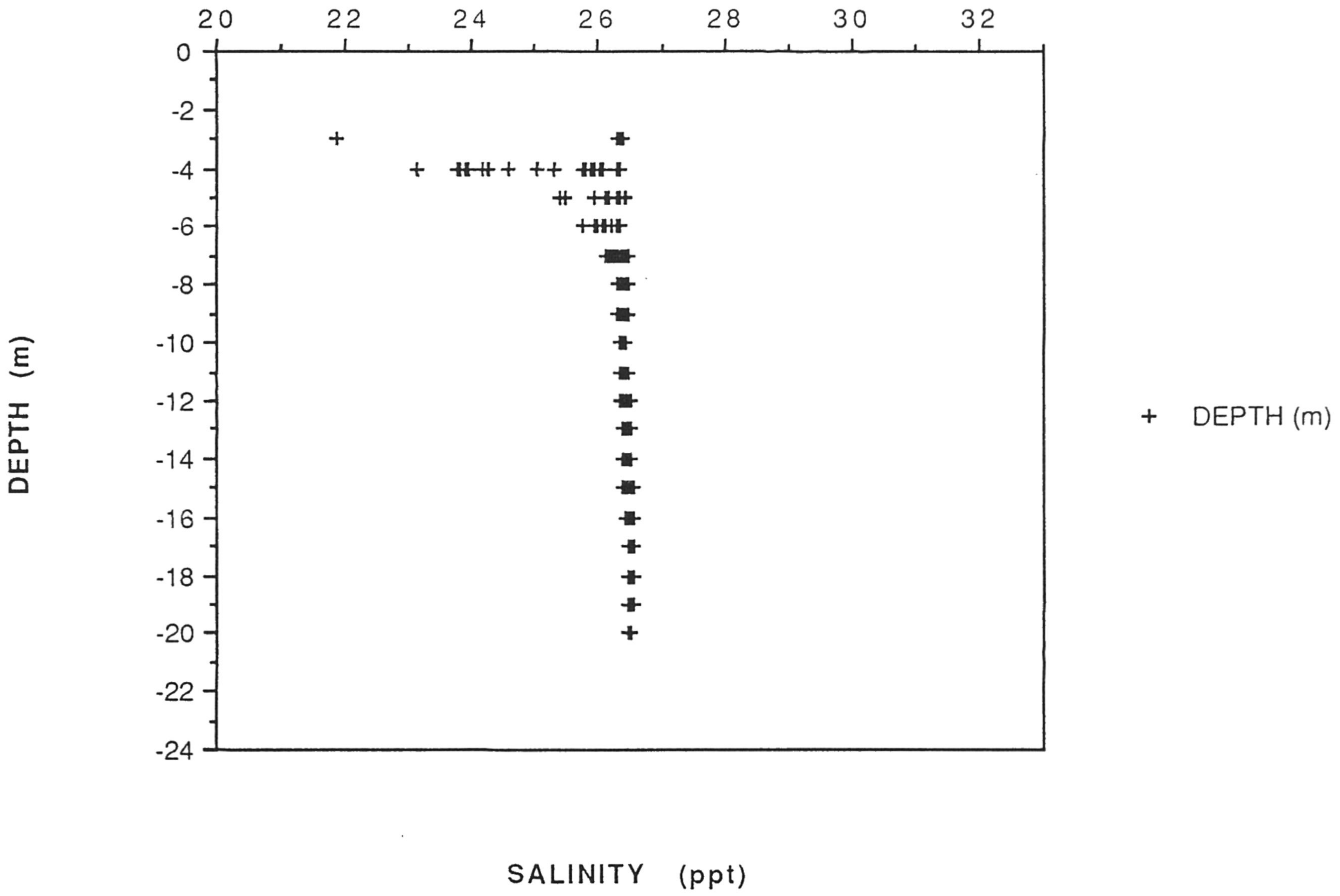


Fig. 28 Tow 12 TvZ

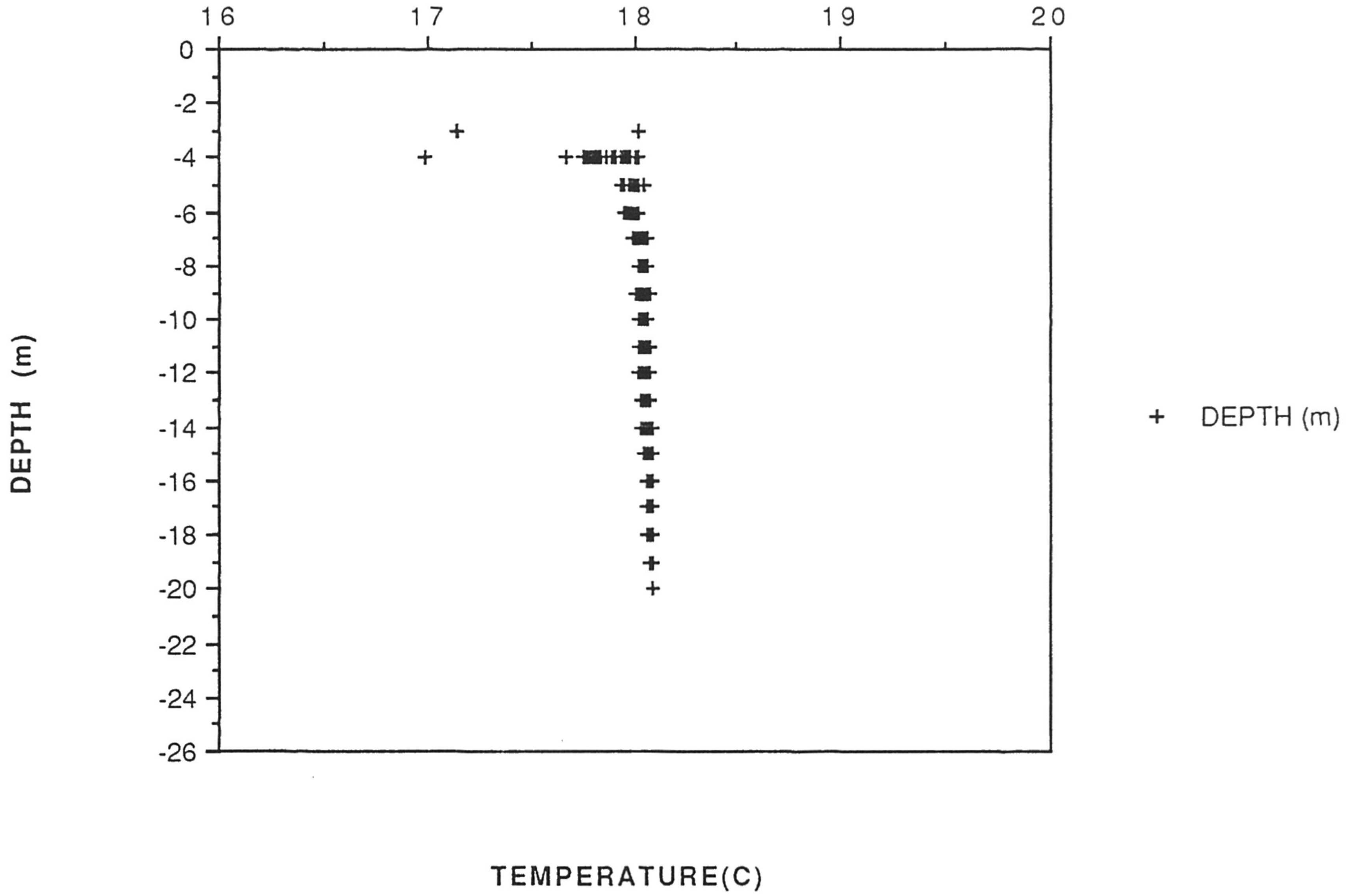


Fig. 29 Tow 13 SvZ

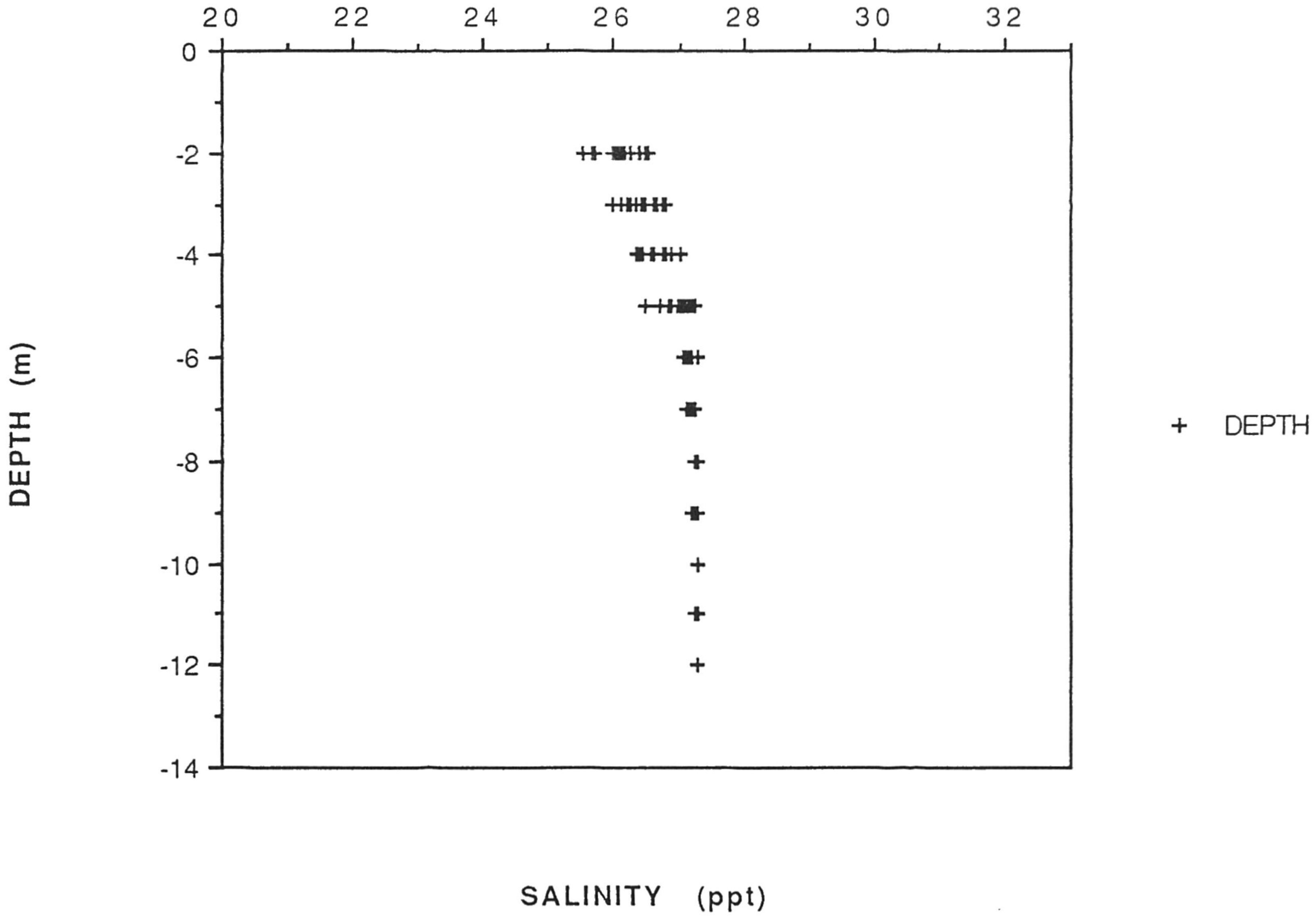


Fig. 30 Tow 13 TvZ

