

Physical Processes in Upper Laguna Madre.

Contract Study for NPS (PAIS) By
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Physical Processes in Upper Laguna Madre

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INTRODUCTION

The Laguna Madre of Texas is recognized as an important natural resource. The physical environment of this semi-enclosed lagoon is a harsh one, yet resident plant and animal populations flourish. The central Texas Gulf coast is an area of generally high evaporation, relative to the available precipitation, however occasionally heavy rainfall is recorded. Extreme cases of heavy rainfall occur as hurricanes cross the Texas coast. For example, Behrens (personal communication) conducted a survey through Upper Laguna Madre and Baffin Bay shortly after Hurricane Beulah crossed the coast near Brownsville in September, 1967. Salinities were found to be generally between 5 and 15 parts per thousand. Thus, there is a high variation in salinity, which in some years may range from near zero to over 50 parts per thousand. In addition, annual temperature extremes characteristically range from over 30°C in the summer months to less than 10°C following frontal passages in midwinter. In spite of this, the Laguna Madre has provided substantial sport and commercial fishing since the early days of South Texas.

The central Texas coast is an area of increasing population pressures. The dredging and maintenance of the Intracoastal Waterway and smaller navigational channels has resulted in a series of spoil islands extending the length of Upper Laguna Madre. The natural circulation of the region just south of the Kennedy Causeway has further been modified by the creation of a network of smaller channels associated with a housing development on Padre Island. These bulkheaded, dead-end channels

characteristically have a poor internal circulation of water. Both sport and commercial fishing has increased in recent years. Commercial barge traffic along the Texas Intracoastal Waterway continues at between 63 and 69 million short tons per year (Miloy, et al., 1975)

The combination of the value of the region and the possible effects of human activity has generated interest in Upper Laguna Madre over the past 30 years. Environmental monitoring programs have been carried out routinely by various state agencies, including the Texas Water Development Board, the Texas Water Quality Board and the Texas Parks and Wildlife Department. The University of Texas, through the Marine Science Laboratory at Port Aransas, The University of Corpus Christi (now the Corpus Christi campus of Texas A&I University) and Texas A&I University at Kingsville have conducted various diverse, short-term studies to investigate primarily ecological and geological problems.

Nevertheless, a hiatus has persisted in the area of hydrographic or physical processes, though investigators have recognized the often direct relationship between plant and animal populations and their physical environment. Thus, a study was initiated in May of 1974 to investigate a series of physical processes for the National Park Service which would result in a data base to both fill existing gaps and provide information needed for management decisions affecting the adjacent National Seashore. Recreational use of the waters bordering the National Seashore on the west requires that water quality be maintained at a high level. Water quality, in turn, requires that there be an adequate exchange of

water between Upper Laguna Madre and, if only indirectly, the Gulf of Mexico.

The first year's study focused on the northern extreme of Upper Laguna Madre, from the Kennedy Causeway to approximately Marker 31, opposite Pita Island, a distance of about 3.5 nautical miles along the Intracoastal Waterway. The emphasis was directed toward understanding the internal circulation and exchanges between the study site and Corpus Chrisit Bay. Results from this work provided information relating to the residence times of water in Upper Laguna Madre, and, by implication, the susceptibility or resistance of the area to deteriorating water quality.

During the second year, the study was expanded to include all of Upper Laguna Madre between the Causeway and the Land Cut at the southern end. In addition, the scope of the work was broadened to include direct current measurements and synoptic surveys of temperature and salinity patterns. These surveys were designed to investigate the possibility that the presence of spoil islands inhibits the exchange of water between the Intracoastal Waterway and the shallow grass flats.

As a part of the second year's effort, a number of state and consulting scientists were contacted to obtain supplemental data. Results of this historical data search were mixed, but, where appropriate, results have been integrated into this report to aid in the overall understanding of the study area.

REVIEW OF THE 1974-75 FIELD STUDY

The 1975-76 study of Upper Laguna Madre was designed and carried out in light of the results which came out of the field exercises conducted the first year. Information appearing in the First Annual Report (Smith 1975), which provide a necessary background for this past year's work, are reviewed and summarized below.

The water quality in a particular area depends primarily upon the concentration and types of materials introduced, and upon the ability of the water body to disperse the material by transporting it in some way from the point at which it is introduced. The two principal dispersal mechanisms are the advective transport by currents and diffusion by small-scale turbulence. This latter mechanism involves a mixing by small eddies very near the bottom or within seagrass beds, for example. This is particularly difficult to study without highly specialized instrumentation and was not investigated in this research program. Advection by currents is primarily in response to tidal and windstress forces, and thus occurs over time scales of up to several days.

The movement of water into or out of a semi-enclosed basin such as Upper Laguna Madre must be reflected by water level variations, which can be monitored to follow net gains or losses of water. Thus, the 1974-75 study was centered mainly around an analysis of water level data, collected both along the coast at Port Aransas and at several points in the study area itself.

Tides in the northwestern Gulf of Mexico are characteristically small. Tidal ranges along the eastern and western coasts,

while variable from one location to the next, are on the order of 2-3 meters, with two high and low waters recorded daily. In the Gulf of Mexico, the tide is principally diurnal, and at Port Aransas in particular maximum tidal ranges are nearly always less than one meter.

In intracoastal waters, tidal ranges are still further reduced by the constricting effects of channels and the frictional effects of shallow water bays. There is very definitely a tidal crest moving up the Corpus Christi Ship Channel, across Corpus Christi Bay and into the study site, but in the process, which takes between seven and nine hours, tidal ranges are diminished to a few centimeters at most. At Marker 21 along the Intracoastal Waterway, for example, maximum tidal ranges computed in the 1974-75 study were no more than 2.8 cm for any single tidal constituent. The exchange of water by tidal forces must therefore be considered to be of limited importance.

Water level variations are not absent in the 1974-75 study area, however. They occur primarily over longer time intervals and in response to meteorological forces. Surface winds play the dominant role in producing non-tidal changes. By numerically filtering out the tidal contribution to the observed variations in water level, it was found that approximately 92% of the variation remained, indicating that the principal mechanism responsible for moving water through the study site is a longer-period, meteorological forcing. This is not necessarily a process acting directly on the waters of Upper Laguna Madre, however. Rather, data from the 1974-75 study and results obtained in a related

study of Corpus Christi Bay over the past year suggest that windstress need only move water onshore or offshore across the inner continental shelf. The resulting increase or decrease in coastal water levels will produce a slow filling or draining of coastal bays, eventually including Upper Laguna Madre.