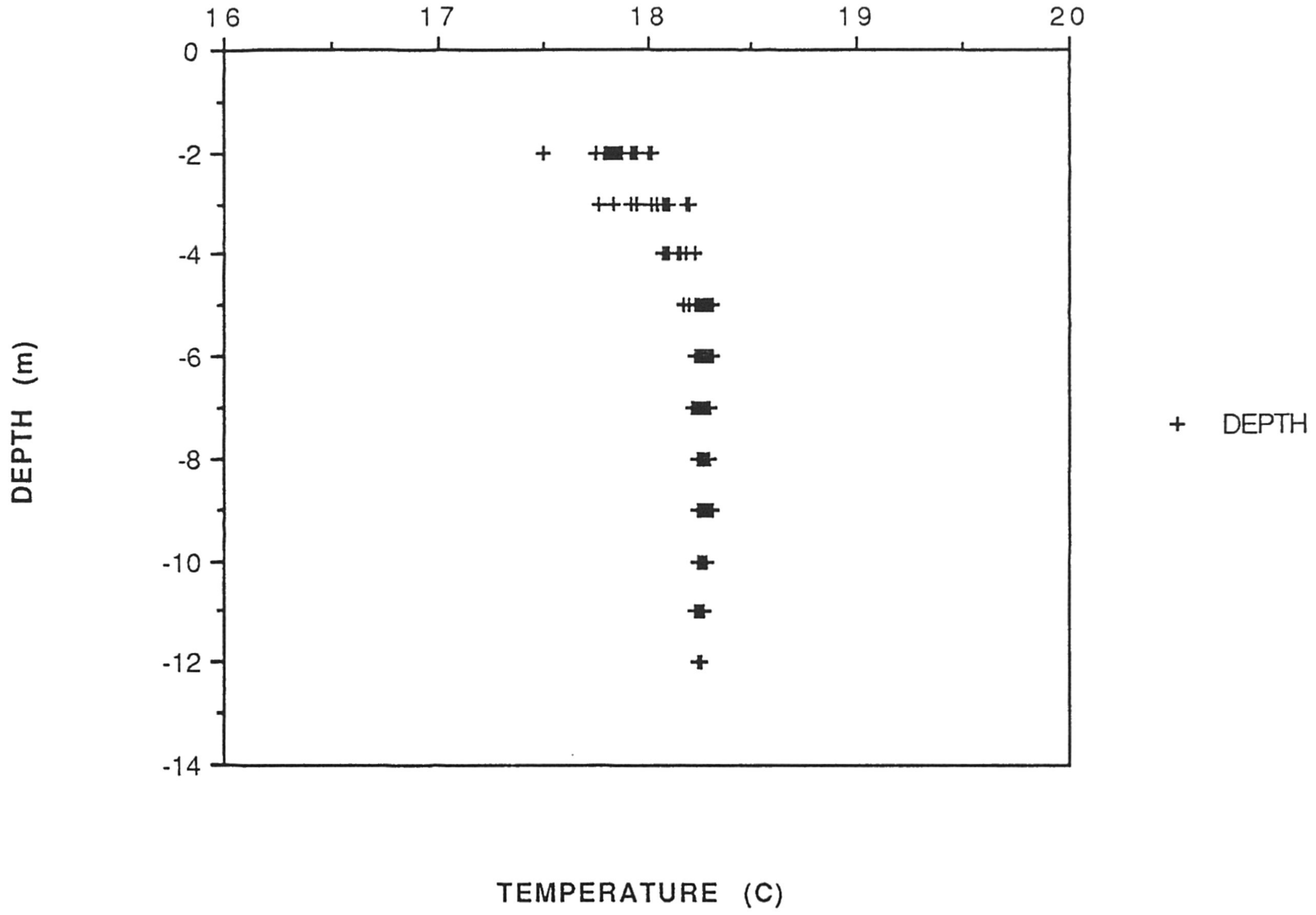


Fig. 31 Tow 14 SvZ

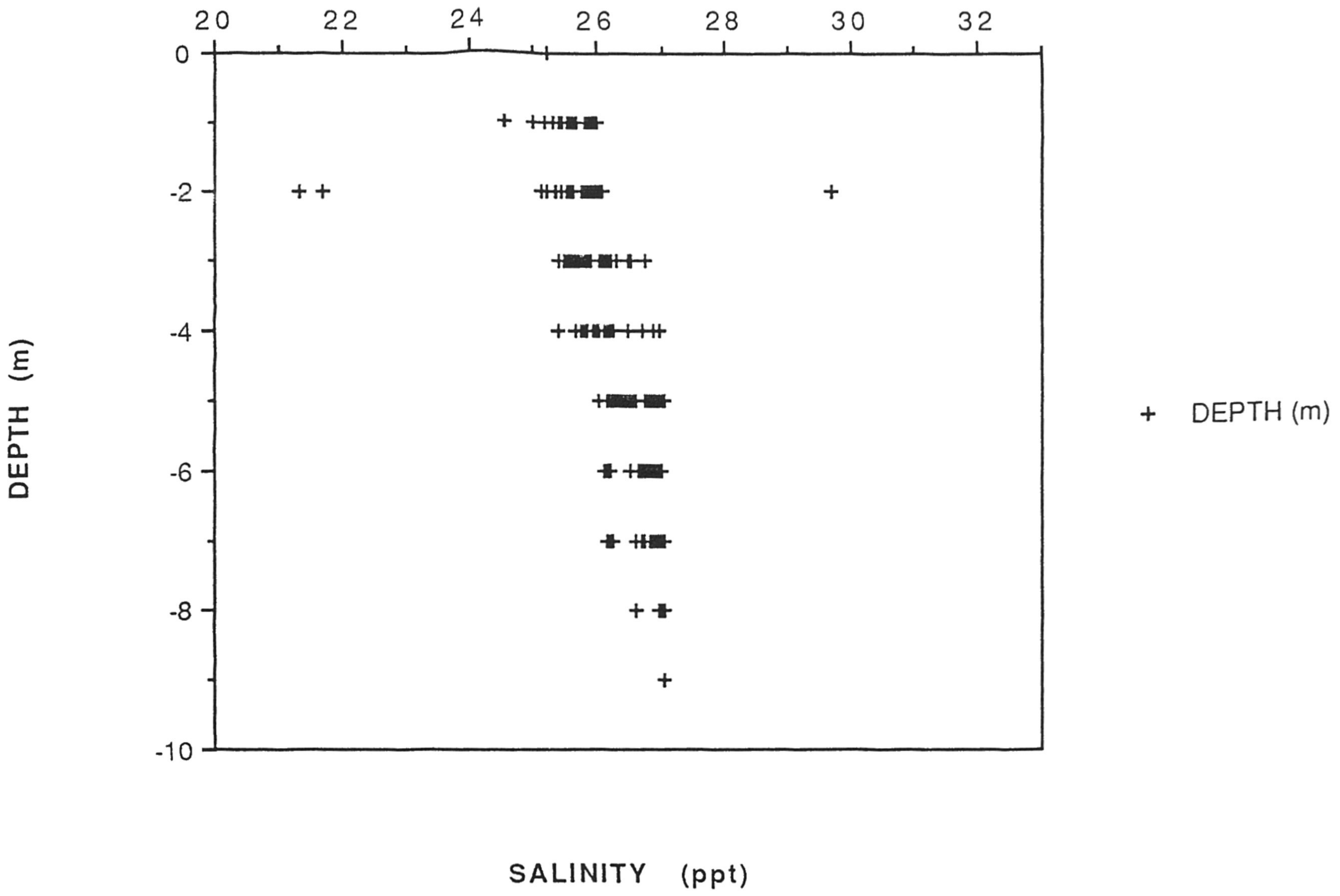


Fig. 32 Tow 14 TvZ

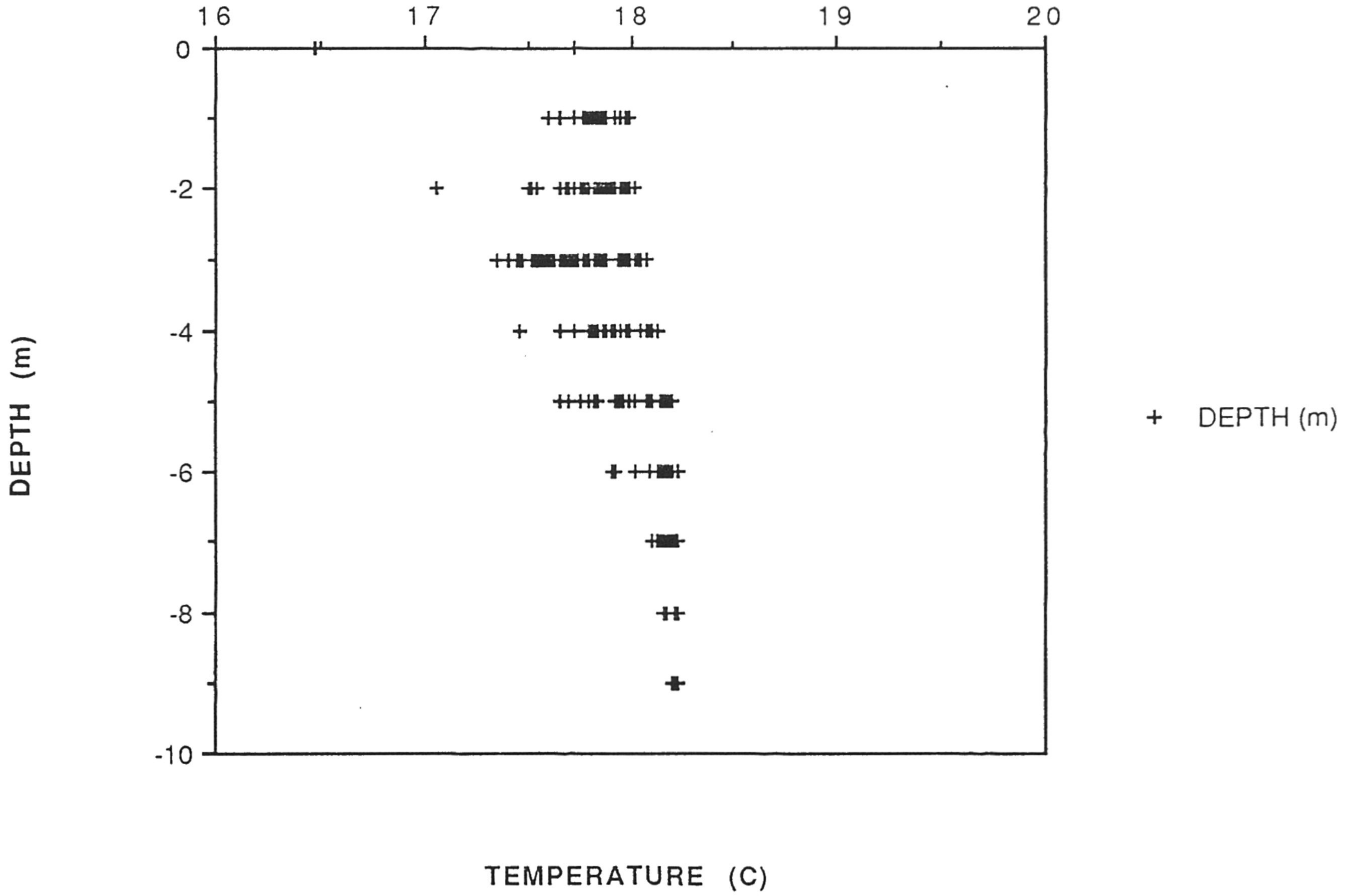


Fig. 33 Tow 15 SvZ

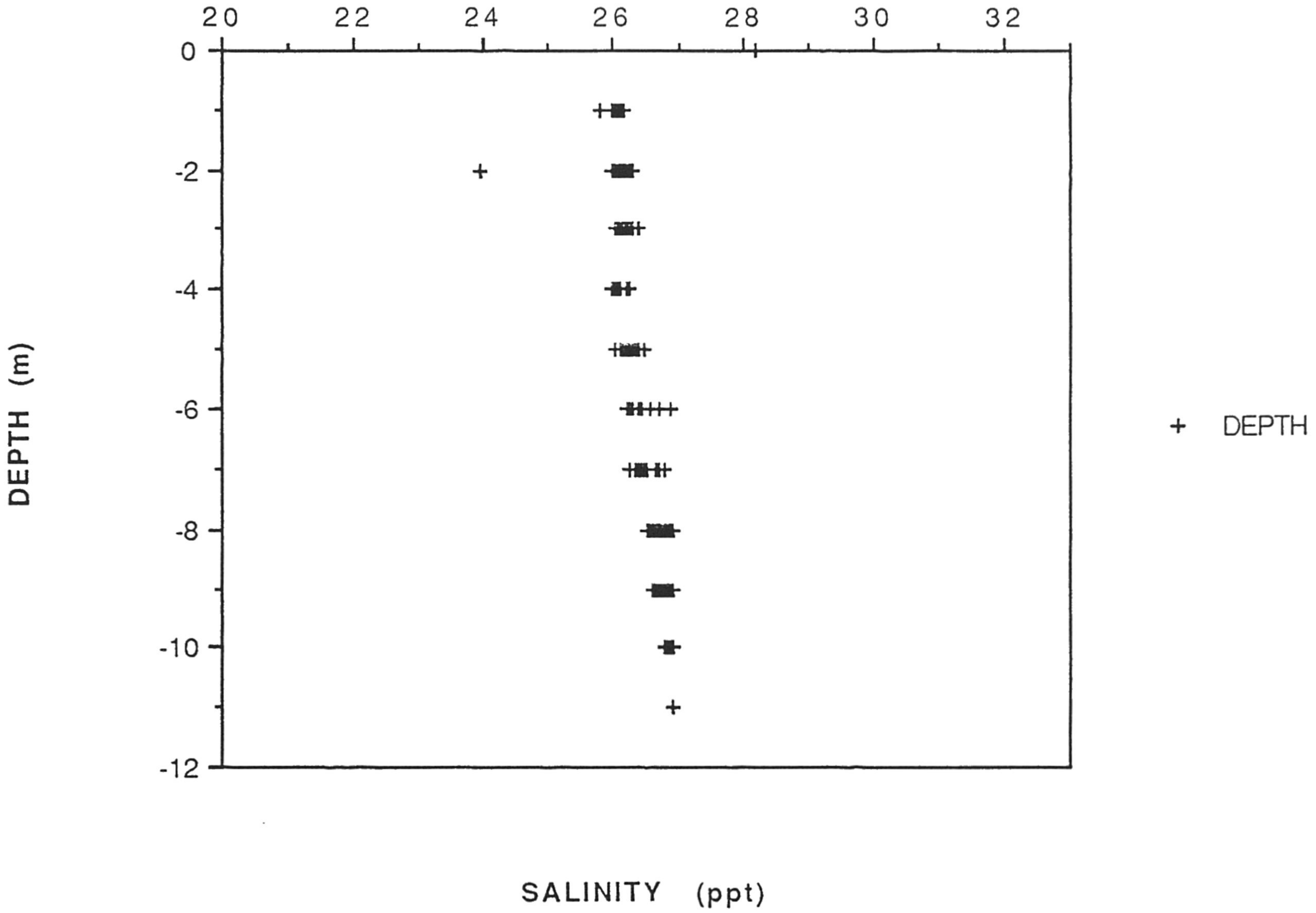


Fig. 34 Tow 15 TvZ

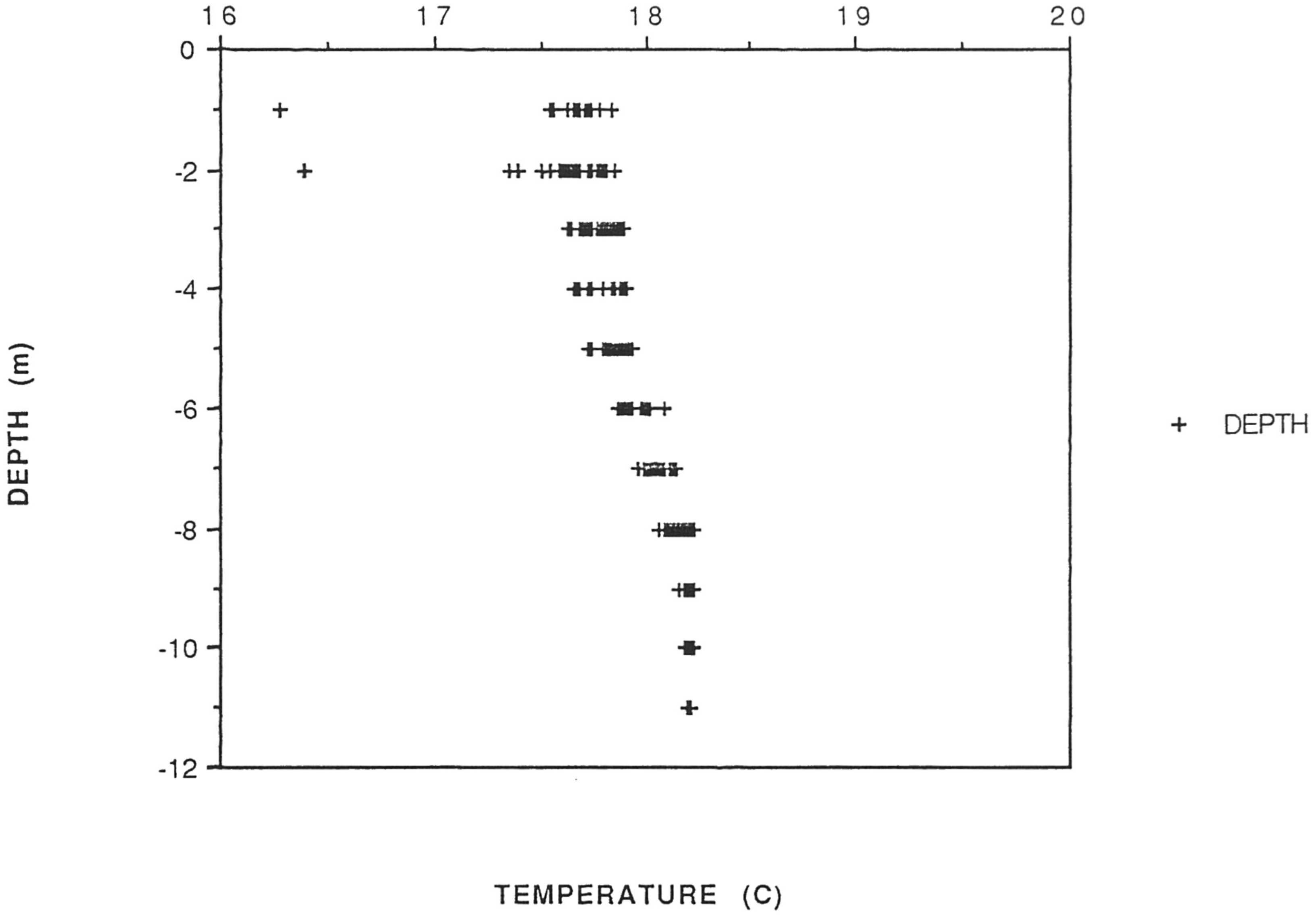


Fig. 35 Tow 16 SvZ

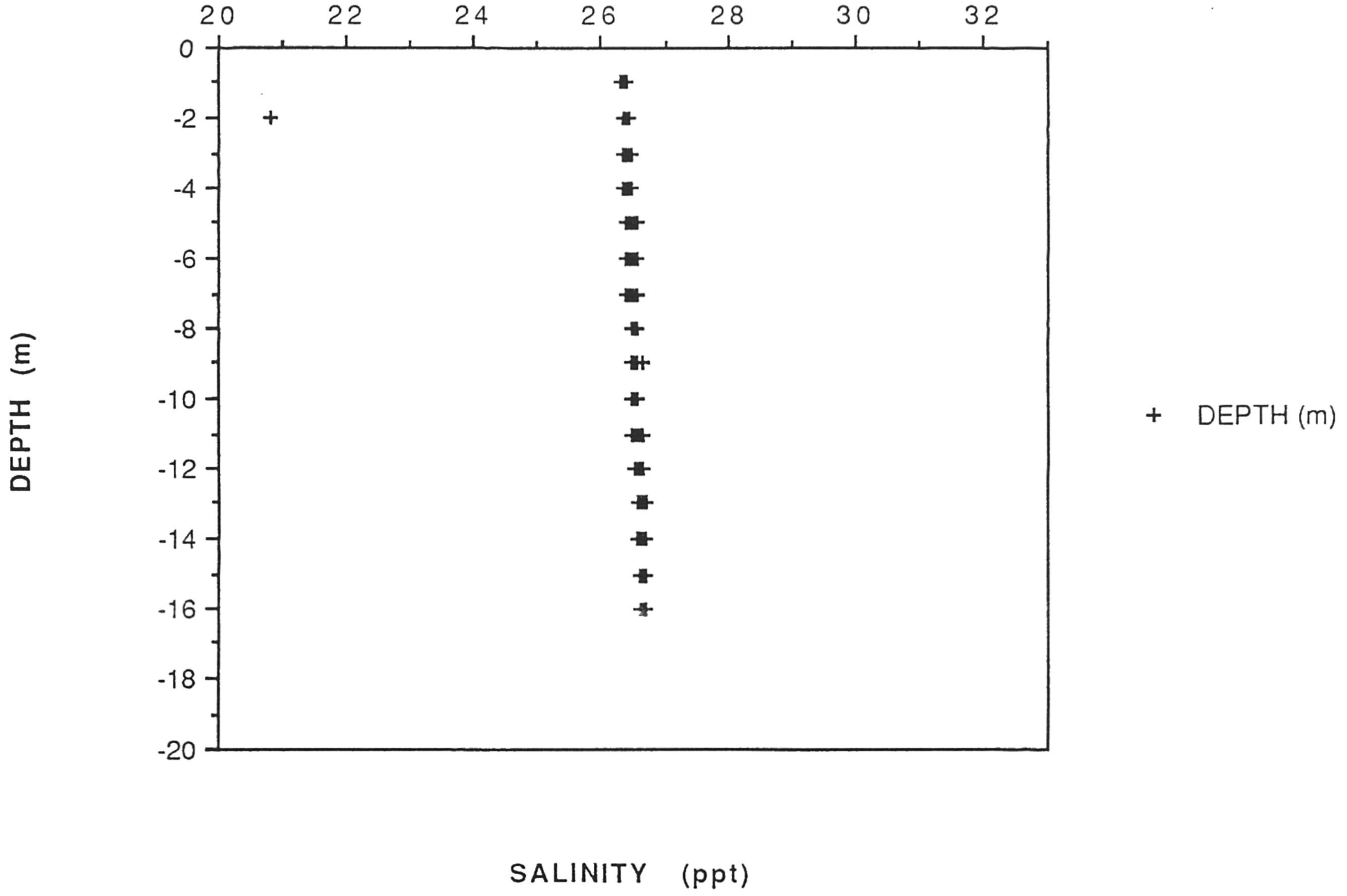


Fig. 36 Tow 16 TvZ

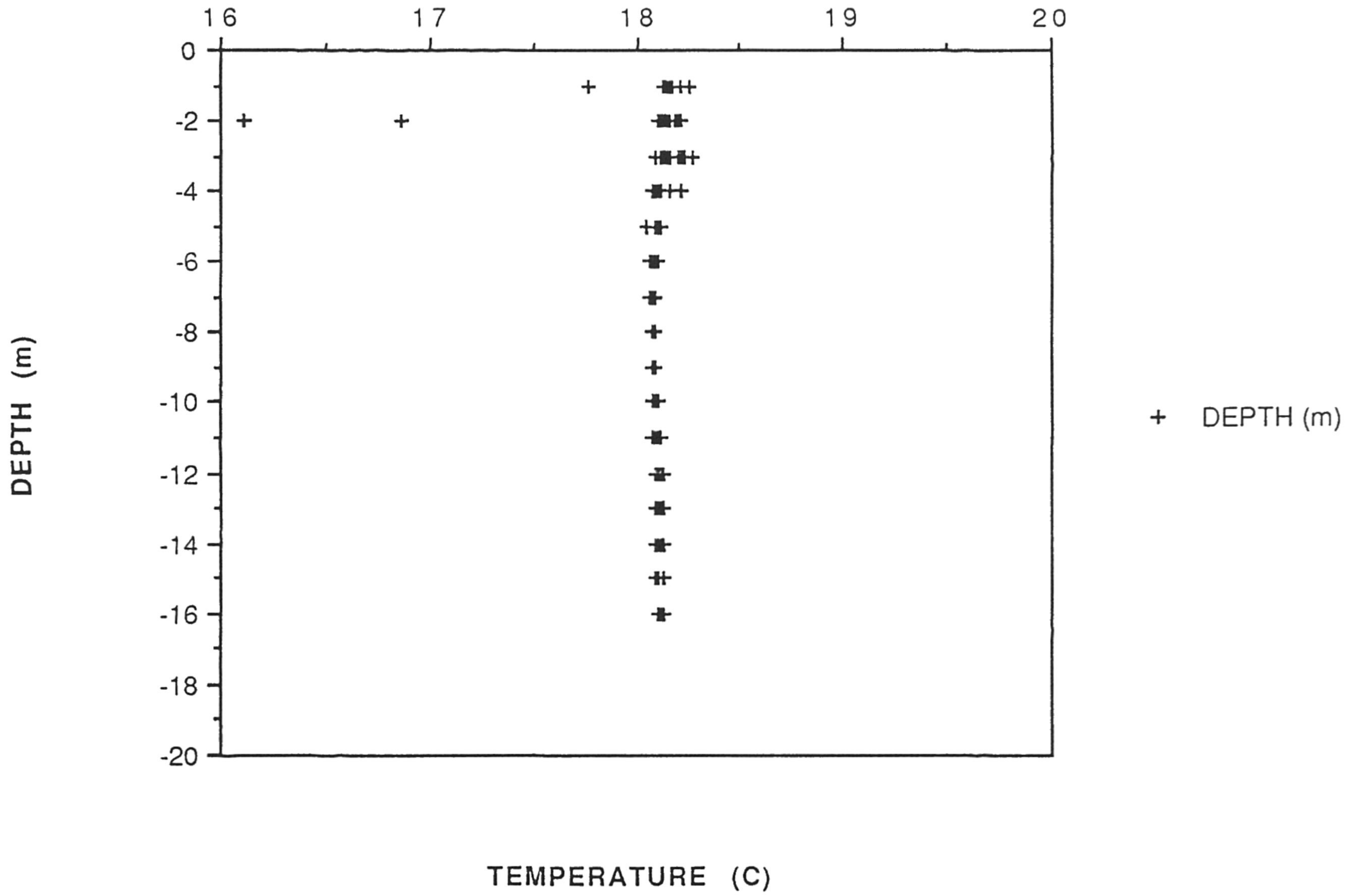


Fig. 37 Tow 17 SvZ