Direct windstress effects on the surface of Upper Laguna Madre are not insignificant. They can be measured by monitoring the local set-up and set-down on the downwind and upwind shores, respectively. The slope in the surface of the study site was found to be on the order of 3 cm/km as water moved in or out. This slope should be thought of as quite large. Similar analysis of Corpus Christi Bay surface slopes (Smith 1974) indicated that a value of 0.5 cm/km is characteristic of the bay. A water level increase or decrease of 10-12 cm at some point along the shore of the bay would in turn cause the water line to advance or retreat perhaps 10 m or more. In the open Gulf or ocean, slopes rarely exceed 0.1 cm/km.

Variations in Upper Laguna Madre water levels could be interpreted in terms of the net amount of inflow or outflow that would be required to produce these changes. The time scales associated with the computed surface slopes provided a good indication of the mechanisms producing the slope and therefore forcing the exchange. Very little tidal influence was indicated, in agreement with the low computed tidal ranges. Instead, water moving through Upper Laguna Madre occurred as a slow inflow and outflow, alternating in response to variations in regional winds, and occurring over time intervals of several weeks. The winter

field exercise, for example, lasted a month, yet included only the last part of an inflow episode and the first part of a return outflow.

The internal circulation within the study area was found to be made up of three components. Talks with engineers at Central Power and Light Co. revealed that there is a steady outflow from study site of over 926,000 m³ per day, as cooling water is pumped into the power plant just west of Pita Island. It is probable that most of this water enters from Corpus Christi Bay through the Kennedy Causeway. The volume of water entering and moving through the area may have a substantial effect in preventing the build-up of pollutants or hypersaline conditions in the northern extreme of Upper Laguna Madre. The heated water from the power plant is then discharged into Corpus Christi Bay and represents a net loss from the study area.

A second component of the internal circulation of the study area is the back-and-forth oscillation of tidal currents, guided to some extent by the navigation channels in the area, particularly the Intracoastal Waterway. The volume of water entering and leaving the study area on each diurnal tidal cycle may be as high as 12% of the estimated total water volume, but there are also periods of perhaps several days when tidal exchanges are insignificant.

The third component of the local circulation is that driven by windstress. Direct measurements of wind-drift currents indicated speeds of up to 10 cm/sec. The representativeness of individual speed and direction measurements in both space and

time, however, is greatly restricted, and the value of isolated measurements is open to question.

The results of the first year's study significantly broadened the understanding of physical processes in Upper Laguna Madre which had been accumulated from earlier studies, and provided information useful in designing a more efficient sampling program for the second year. The study was expanded to include all of Upper Laguna Madre, between the Kennedy Causeway and the Land Cut. Results obtained during the first year indicated that surface slopes could be taken as a measure of horizontal transport of water. It was therefore felt that additional water level data, from Marker 115 at the entrance to Baffin Bay, should be obtained and analyzed as one component of the second year's study.

It became apparent during the first year's study that the internal circulation is, at any given moment, a highly local and transient response to such things as water depth, the presence of navigation channels, and the speed and direction of the overlying winds. Thus, the method chosen for investigating the local circulation of Upper Laguna Madre and its specific effect on water quality was to use temperature and salinity as natural tracers of water movement.

Temperature was also used to investigate the effects of meteorological forces in Upper Laguna Madre, especially those associated with frontal passages through the central Texas Gulf coast. The first year's work suggested a substantial water movement would be associated with the sudden change in surface

windstress. The other principal effect--that of cooling, especially in the shallow flats--could be expected to have a significant effect on the local ecology. In addition, a temperature study in the area would put into better perspective the occasional temperature measurements obtained as part of the synoptic surveys.

With a feeling for these aspects of the physical environment of Upper Laguna Madre, the 1975-76 field program was designed and carried out with an emphasis on water movement through and within the area, and the possible effects of spoil islands on the local circulation. The results of this second year's work are summarized in the following section.

SUMMARY OF THE 1975-76 FIELD STUDY

Both direct and indirect indicators were used in the second year of the Upper Laguna Madre Study to investigate and describe several aspects of the local hydrography. Synoptic surveys were conducted between the Kennedy Causeway and the Land Cut, using temperature and salinity as natural tracers of water movement. Temperature and salinity patterns gave no indication that the existing number and distribution of spoil islands is inhibiting the local circulation enough to significantly affect water quality. The slight variations in temperature and salinity were noted on both sides of the Intracoastal Waterway, suggesting that these gradients can be attributed to shallow water effects.

Temperature measurements made over an approximately thirteen month period suggest an annual temperature range of nearly 21°C.

Hourly temperature measurements obtained over a shorter period of time indicate that in the winter months at least there may be shorter-period temperature variations of over 10°C . Diurnal temperature variations in the shallow grass flats are small and depend on cloudiness on a given day, but range generally less than two degrees Centigrade.

Salinity measurements made along the axis of the Intra-coastal Waterway show a significant increase in the average salinity just beyond Marker 33. This is interpreted as the average limit of penetration of tidal exchanges with Corpus Christi Bay. Increasing salinity values to the south indicate that wind-induced exchanges become progressively less efficient in renewing water.

In a hydrographic sense, the most significant natural events in the study area are the relatively rare hurricanes and the occasional winter frontal passages. The shallow waters in the grass flat areas may cool by 10°C or more in a matter of one or two days. The water movement generated by the sudden wind shift may lead to a renewal of a substantial fraction of the water in Upper Laguna Madre. In the process, significant areas of shallow flats may be exposed for periods of up to several days.

RESULTS AND DISCUSSION

A. Synoptic Surveys

A series of synoptic surveys was scheduled between mid June and early January to provide a near instantaneous picture

temperature and salinity distributions throughout Upper Laguna Madre. Previous survey work by other investigators had concentrated on one-dimensional temperature-salinity (T-S) variations along the axis of the Intracoastal Waterway. This aspect of the 1975-76 study was intended to expand such surveys laterally to the areas behind the spoil islands, and investigate the possibility that the presence of spoil islands along the eastern side of the Waterway was inhibiting circulation in Upper Laguna Madre, allowing higher salinities to exist in the more isolated areas and therefore deteriorating water quality. In order to definitely attribute high salinities to the effects of spoil islands, T-S measurements were made on both sides of the Intracoastal Waterway. This provided a check against processes which were related only to shallow water or distance from the Waterway.

A series of eight synoptic surveys were conducted between the Kennedy Causeway and the Land Cut in the 1975-76 study. In addition, similar T-S data from surveys conducted by the U. S. Geological Survey for the Texas Water Development Board between 1968 and 1970 provided data which are included in this section.