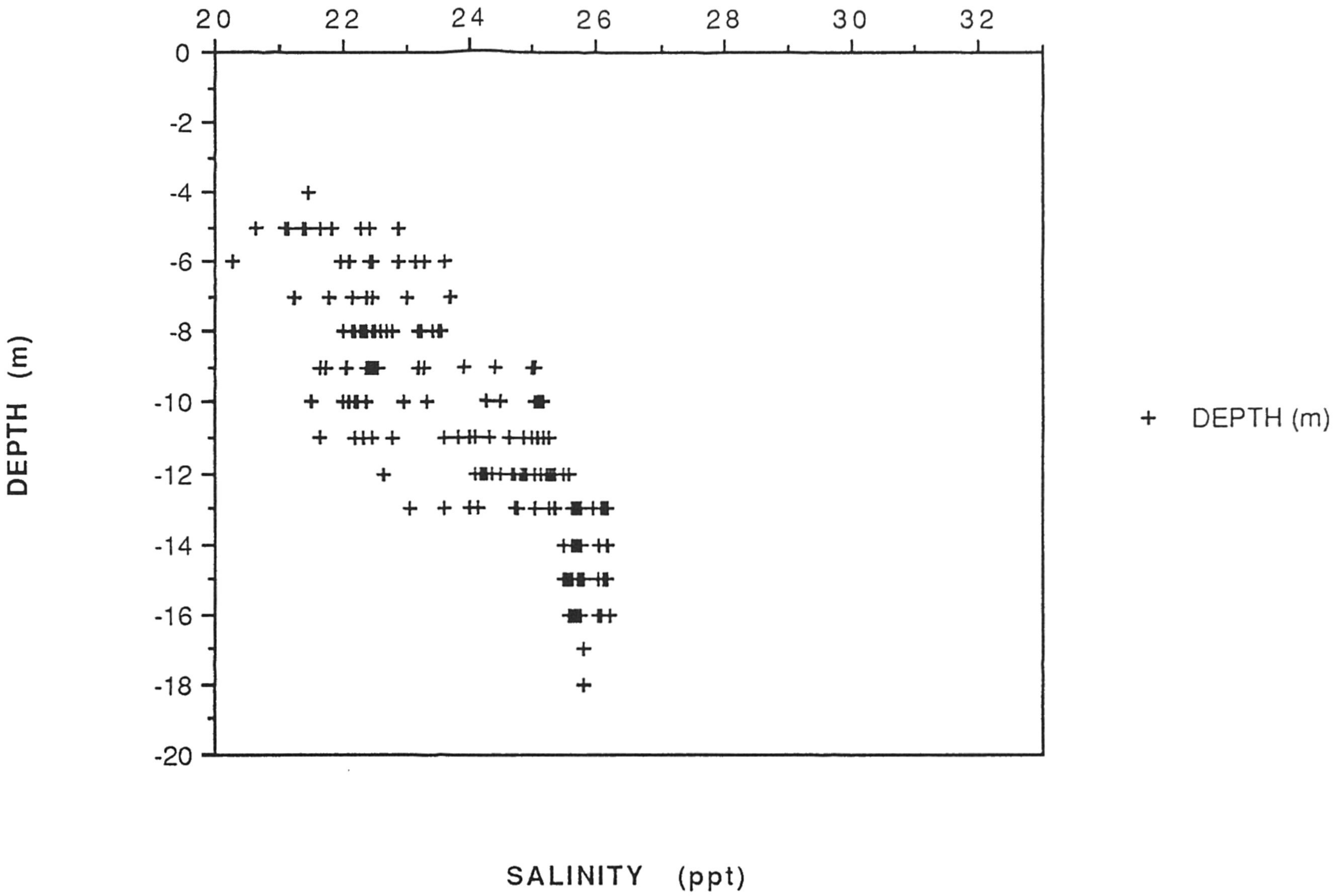


Fig. 38 Tow 17 TvZ

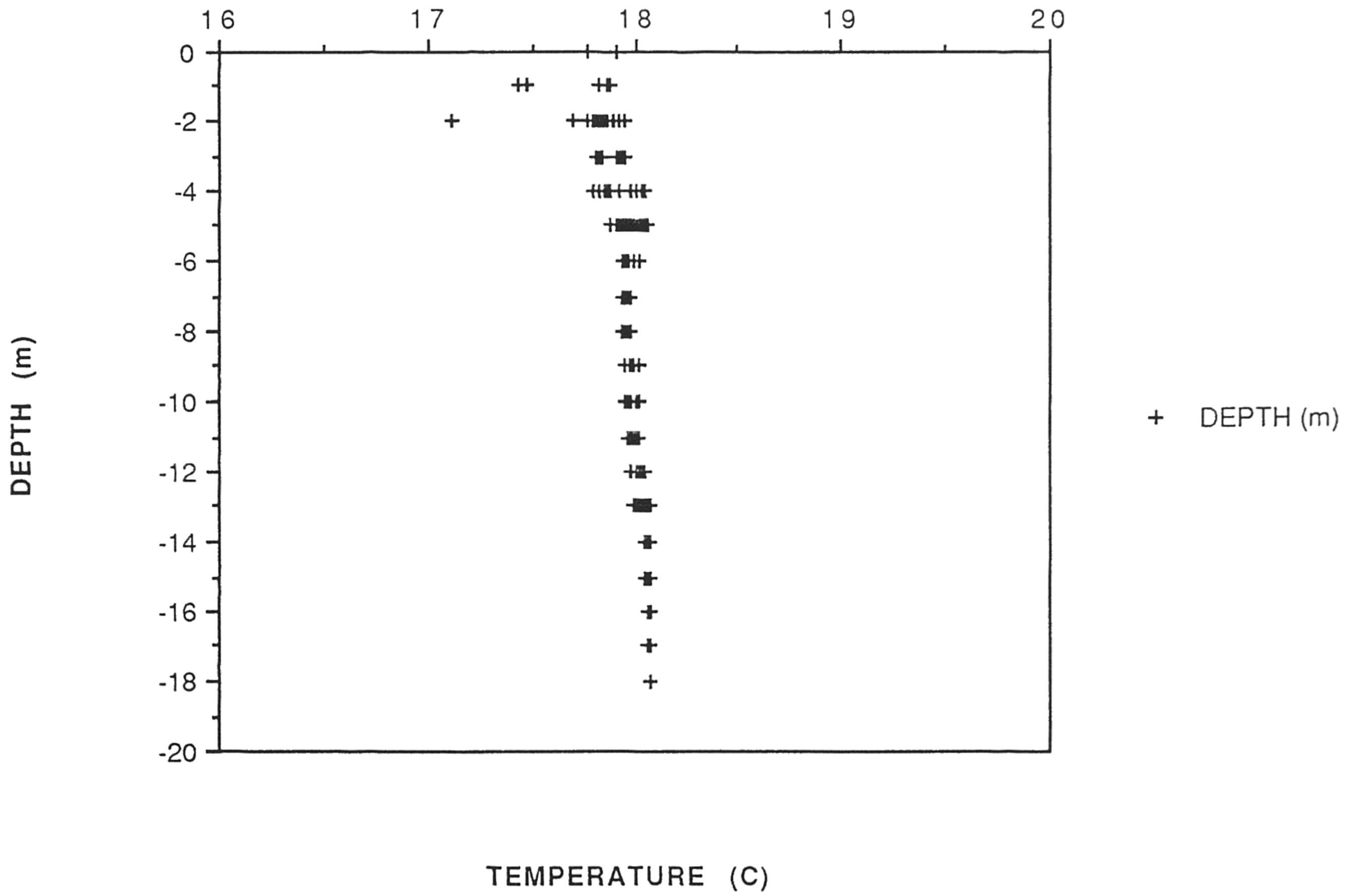


Fig. 39 Tow 18 SvZ

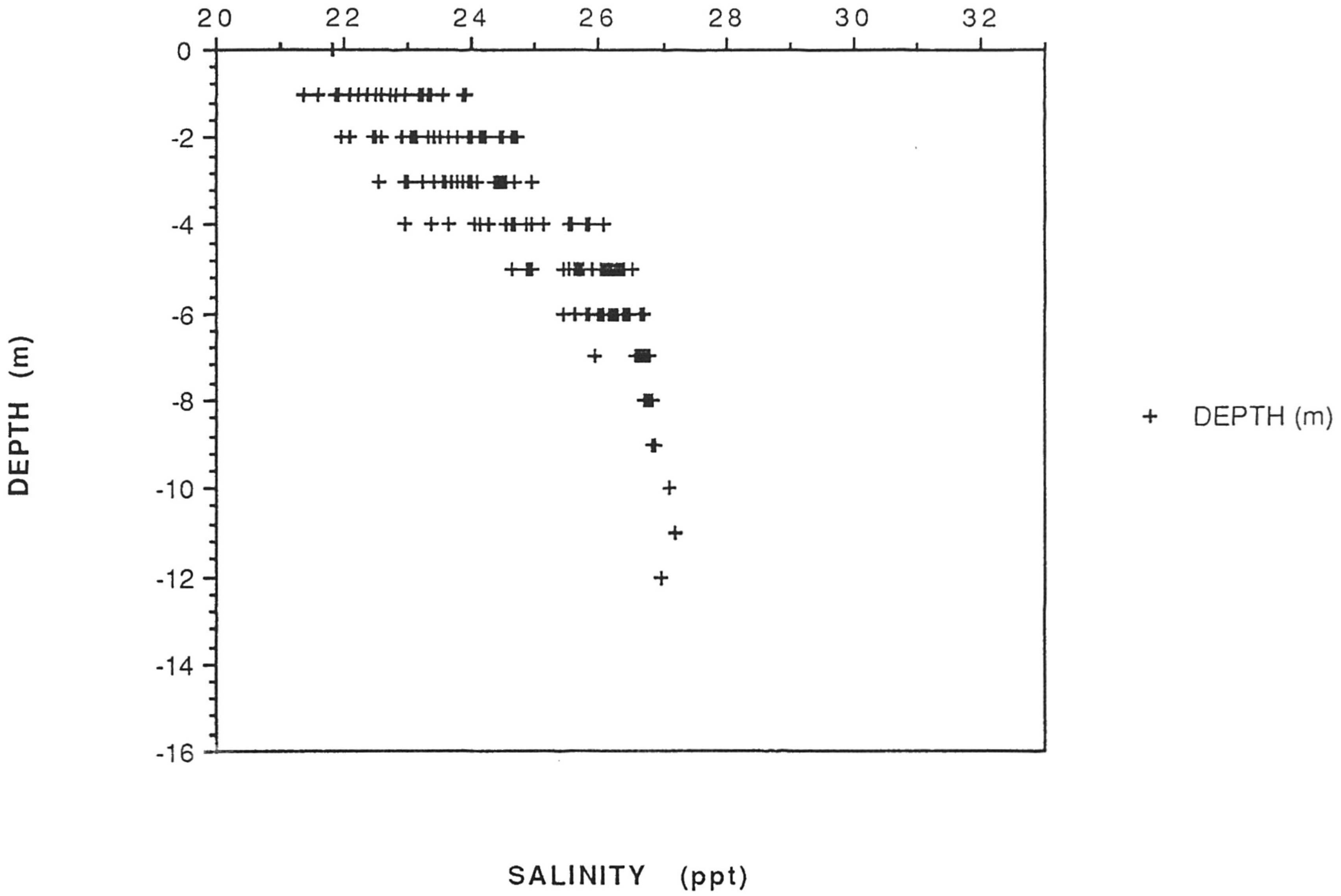
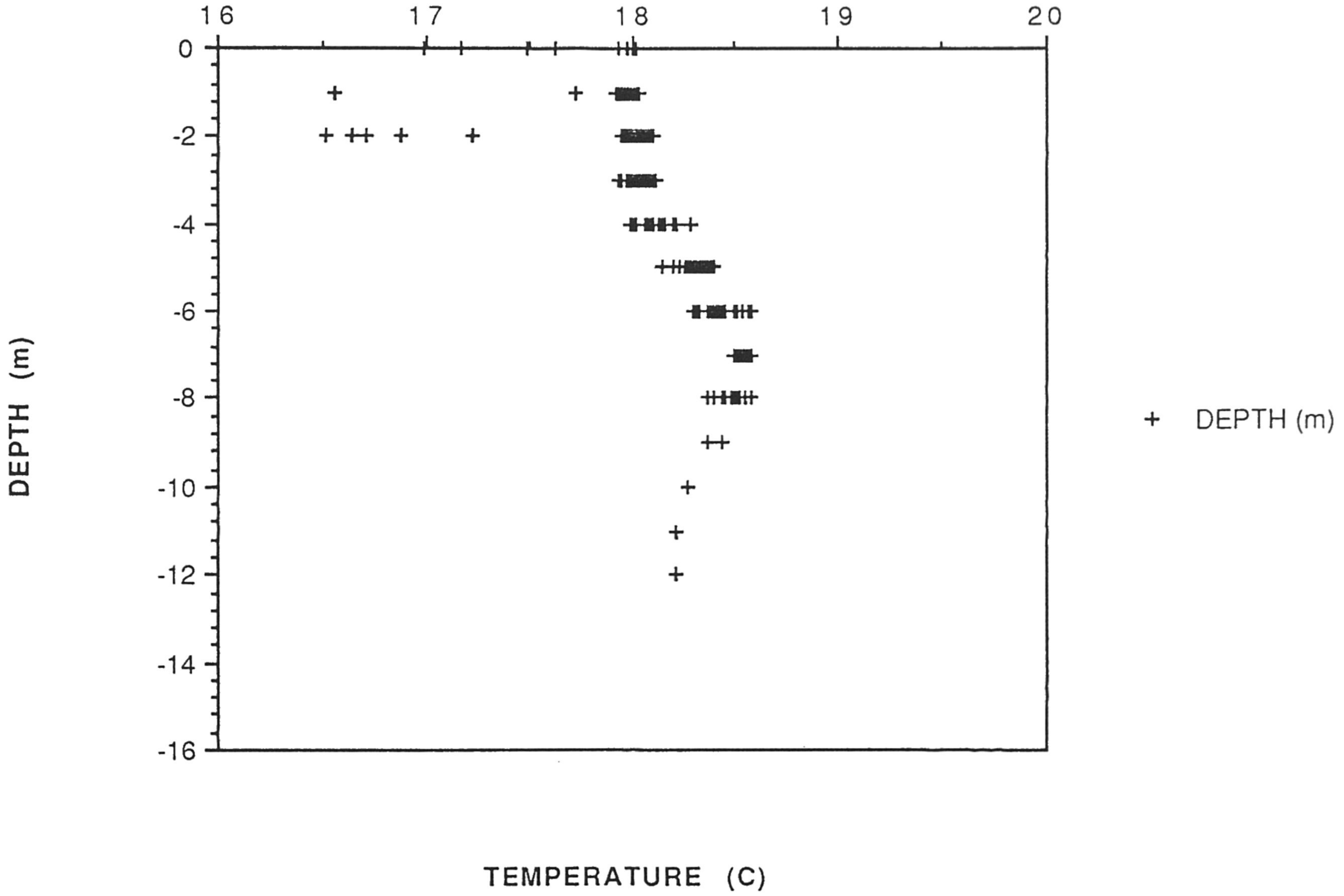


Fig. 40 Tow 18 TvZ



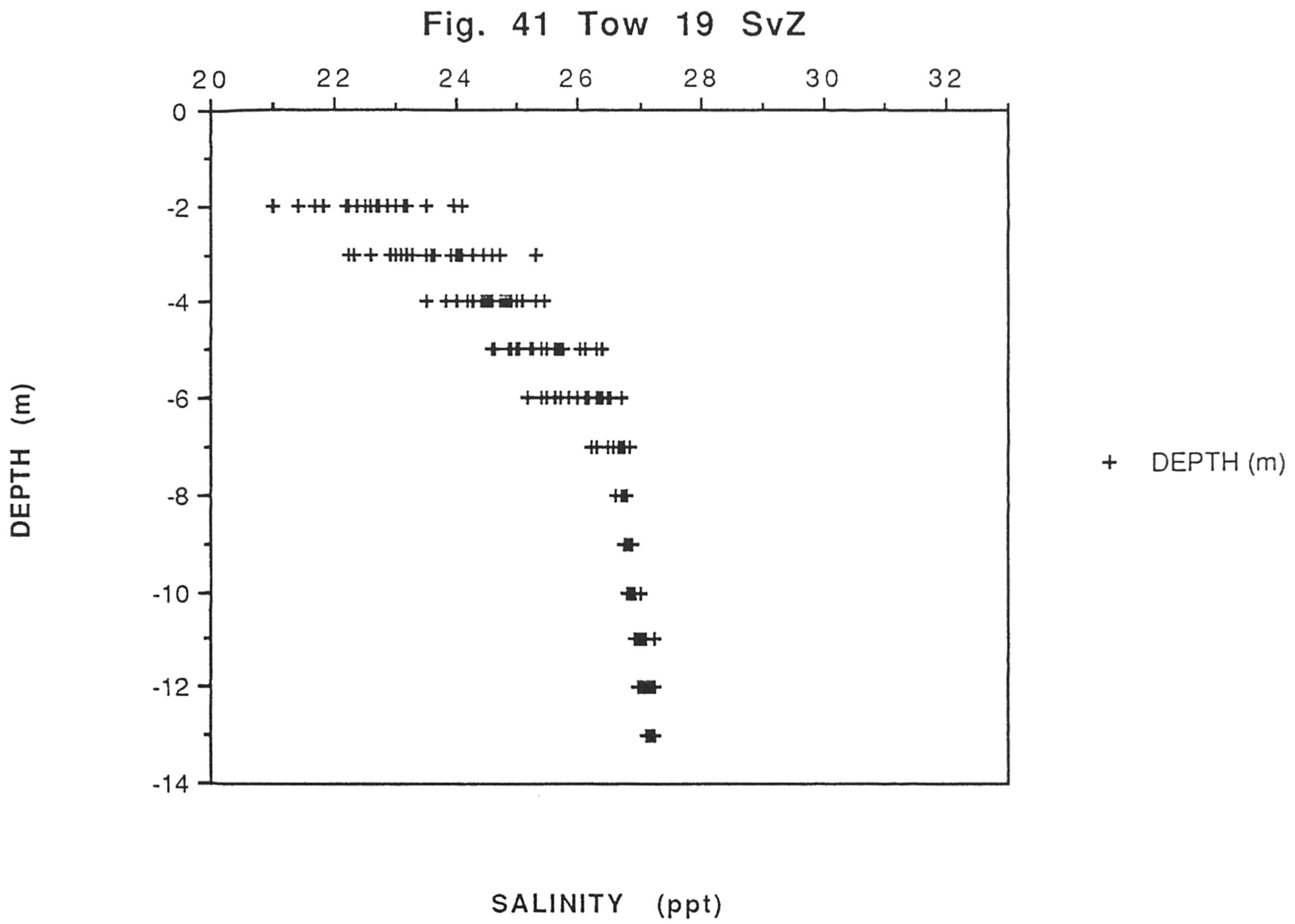


Fig. 41 Tow 19 SvZ
20
22
24
26
28
30
32
0
-2
-4
-6
-8
-10
-12
-14
DEPTH (m)
+ DEPTH (m)
SALINITY (ppt)