1. 13 June, 1975

The first survey was intended as a shakedown cruise to test equipment and techniques, and to provide the first direct exposure to the enlarged study area. The survey was conducted between Marker 3, at the southern edge of Corpus Christi Bay, and Marker 75, just over 14 nautical miles south of the Kennedy Causeway. Results are shown in Figure R1. Temperatures vary only slightly more than a degree centigrade over the approximately

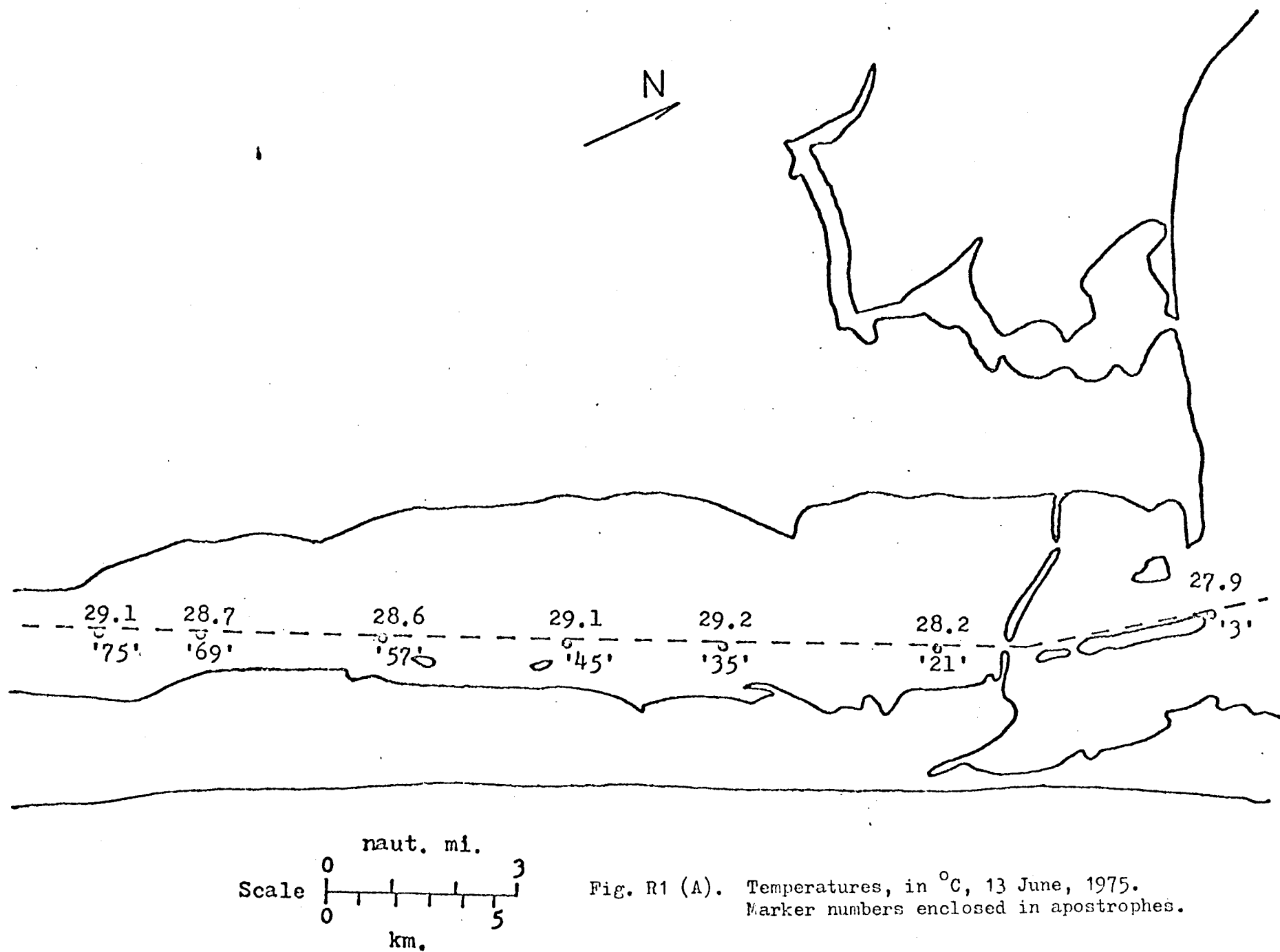
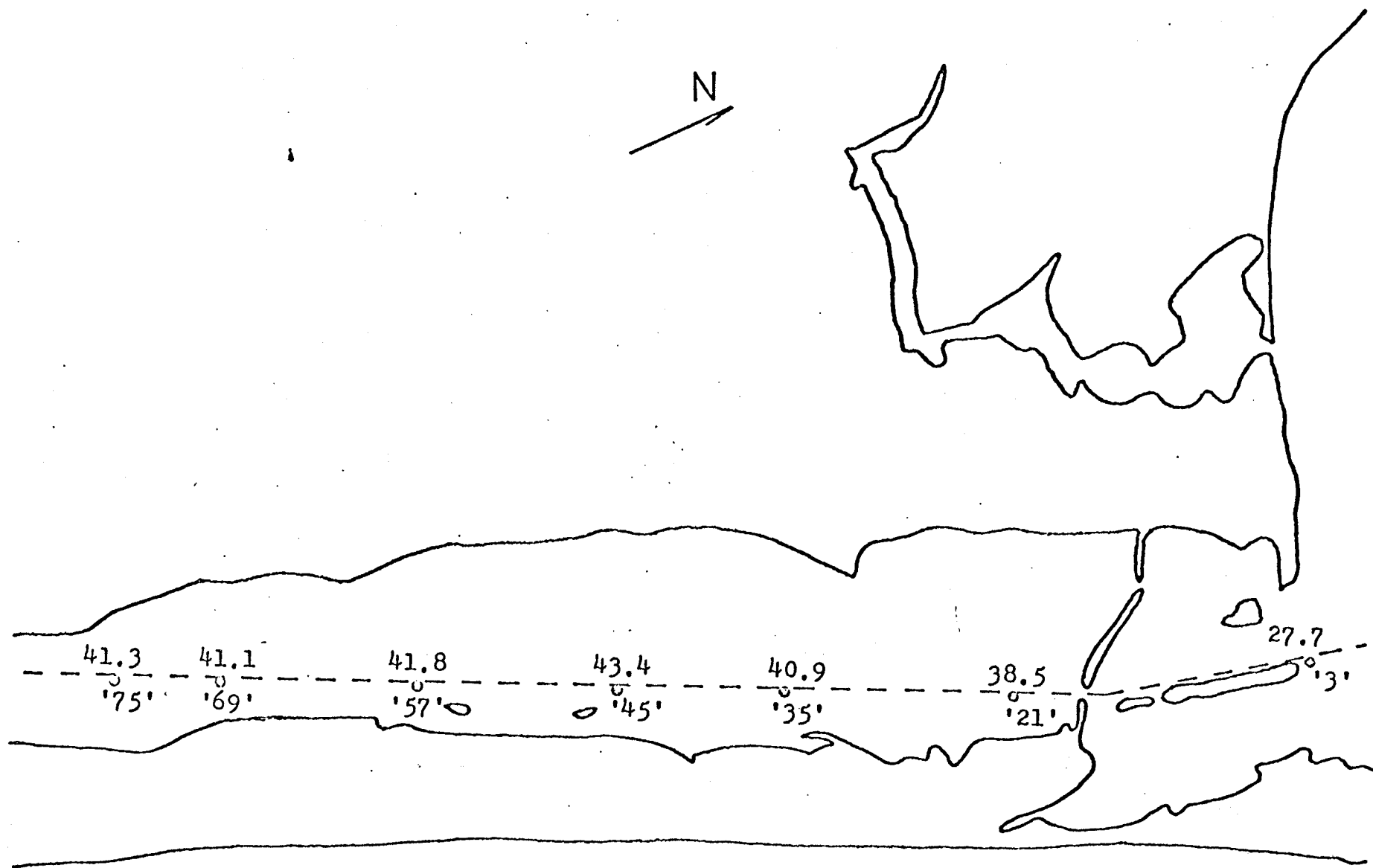


Fig. R1 (A). Temperatures, in °C, 13 June, 1975.
Marker numbers enclosed in apostrophes.



Scale

naut. mi.

0 3

0 5

km.

Fig. R1 (B). Salinities, in parts per thousand, 13 June, 1975. Marker numbers enclosed in apostrophes.

17.5 nautical miles covered in this study. Salinities show a sharp gradient, however, especially between the edge of Corpus Christi Bay, where a value of 27.7 parts per thousand (ppt) was recorded, and Marker 21 below the Causeway, where the salinity had risen to 38.5 ppt. The rapid increase of nearly 11 ppt over this distance indicates that Corpus Christi Bay water was not penetrating into Upper Laguna Madre at that time. Below Marker 21, salinity varies little over the next seven nautical miles, reaching a maximum of 43.4 ppt at Marker 45 before decreasing slightly to 41.3 ppt at Marker 75.

2. 17 July, 1975

The second survey covered a smaller area, but included the first T-S measurements behind the spoil islands on the National Seashore side of the Waterway. T-S measurements were recorded along a distance of approximately two nautical miles, between Markers 39 and 47 (Fig. R2). In addition, T-S measurements were made along a line perpendicular to the Intracoastal Waterway near Marker 41A. Neither temperature nor salinity values showed substantial variation within this area. Along the Waterway, temperatures varied between 27.3 ppt and 27.6°C, and salinities ranged from 35.8 to 37.1 ppt. No clear trend is apparent in the spatial variation of either temperature or salinity. Along the lateral line extending toward the Seashore, there is a fairly distinct increase in temperature from 27.7°C at the Waterway to 31.7°C near the shore, and a decrease in salinity from 37.0 ppt at the Waterway to just under 35 ppt near the shore. The T-S gradients are not concentrated across the spoil islands, and this may well be only an effect of

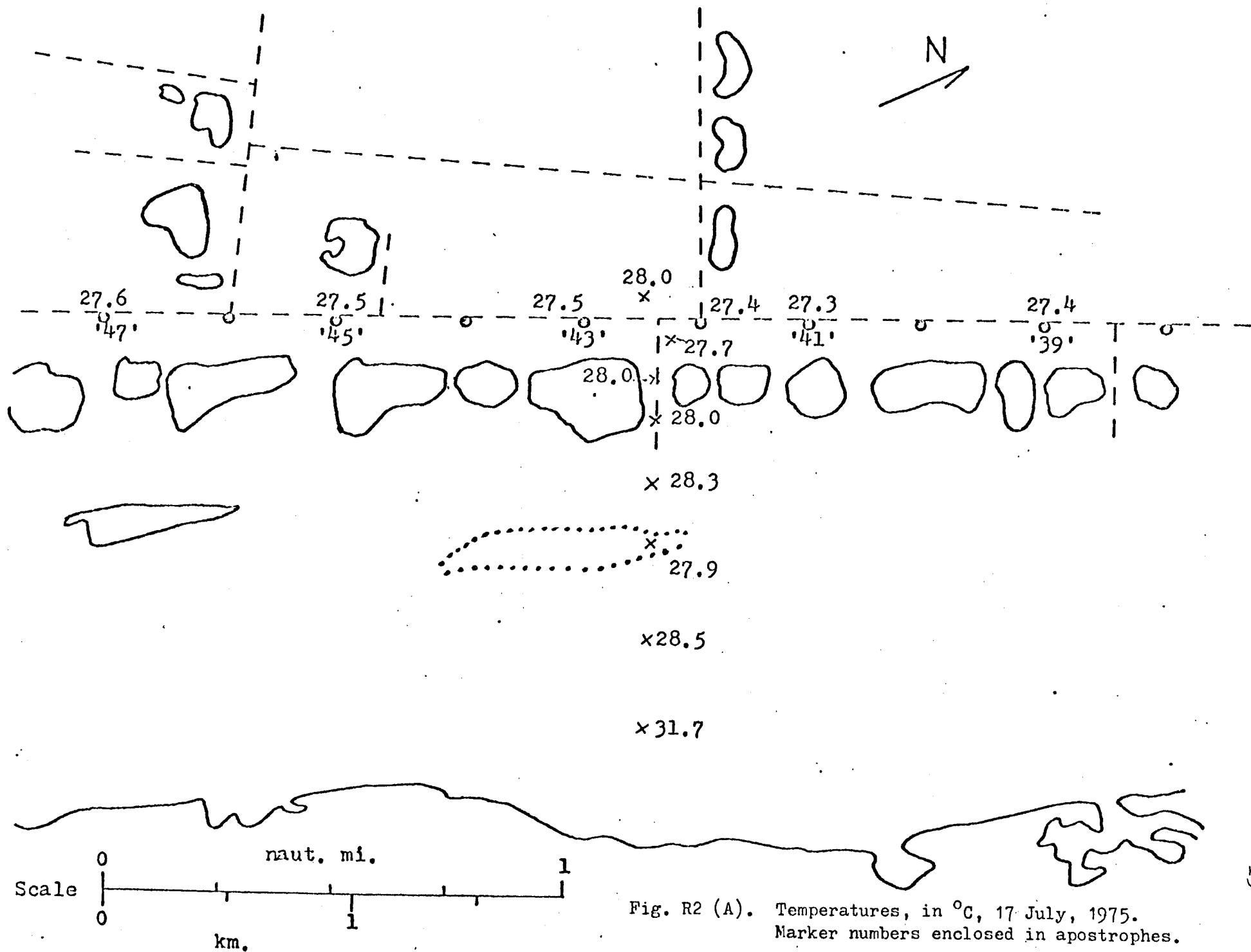


Fig. R2 (A). Temperatures, in °C, 17 July, 1975.
Marker numbers enclosed in apostrophes.