Fig. 42 Tow 19 TvZ

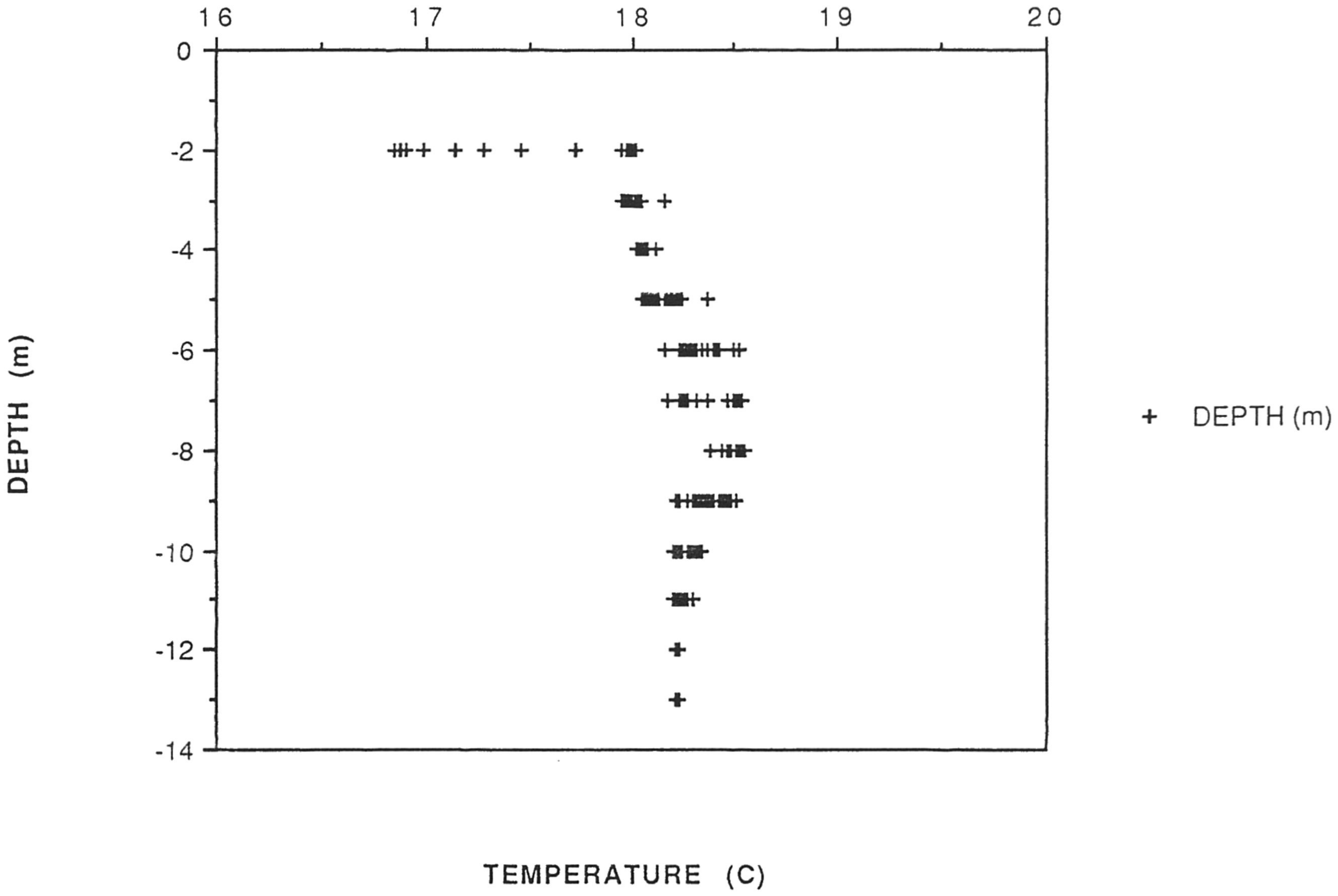


Fig 43. Tow 20 SvZ

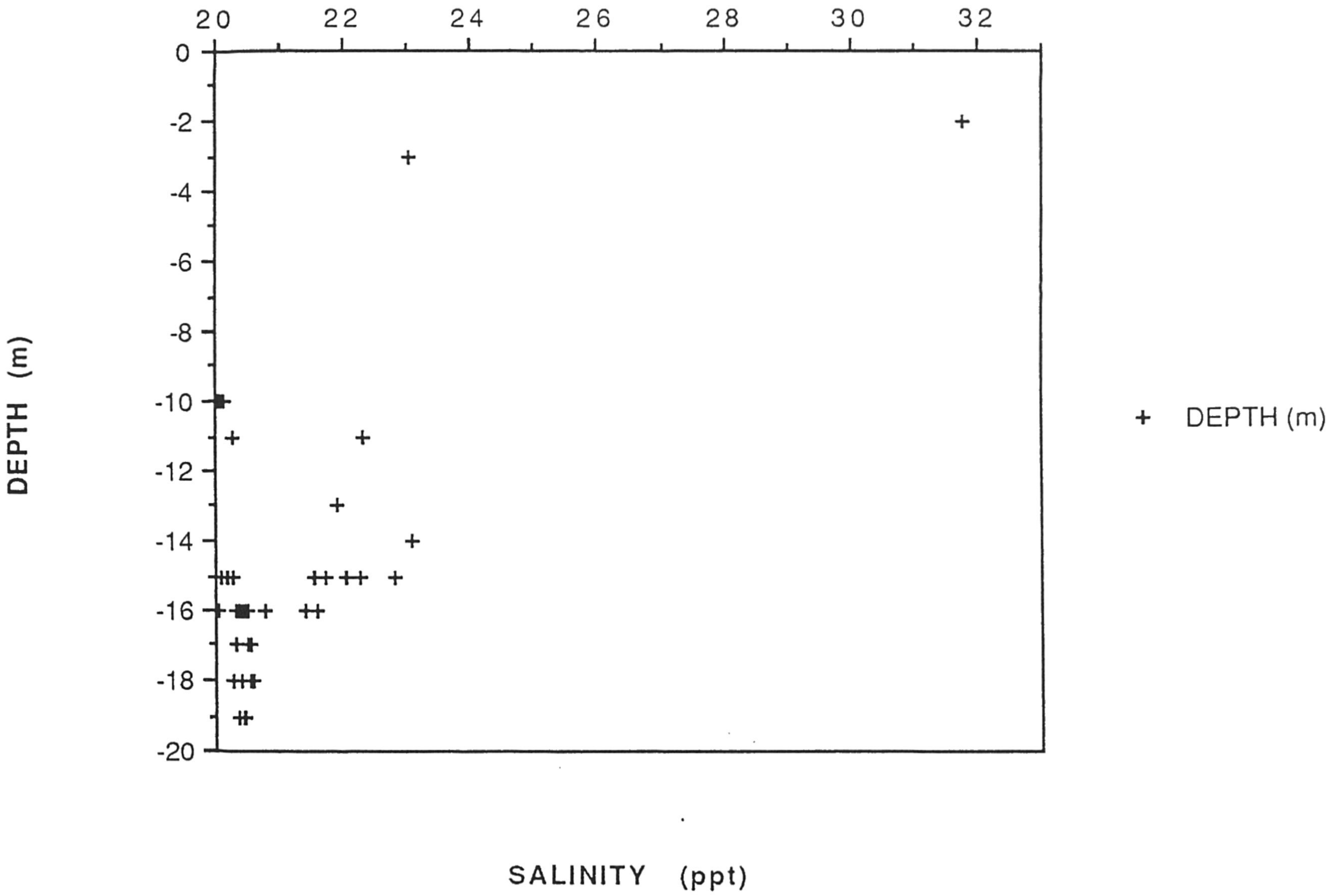
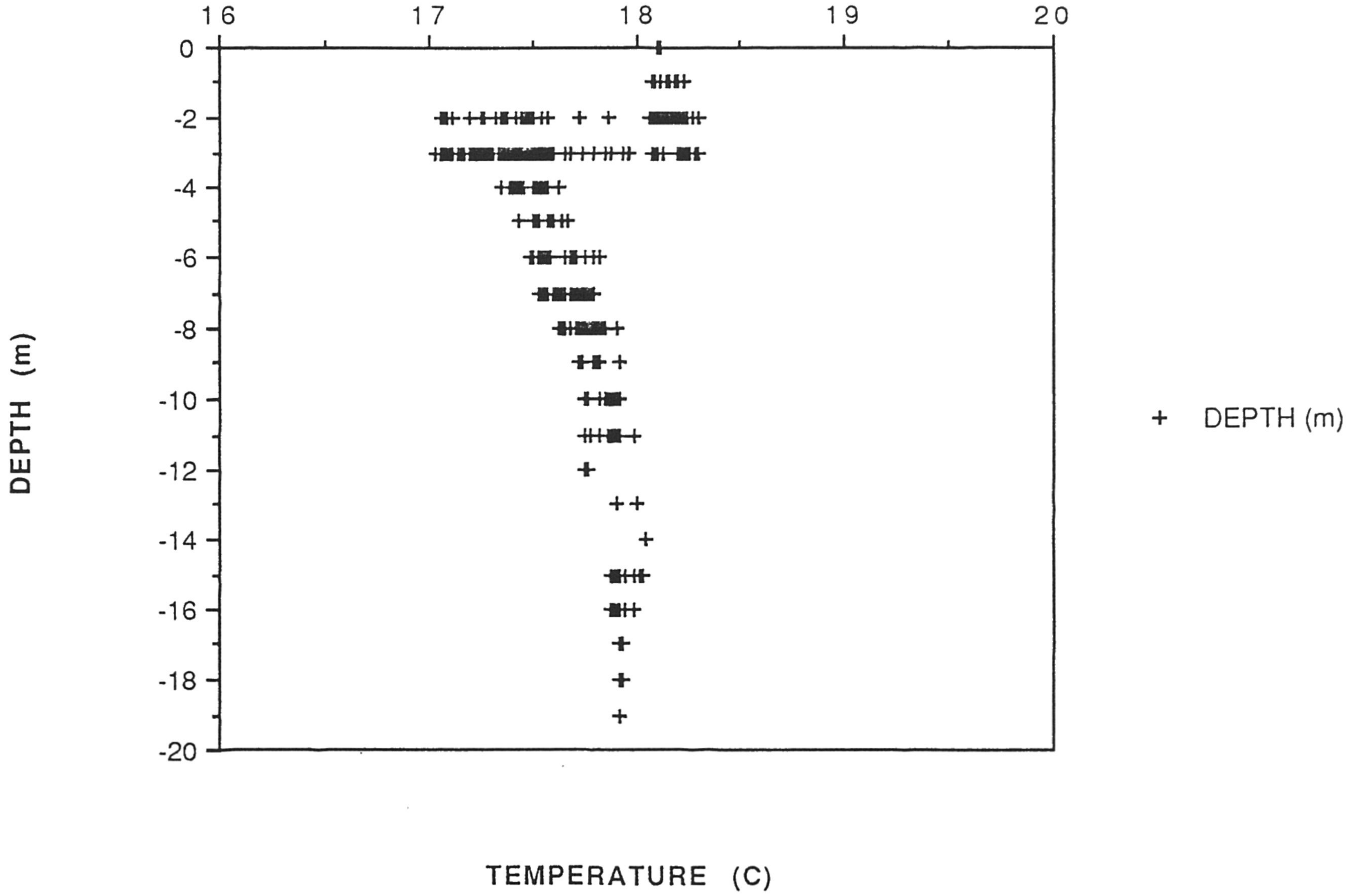


Fig. 44 Tow 20 TvZ



Figures 45-47 represent the different tide stages and compare abundance to depth. Fig. 45 represents abundance versus depth during a flood tide. Due to an accident that occurred on this cruise, only one flood tide tow was taken. This data states that the greatest abundance occurred at a depth of 5.0 meters during the flood tide. Fig. 46 compares abundance to depth during the ebb tides. Thirteen ebb tide tows were taken and their tow numbers are listed on the right hand side of Fig. 46. The data here states that the overall greatest abundance was found at a depth of roughly 6.0 meters during the ebb tides. Fig. 47 represents abundance versus depth during the slack tides. Six slack tide stage tows were taken and their numbers are also listed on the right hand side of Fig. 47. This data states that the overall greatest abundance during the slack tide was found near a depth of near 4.0 meters.

Figures 48 and 49 represent the two different diel stages and compare abundance to depth. Fig. 48 compares abundance to depth during the day. Eight tows were taken during the day and they are listed on the right hand side of Fig 48. This data states that the overall highest abundance occurred at a depth of roughly 4.5 meters during the day. Fig. 49 represents abundance versus depth during the night. Twelve night tows were taken and their numbers are listed on the right hand side of Fig. 49. This data states that the overall greatest abundance at night occurred at a depth of about 6.9 meters.

Chart 1

	TOW NUMBER	NET NUMBER	VOLUME	#PL	#PL/m^3	DEPTH	TIME	TIDE STAGE	DAY/NIGHT
1									
2	1	1	110	137	1.25	-3.0	519	E	T
3	1	2	90	198	2.20	-6.0	519	E	T
4	1	3	81	167	2.06	-9.0	519	E	T
5	1	4	83	388	4.65	-12.0	519	E	T
6	1					0.0	519	E	T
7	2	1	51	1	0.02	-4.0	734	E	D
8	2	2	49	2	0.04	-4.0	734	E	D
9	2	3	50	3	0.06	-6.0	734	E	D
10	2	4	51	22	0.43	-6.0	734	E	D
11	2					0.0	734	E	D
12	3	1	51	23	0.45	-3.0	830	E	D
13	3	2	52	6	0.12	-5.0	830	E	D
14	3	3	51	1	0.02	-7.0	830	E	D
15	3	4	51	0	0.00	-10.0	830	E	D
16	3					0.0	830	E	D
17	4	1	51	135	2.65	-4.0	1016	E	D
18	4	2	52	118	2.27	-7.0	1016	E	D
19	4	3	53	17	0.32	-12.0	1016	E	D
20	4	4	52	3	0.06	-15.0	1016	E	D
21	4					0.0	1016	E	D
22	5	1	51	0	0.00	-4.0	1103	S	D
23	5	2	51	1	0.02	-8.0	1103	S	D
24	5	3	54	0	0.00	-11.0	1103	S	D
25	5	4	52	0	0.00	-11.0	1103	S	D
26	5					0.0	1103	S	D
27	6	1	51	39	0.76	-3.0	1622	S	D
28	6	2	53	13	0.25	-7.0	1622	S	D
29	6	3	48	3	0.06	-11.0	1622	S	D
30	6	4	50	0	0.00	-15.0	1622	S	D
31	6					0.0	1622	S	D
32	7	1	50	0	0.00	-2.0	1717	E	D
33	7	2	52	0	0.00	-4.0	1717	E	D
34	7	3	52	0	0.00	-6.0	1717	E	D
35	7	4	52	0	0.00	-8.0	1717	E	D
36	7					0.0	1717	E	D
37	8	1	51	1	0.02	-2.0	1806	E	D
38	8	2	52	0	0.00	-4.0	1806	E	D
39	8	3	52	0	0.00	-6.0	1806	E	D
40	8	4	51	2	0.04	-8.0	1806	E	D
41	8					0.0	1806	E	D
42	9	1	31	24	0.77	-4.0	2100	E	N
43	9	2	31	14	0.45	-8.0	2100	E	N
44	9	3	30	2	0.07	-12.0	2100	E	N
45	9	4	ns	ns		-16.0	2100	E	N
46	9					0.0	2100	E	N
47	10	1	51	0	0.00	-3.0	2151	S	N
48	10	2	52	1	0.02	-6.0	2151	S	N
49	10	3	51	0	0.00	-9.0	2151	S	N
50	10	4	52	0	0.00	-11.0	2151	S	N
51	10					0.0	2151	S	N
52	11	1	51	0	0.00	-4.0	2239	F	N
53	11	2	51	2	0.04	-7.0	2239	F	N
54	11	3	51	0	0.00	-10.0	2239	F	N
55	11	4	52	0	0.00	-14.0	2239	F	N
56	11					0.0	2239	F	N
57	12	1	52	11	0.21	-4.0	553	E	T
58	12	2	51	43	0.85	-8.0	553	E	T
59	12	3	37	59	1.59	-12.0	553	E	T
60	12	4	46	54	1.17	-15.0	553	E	T
61	12						553	E	T
62	13	1	51	0	0.00	-3.0	655	E	D
63	13	2	52	2	0.04	-5.0	655	E	D
64	13	3	53	0	0.00	-7.0	655	E	D
65	13	4	52	0	0.00	-9.0	655	E	D
66	13					0.0	655	E	D
67	14	1	211	0	0.00	-2.0	749	E	D
68	14	2	209	0	0.00	-4.0	749	E	D
69	14	3	207	0	0.00	-6.0	749	E	D
70	14	4	205	0	0.00	-8.0	749	E	D
71	14					0.0	749	E	D
72	15	1	53	0	0.00	-2.0	835	E	D

	TOW NUMBER	NET NUMBER	VOLUME	#PL	#PL/m^3	DEPTH	TIME	TIDE STAGE	DAY/NIGHT
73	15	2	50	0	0.00	-4.0	835	E	D
74	15	3	51	0	0.00	-7.0	835	E	D
75	15	4	50	0	0.00	-9.0	835	E	D
76	15					0.0	835	E	D
77	16	1	50	5	0.10	-3.0	1111	S	D
78	16	2	53	3	0.06	-7.0	1111	S	D
79	16	3	51	3	0.06	-11.0	1111	S	D
80	16	4	51	1	0.02	-15.0	1111	S	D
81	16					0.0	1111	S	D
82	17	1	51	0	0.00	-4.0	1642	S	D
83	17	2	51	0	0.00	-8.0	1642	S	D
84	17	3	51	4	0.08	-12.0	1642	S	D
85	17	4	51	3	0.06	-15.0	1642	S	D
86	17					0.0	1642	S	D
87	18	1	51	6	0.12	-2.0	1935	E	N
88	18	2	51	0	0.00	-5.0	1935	E	N
89	18	3	54	0	0.00	-7.0	1935	E	N
90	18	4				-9.0	1935	E	N
91	18					0.0	1935	E	N
92	19	1	51	2	0.04	-2.0	2020	E	N
93	19	2	54	2	0.04	-5.0	2020	E	N
94	19	3	52	1	0.02	-8.0	2020	E	N
95	19	4	51	0	0.00	-11.0	2020	E	N
96	19					0.0	2020	E	N
97	20	1	37	19	0.51	-4.0	2115	S	N
98	20	2	16	50	3.21	-8.0	2115	S	N
99	20	3	5.7	8	1.40	-15.0	2115	S	N
100	20	4	7.7	12	1.56	-15.0	2115	S	N
101	20					0.0	2115	S	N