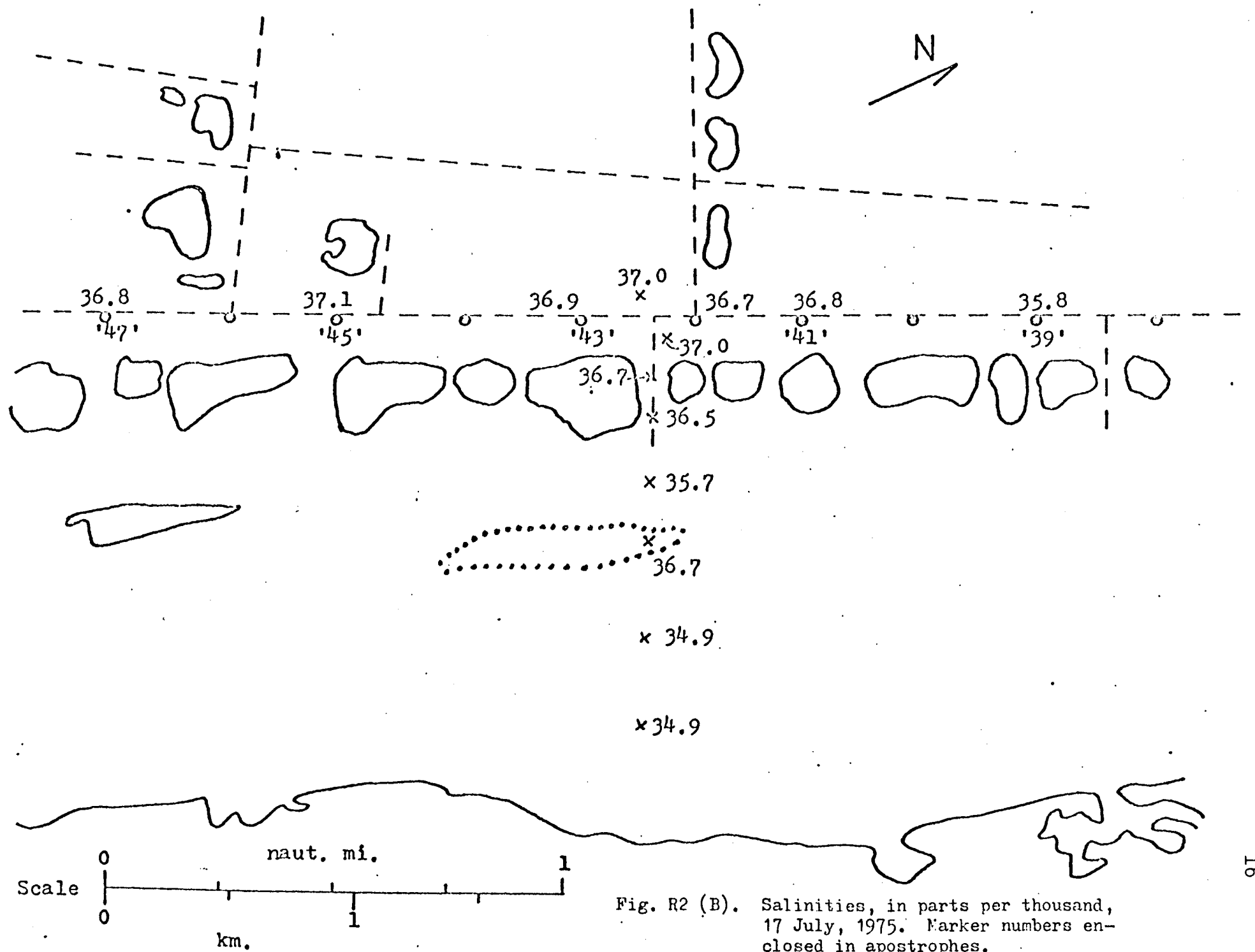


Fig. R2 (B). Salinities, in parts per thousand, 17 July, 1975. Marker numbers enclosed in apostrophes.

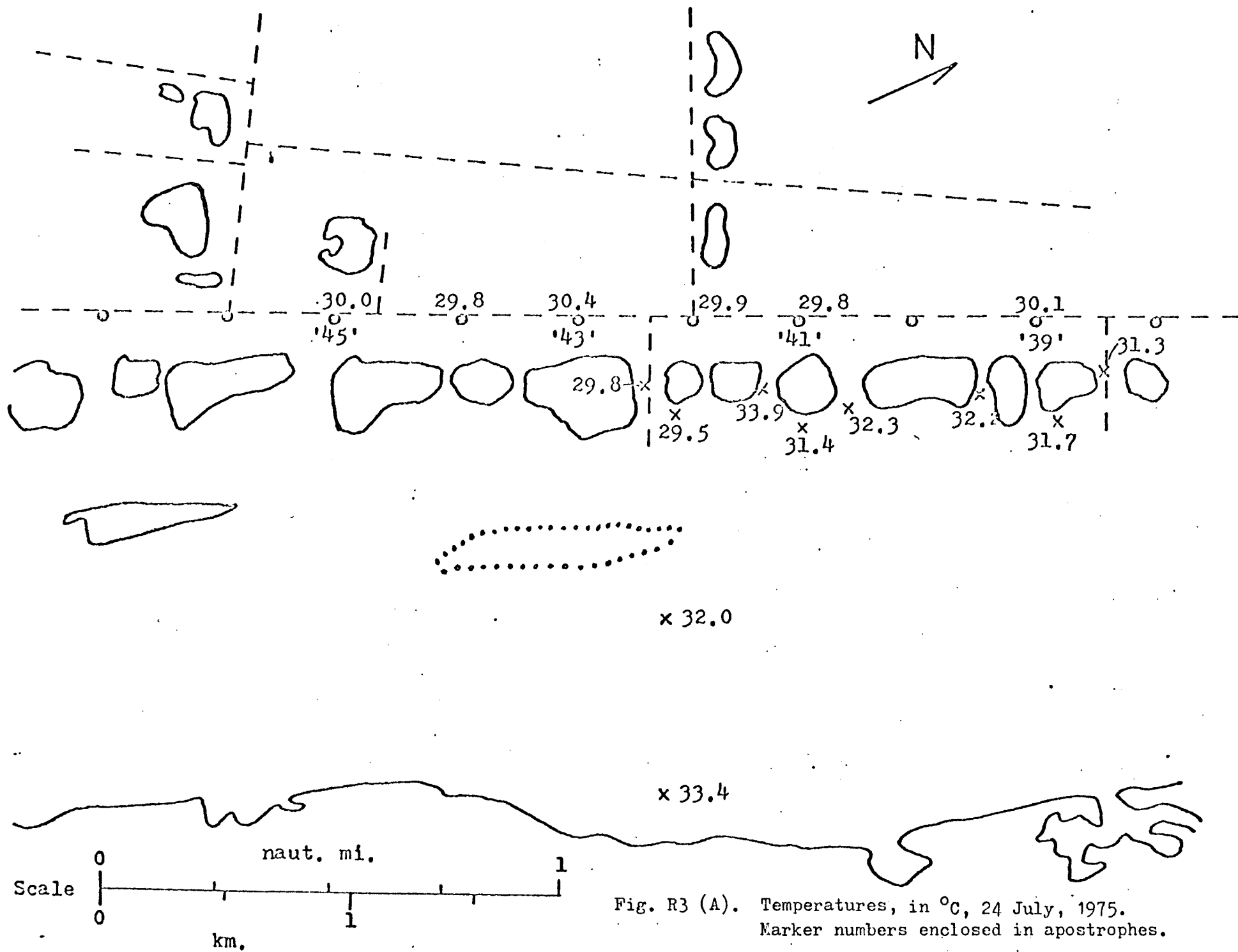
shoaling water near the eastern shore. This would almost certainly explain the gradual increase in temperature.

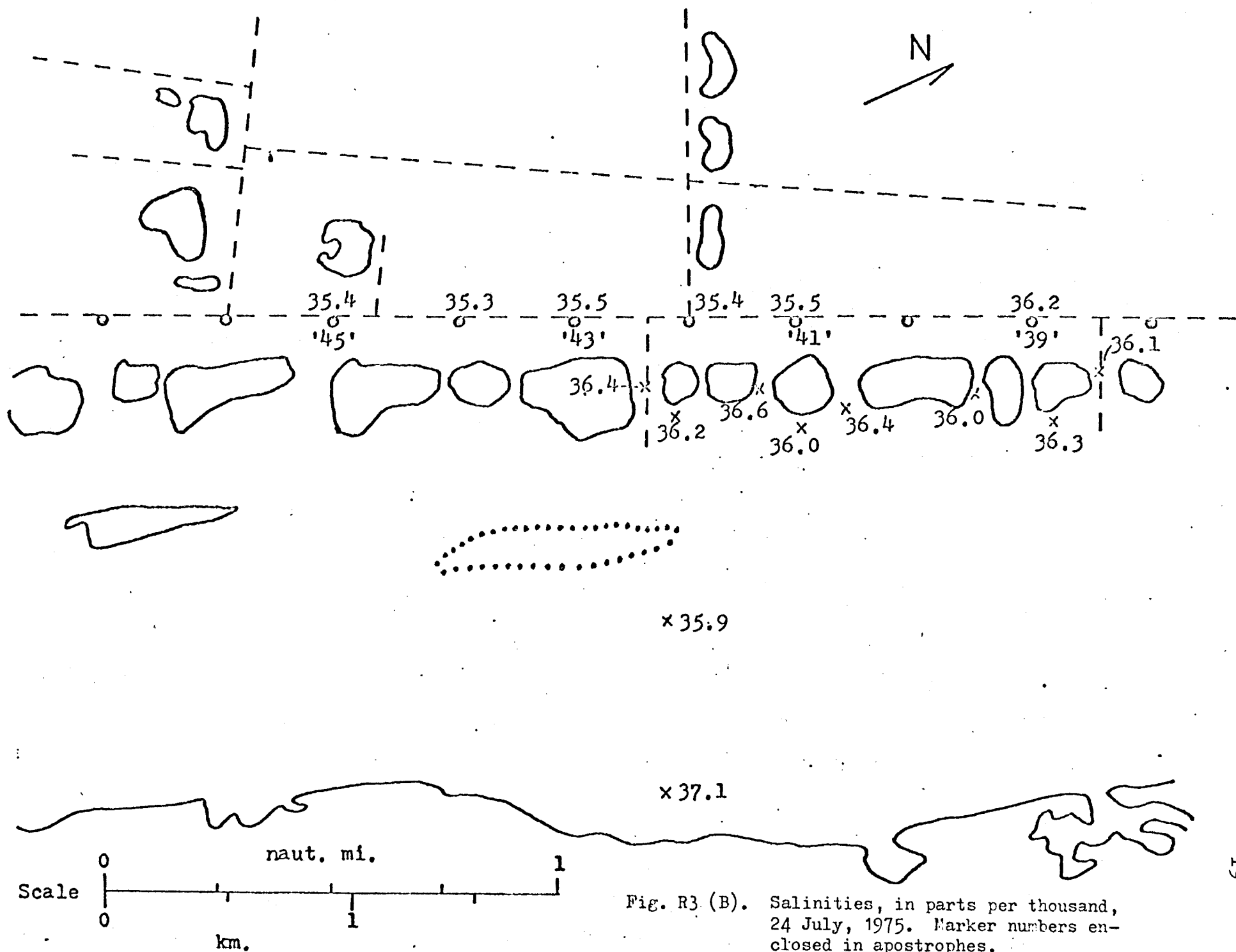
3. 24 July, 1975

The cruise plan for the third survey was similar to that of the second. T-S measurements were made along an approximately 1.5 nautical mile length of the Waterway between Markers 39 and 45, and again laterally toward the Seashore from near Marker 41A. Salinities along the Waterway varied only between 35.3 and 36.2 ppt. The highest value recorded was 37.1 ppt in the shallow water near the eastern shore. Temperature values along the Waterway are on the order of 3°C higher than they had been five weeks before, and ranged between 29.8 and 30.4°C . Temperatures behind the spoil islands are approximately $2\text{--}3^{\circ}\text{C}$ higher, with highest values just under 34°C . This is most likely attributable to the fact that shallower water characteristically has a greater response to available sunshine.

4. 2 September, 1975

The fourth survey focused on the area between Markers 51 and 59 (Fig. R4), a distance of only two nautical miles, but included a considerable amount of T-S data from either side of the channel. Temperatures along the Waterway varied irregularly between 27.9 and 29.2°C . Water temperatures over the flats on either side of the Waterway were generally within this range, with the exception of a 29.8°C reading very near the west shore, and two 29.3°C readings just beyond the spoil islands to the east of the Waterway. These are not felt to be significant, as they are most likely a shallow water effect. Salinity variations were also found to be small, ranging between 34.4 and 36.6 ppt





along the Waterway, and no higher than 37.1 ppt throughout the area sampled on this survey.