Fig. 45 Abundance v Depth for Flood Tide

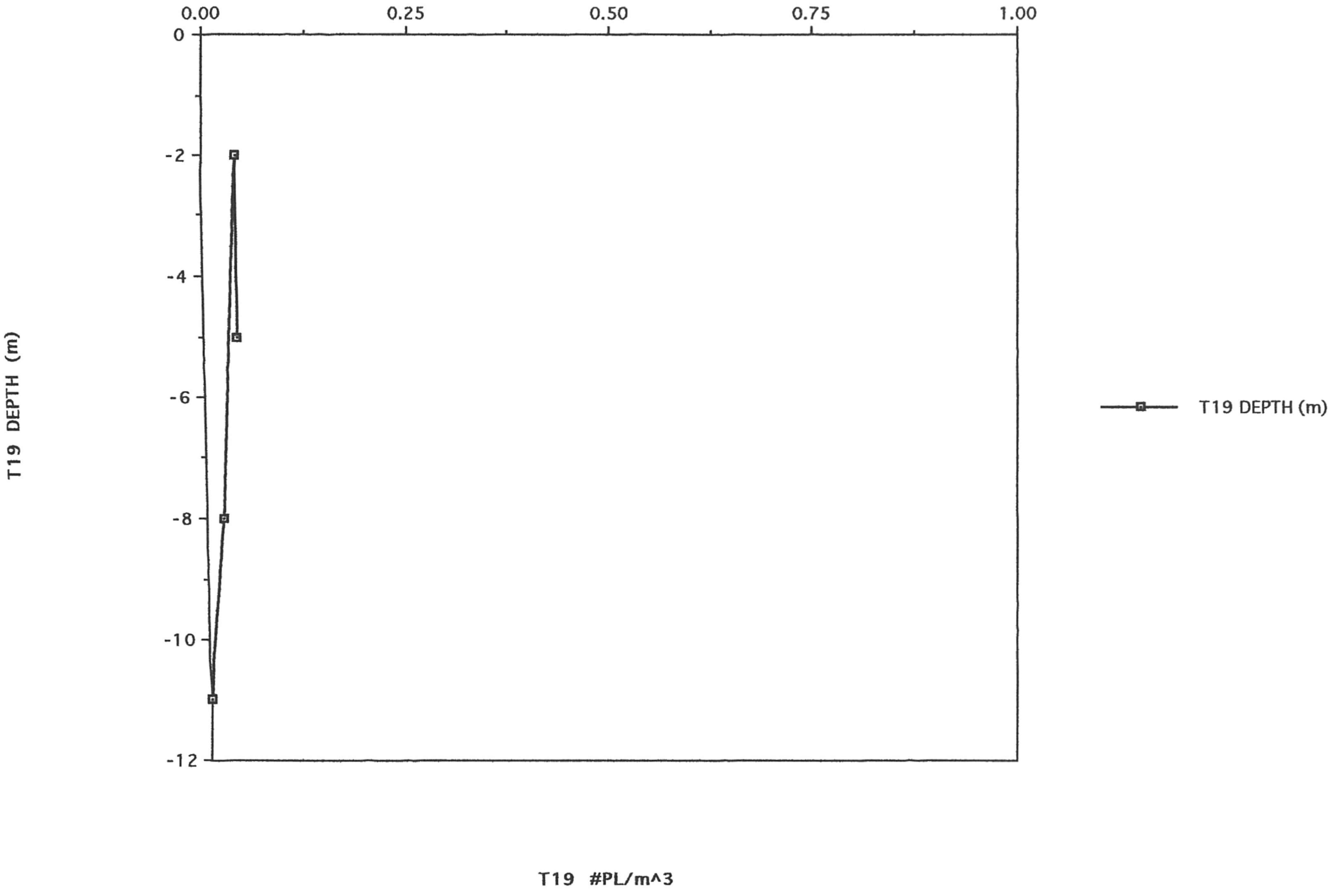


Fig. 46 Abundance v Depth for Ebb Tide

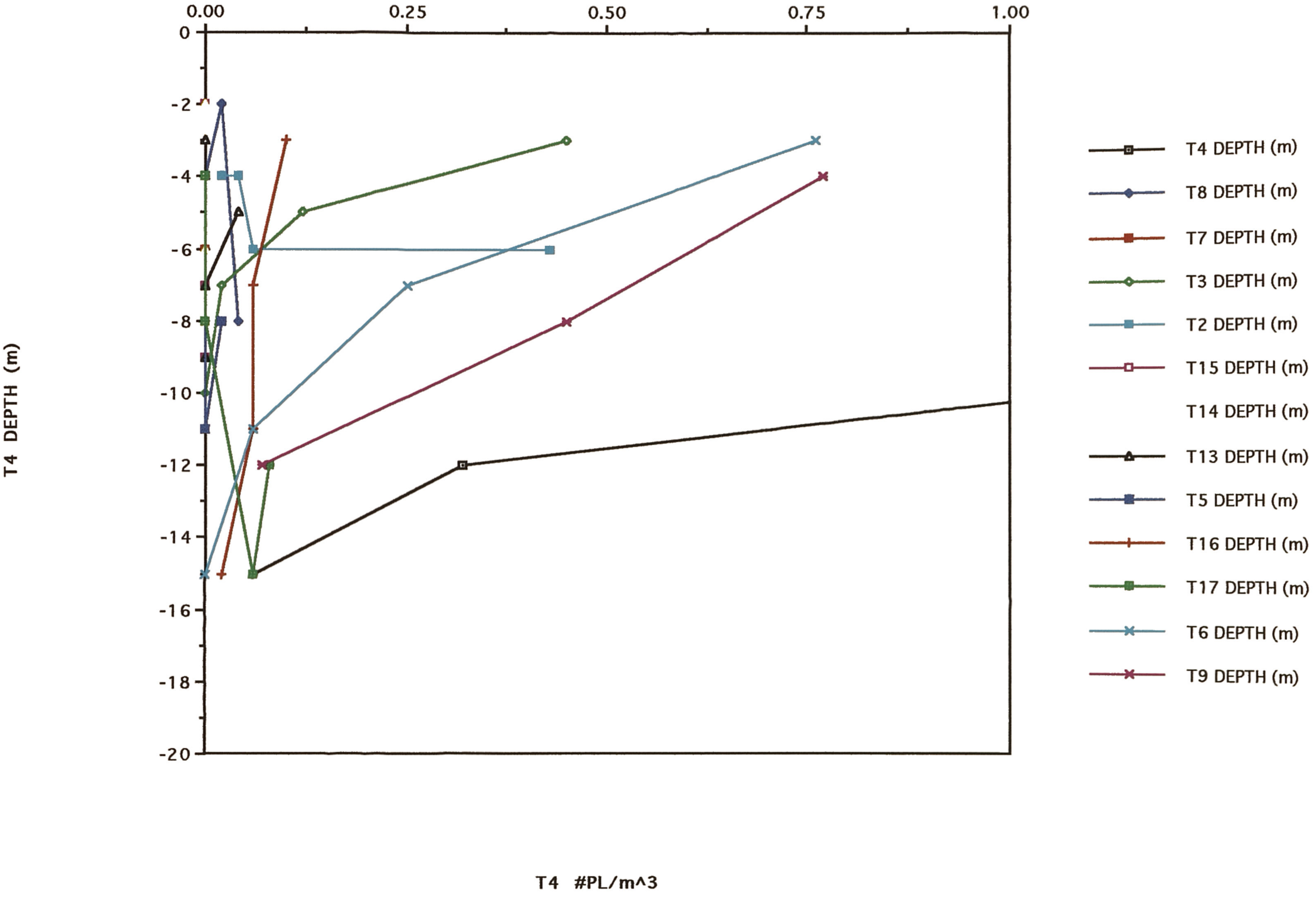


Fig. 47 Abundance v Depth for Slack Tide

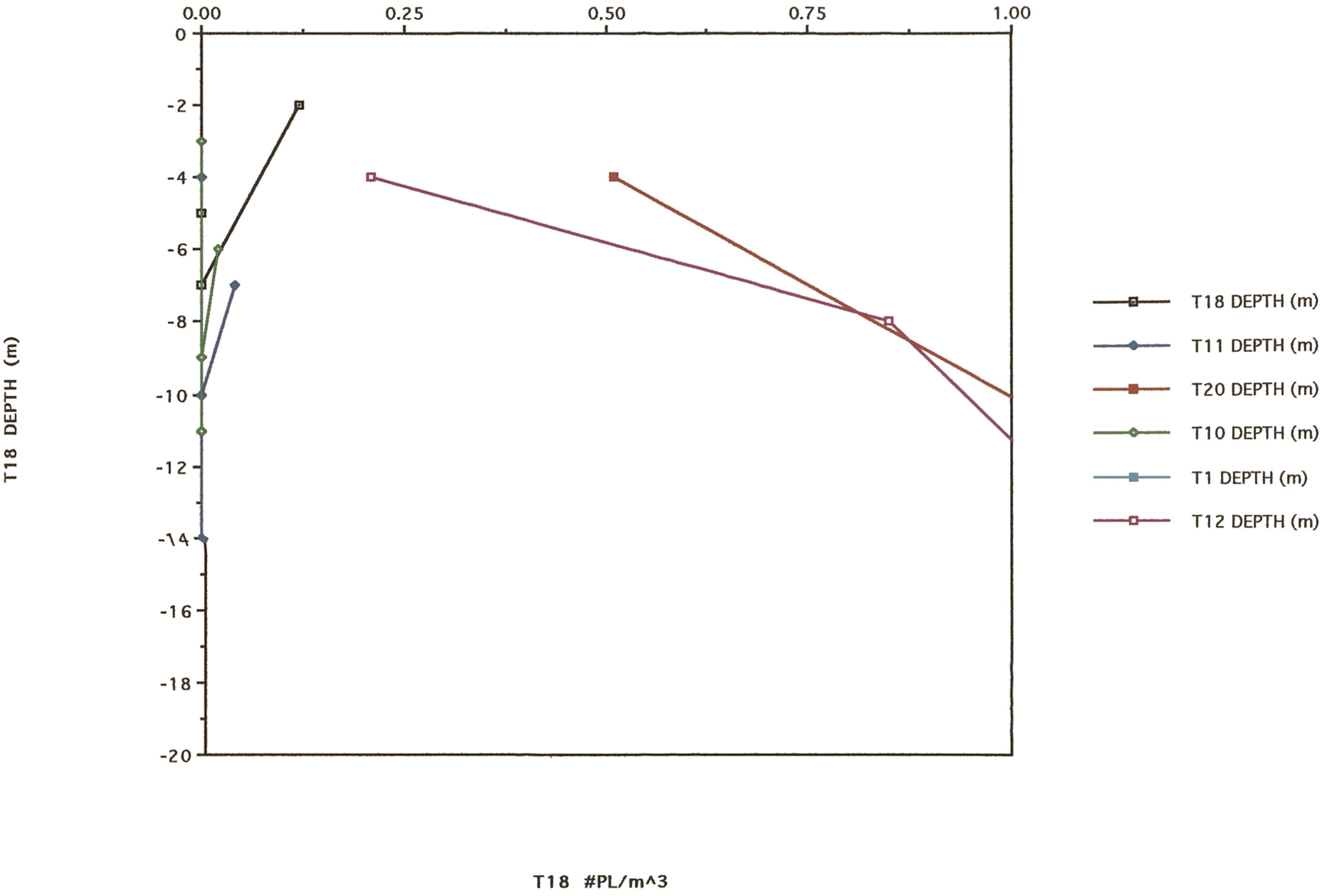


Fig. 48 Abundance v Depth during Day

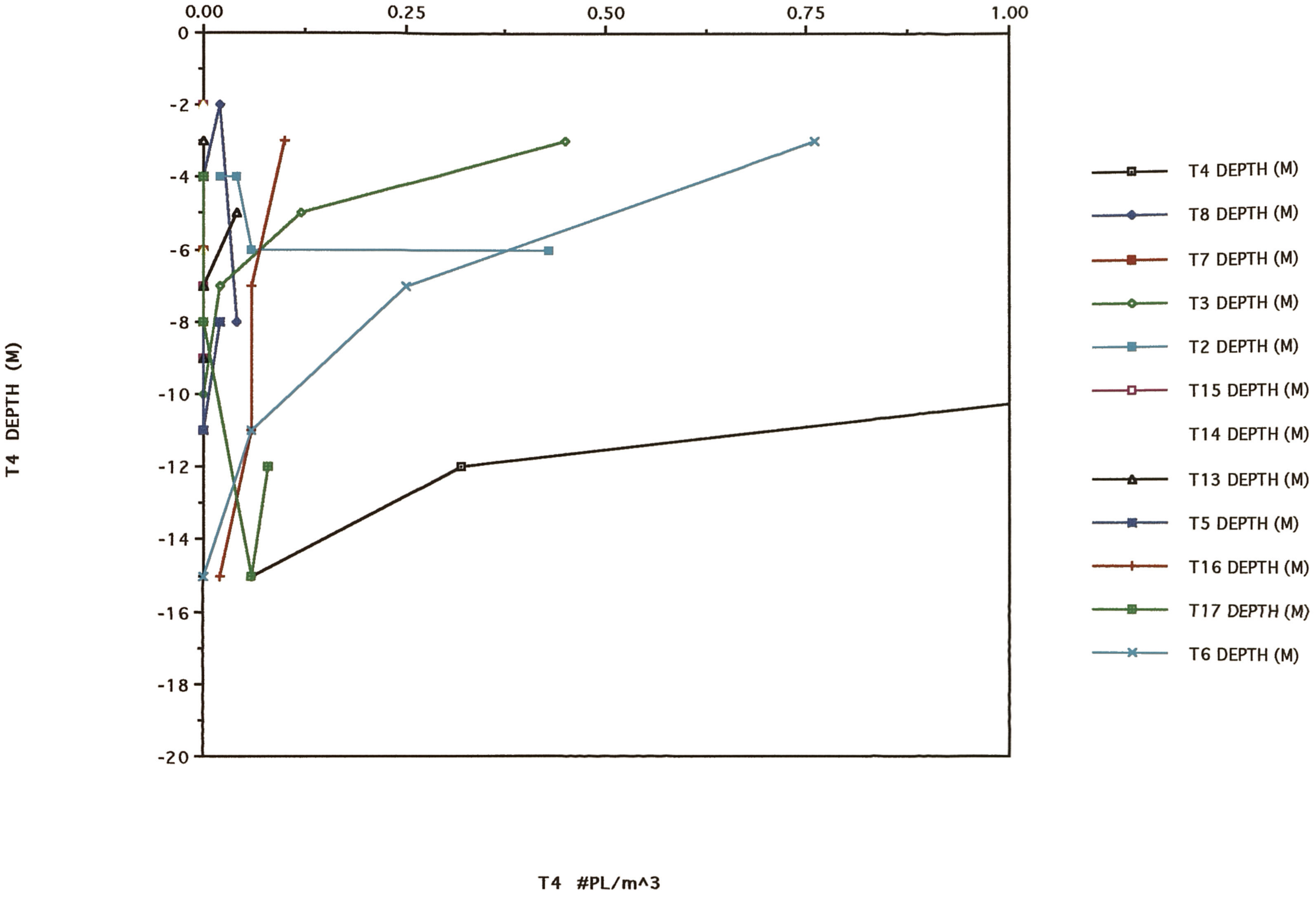
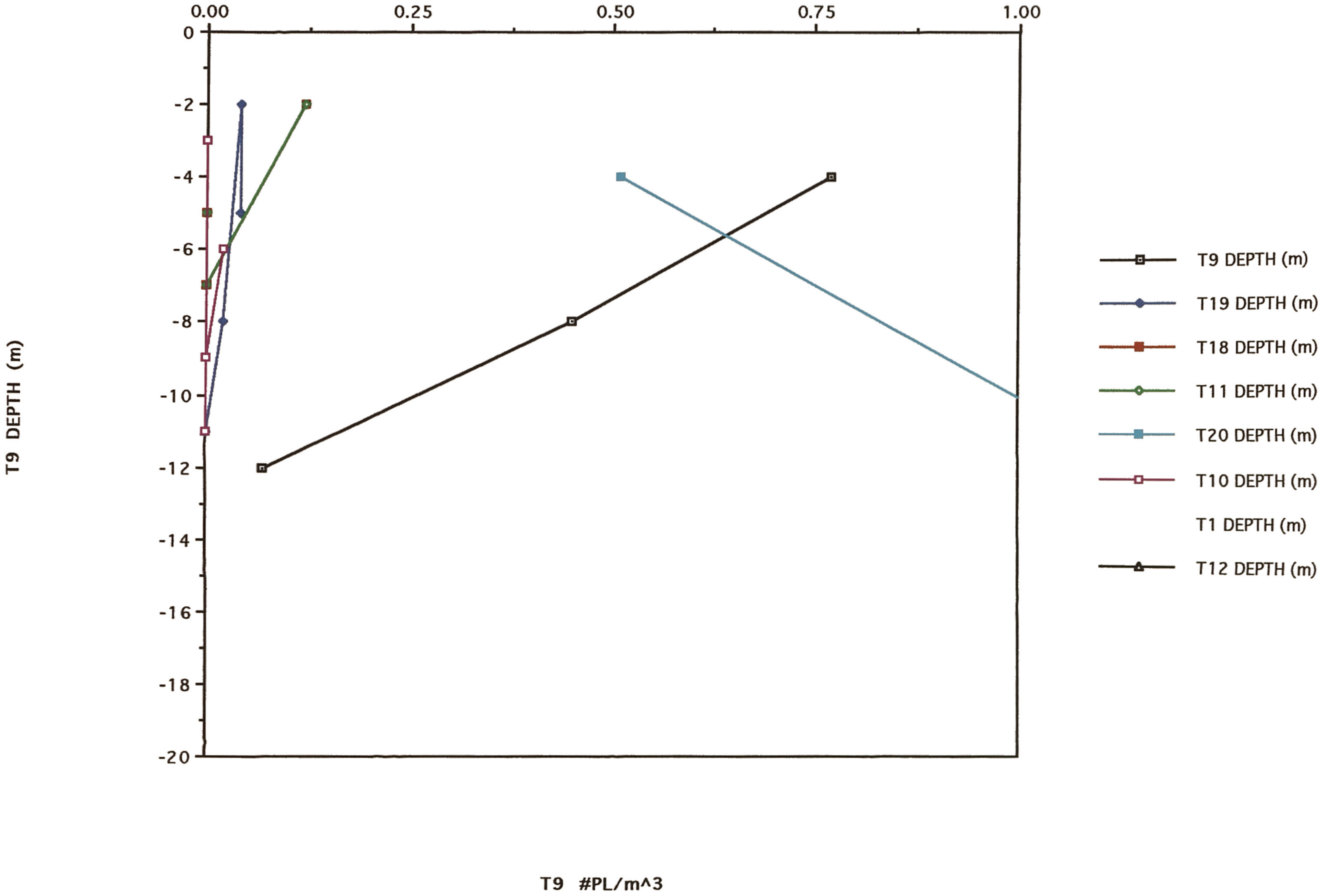


Fig. 49 Abundance v Depth during Night



DISCUSSION

Salinity:

The salinity data presented for depth indicates that tows 2, 3, 7, 8, 11, 13, and 19 have the highest average salinities. From Chart 1 it is known that tow 2 had a slight abundance near the surface and a large abundance at the bottom; tow 3 had a large abundance near the surface; tow 7 had zero abundance; tow 8 had a very slight abundance near the surface and slight abundance near the bottom; tow 11 had a slight abundance near the surface; tow 13 had a slight abundance near the surface; and tow 19 had a slightly greater abundance near the surface.

The salinity data presented for depth also indicates that tows 6 and 10 have the lowest average salinities. Tow 6 had a large abundance near the surface, and tow 10 had a slight abundance near the surface.

These results can be interpreted in three ways The first way is with respect to the tide stage. Hughes observed that postlarvae dropped to the substrate when salinity was reduced, where they remained inactive. In nature, such behavior could allow immigrants to evade displacement by the ebb tide. When the salinity increased, they became active in the water column; again in nature, such behavior would allow displacement inshore on a flood tide (Rogers, 1993 p. 387). Using this theory of high abundance near the surface in the presence of high salinities and high abundances near the bottom in the presence of low salinities, this study's data can be analyzed. If among the tows with the highest salinities, tows 2 and 8 were discarded as exceptions, the data would support Hughes' claim, except that tows 3, 13, and 19 were taken during ebb tides. However, both of the tows with the lowest salinities experienced abundances near the surface, not near the bottom. And, both tows were taken during a slack tide. Therefore, the data from this study cannot be said to agree with Hughe's theory. In fact, because of the fact that this study recorded high salinities with high surface abundances on mostly ebb tides and low salinities with high surface abundances on slack tides, no conclusions can be drawn with respect to salinity and tide stage.

The second method to analyzing the salinity data is with respect to diel stage. Mathews (1992) found that postlarvae responded directly to salinity signals in the laboratory only during night/dark conditions. Specifically, significant activity increases occurred only during salinity increases under night/dark conditions. Significant activity decreases occurred during salinity decreases under these conditions (Mathews, 1992 p.186-187). Of the tows with the highest salinities, tows 2, 3, 8, and 13 were taken during the day. Tows 11 and 19 were taken at night. Of the tows with the lowest salinities, tow 6 was taken during the day and tow 10 was taken at night. Tows 8, 10, 11, 13, and 19 had negligible abundance. Tow 3 had the largest high salinity abundance and was taken during the day and tow 6 had the highest low salinity abundance. Also, tow 13 had high abundance near the surface during the day, and tow 6 had high abundance near the surface during the day. This is not in concordance with Mathews's (1992) findings. In addition, these results make no statement about salinity and diel stage. Therefore, this study finds no correlation.

The third way to interpret these results is that there is no perceptible relation between any of the other parameters and salinity. This is the resolve of this study.

Temperature:

The temperature data presented in this study indicates that tows 7, 10, 13, 18, and 19 had the highest average temperatures. Tow 7 had zero abundance; tow 10 had a very slight abundance near the surface; tow 13 had a slight abundance near the surface; tow 18 had a relatively large abundance near the surface, and tow 19 had a slight abundance near the surface.

The temperature data presented in this study also indicates that tows 1, 2, 3, and 20 had the lowest average temperatures. Tow 1 had a very large abundance at all depth intervals but the largest was near the bottom; tow 2 had a slight abundance near the surface but a large abundance near the bottom; tow 3 had a large abundance near the surface; and tow 20 had a slight abundance near the surface.

There are two ways to interpret this data. One, Rogers (1993) found in laboratory experiments that brown shrimp postlarvae were shown to cease activity, sink, and rest on the substrate at temperatures of 15-17 degrees Celsius, to burrow in to the substrate when temperatures fell to 12-16 degrees Celsius, and the emerge when temperatures increased to 18-21.5 degrees Celsius (Rogers, 1993 p.38). Of the tows with the lowest average temperatures, tow 1 was taken at an average temperature of 16.9 degrees Celsius and had a large abundance near the bottom. Tow 2 was taken at an average temperature of 17.2

degrees Celsius and had a large abundance near the bottom. Tow 3 was taken at an average temperature of 17.1 degrees Celsius and had a large abundance near the surface. And, tow 4 was taken at an average temperature of 17.7 degrees Celsius. This evidence of this study in view of Rogers, 1993 's findings is two for and two against. Although, the two against were slightly and well over 17 degrees Celsius. However, nothing definitive can be said about Rogers' (1993) findings and this study without looking at more data.

The second way to analyze this data is by its two largest pieces. All of the tows with the highest average temperatures exhibited abundances near the surface. Also, among the tows with the lowest average temperatures, the two lowest of these exhibited abundances near the bottom, while the highest two of the lowest temperatures had surface abundances. This might suggests the possibility of a correlation between temperature and abundance, supportive of Rogers' (1993) findings. That is, for temperatures below 17 degrees Celsius, brown shrimp postlarvae are found near the bottom, and for temperatures above 17 degrees Celsius, brown shrimp postlarvae are found near the surface.

Tide Stage:

As was stated previously, the tide stage data of this study indicates that the greatest abundance of postlarval brown shrimp on the flood tide was found at an average of 5.0 meters, on the ebb tide at 6.0 meters, and on the slack tide at 4.0 meters.

Mathews (1992) suggested that if a mechanism exists that allows postlarvae to anticipate tidal changes, postlarvae [could] time their movements into the water column and maximize their advection into estuaries (Mathews, 1992 p.186). This would mean a greater abundance of brown shrimp postlarvae near the surface on a flood tide and a greater abundance near the bottom on an ebb tide, with a greater abundance at the intermediate depths on a slack tide. Clearly, because of the lack of flood tide data, the results of this study do not support that hypothesis. However, it is Godwin's (1991) position that it is possible that previous efforts, which failed to demonstrate this relationship [a greater abundance near the surface on flood tides] statistically, may have had sampling designs with sampling events spaced too far apart in time or may have sampled too far away from the pass to truly represent the daily recruiting individuals (Godwin, 1991 p. 85). Clearly, this study's sampling events with respect to flood tides were spaced so far apart as to yield only one sample. Therefore, Godwin (1991) may have a point. However, conclusions cannot be drawn from a lack of data. Therefore, this study's tide stage data cannot support the theory of active migration.

Diel Stage:

As was stated previously, the diel stage data for this study indicates that the average abundance for the day occurred at a depth of 4.5 meters and the average abundance for the night occurred also at a depth of 6.9 meters. These results are in direct contradiction with Mathews (1992) whose results strongly suggest[ed] that postlarvae increase their activity level at night in the absence of any external clue. There were distinct and immediate activity increases at dusk...[and] the decreased inactivity in the predawn hours...also suggests that there is a circadian rhythm involved with this behavior (Mathews, 1992 p.180). They also found that observations of freshly captured postlarvae under all combinations of day/night and light/dark conditions suggest that postlarvae are primarily active at night under dark conditions. Darkened daytime conditions are not sufficient to increase activity (Mathews, 1992 p. 186). This, if true, would rule out the possibility that if the days of April 3rd and 4th, 1992 were overcast, the data would be excused from agreement. Also along these lines, Rogers (1993) took more postlarvae during the night than day in both offshore and marsh waters, which supports the concept that postlarval brown shrimp undergo diel vertical migration, as has been shown for the postlarvae of other *Penaeus* species (Rogers, 1993 p. 387).

The data from this study suggests the opposite of the findings of the researchers above. This study supports the theory that the postlarvae are more active in the water column, hence found nearer the surface, during the day, and that they are less active in the water column, hence founded nearer the bottom, during the day.

CONCLUSIONS

The conclusions of this study are as follows: (1) With respect to salinity changes, in combination with other parameters or not, nothing from this study can be said. There is no evidence of salinity directly aiding or affecting the migration of postlarval brown shrimp. (2) With respect to temperature, the data of this study support the theory that brown shrimp postlarvae are less abundant near the surface of the water column below 17 degrees Celsius. Increases in the water temperature over 17 degrees Celsius overall yielded increased abundance near the surface. (3) With respect to tide stage, there is no evidence in this investigation that supports the theory that postlarval brown shrimp utilize the tide stages to aid in their migration. (4) With respect to diel stage, the data of this study indicates that brown shrimp postlarvae are more abundant near the surface of the water column during the day than at night.

Suggestions for Further Research:

To be wholly accurate and conclusive, the next investigation would need to chose a transitional location between offshore and the estuary, be it Galveston Bay or Aransas Pass. Once the site was chosen, the experiment should take place during one of the peak seasons of postlarval brown shrimp recruitment, preferably the spring peak. The experiment would need to take tows every hour of every day, for at least one month. This time frame would reduce the influence of any anomalous measurements and provide a comprehensive profile of postlarval movements. However, due to funding, budget allocations, and cost of ship time, it is unlikely that an experiment of this duration or magnitude would happen easily or soon.

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