5. 19 September, 1975

The fifth survey was conducted along and again on either side of the Waterway between Markers 59A and 75, a distance of about 3.9 nautical miles (Fig. R5). Along the Waterway, salinities varied between 33.9 and 34.9 ppt. Highest values were a 35.4 ppt reading measured in the flats near the western shore, and a 35.5 ppt in the flats very near the eastern shore. This suggests no significant effect directly attributable to spoil islands, as these would be confined to the eastern side of the Waterway. The entire area was very nearly isothermal, with temperatures varying only between 28.2 and 29.0°C.

6. 5-6 November, 1975

The sixth survey was conducted over a two day period to provide enough time to include measurements made between the Kennedy Causeway and the Land Cut. This survey provided T-S and current data, primarily along the Intracoastal Waterway, but also in lateral channels leading into The Hole from the Land Cut. Temperatures were generally between 24 and 27°C, having dropped around 3°C from their annual maximum in September. Lowest salinities of 26 to 28 ppt were found at opposite ends of Upper Laguna Madre, near the Kennedy Causeway and in The Hole. Salinities along the Waterway in the central part of Upper Laguna Madre were between 31 and 37 ppt; highest values of 37-38 ppt were measured behind the spoil islands on the return trip.

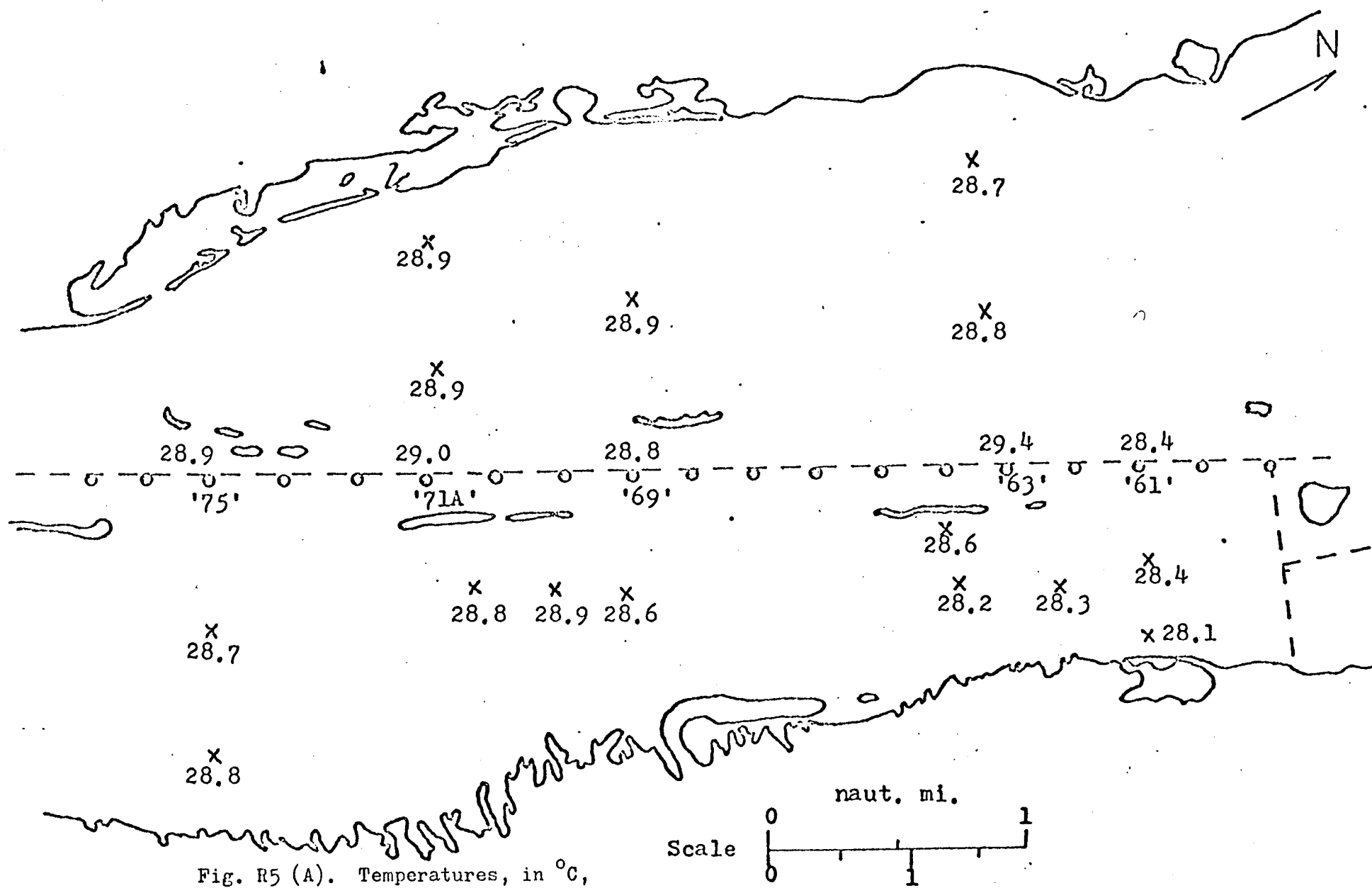


Fig. R5 (A). Temperatures, in $^{\circ}\text{C}$,
19 September, 1975.
Marker numbers enclosed in apostrophes.

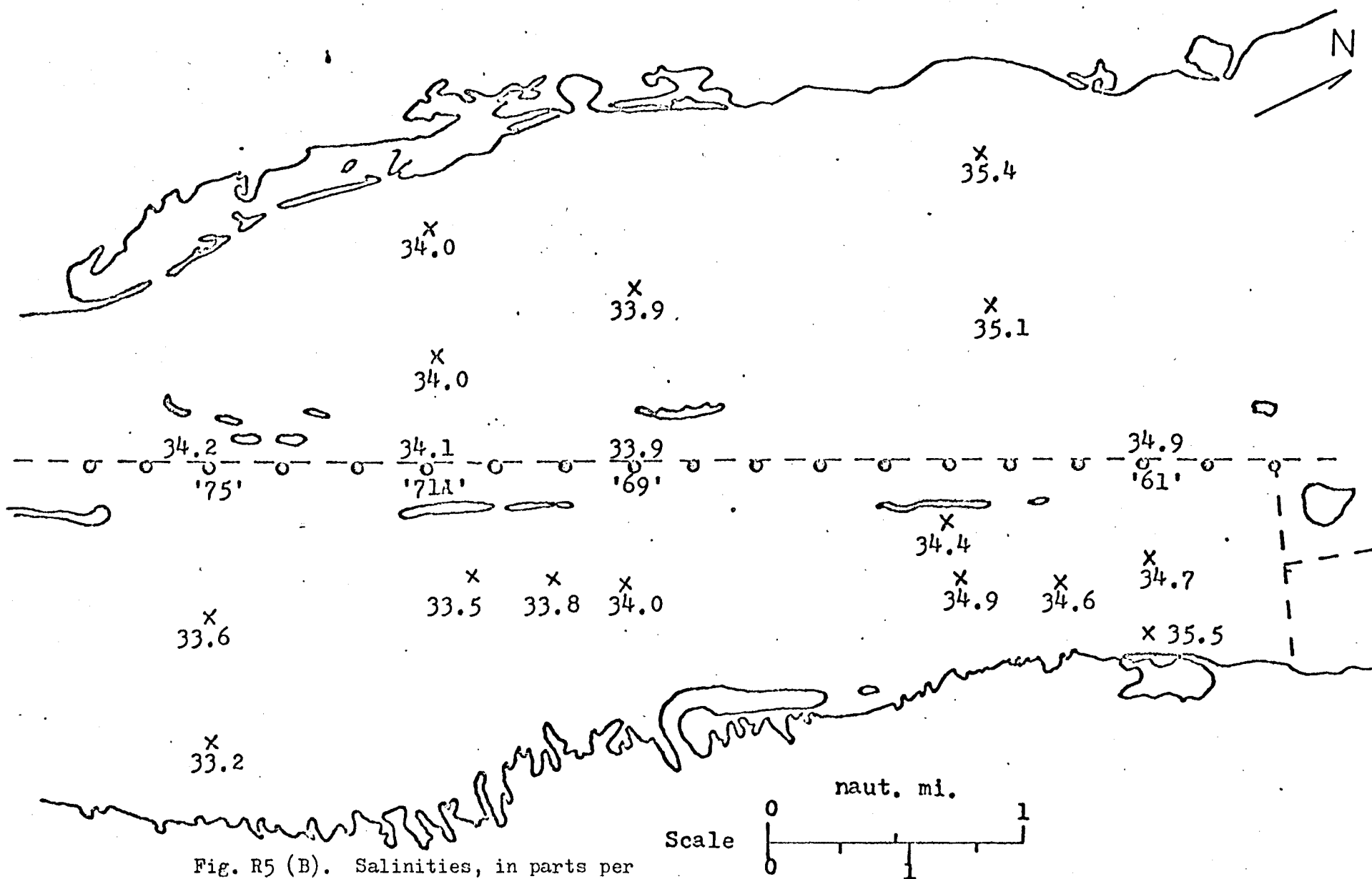


Fig. R5 (B). Salinities, in parts per thousand, 19 September, 1975. Marker numbers enclosed in apostrophes.

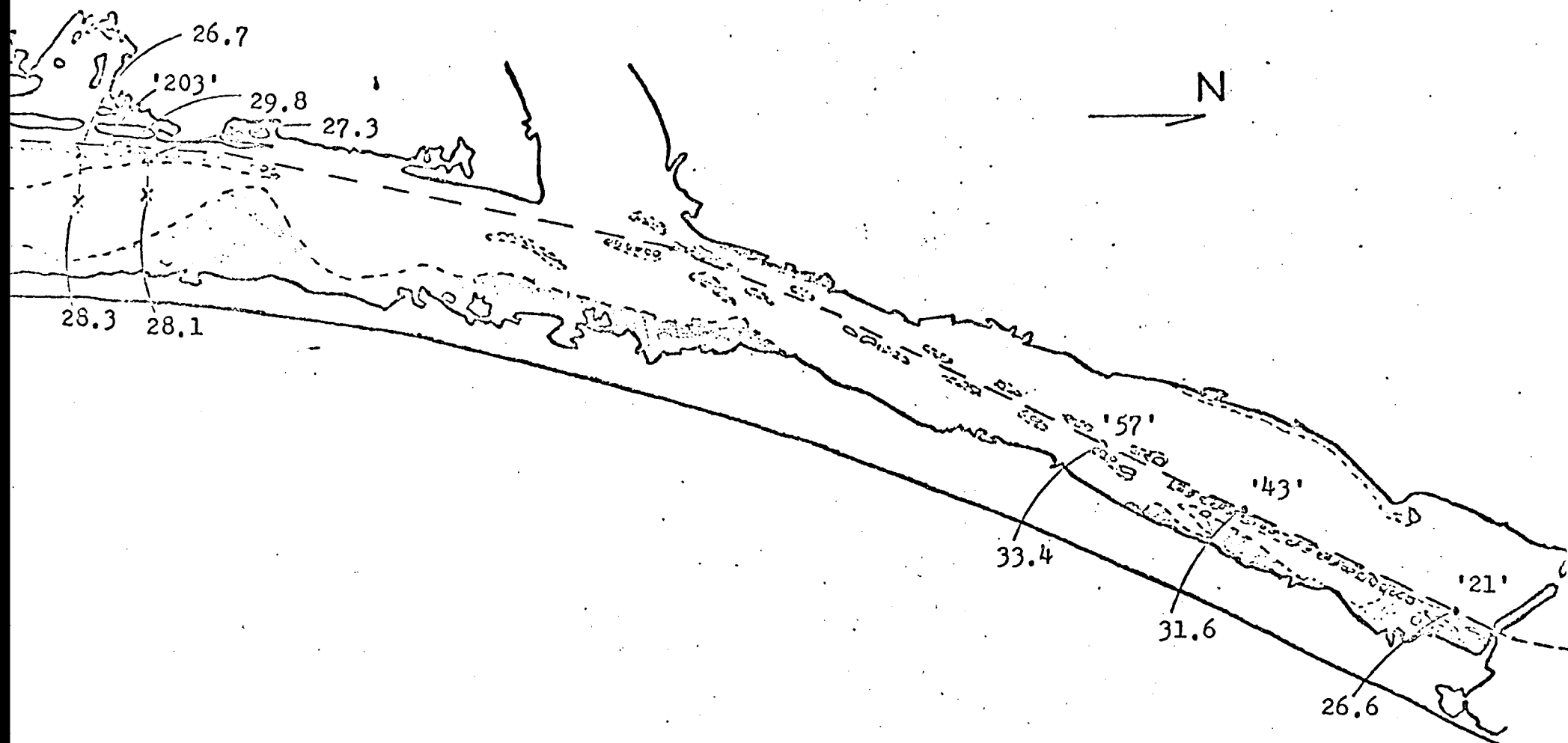


Fig. R6.1 (B). Salinities, in parts per thousand,
5 November, 1975.
Marker numbers enclosed in apostrophes.

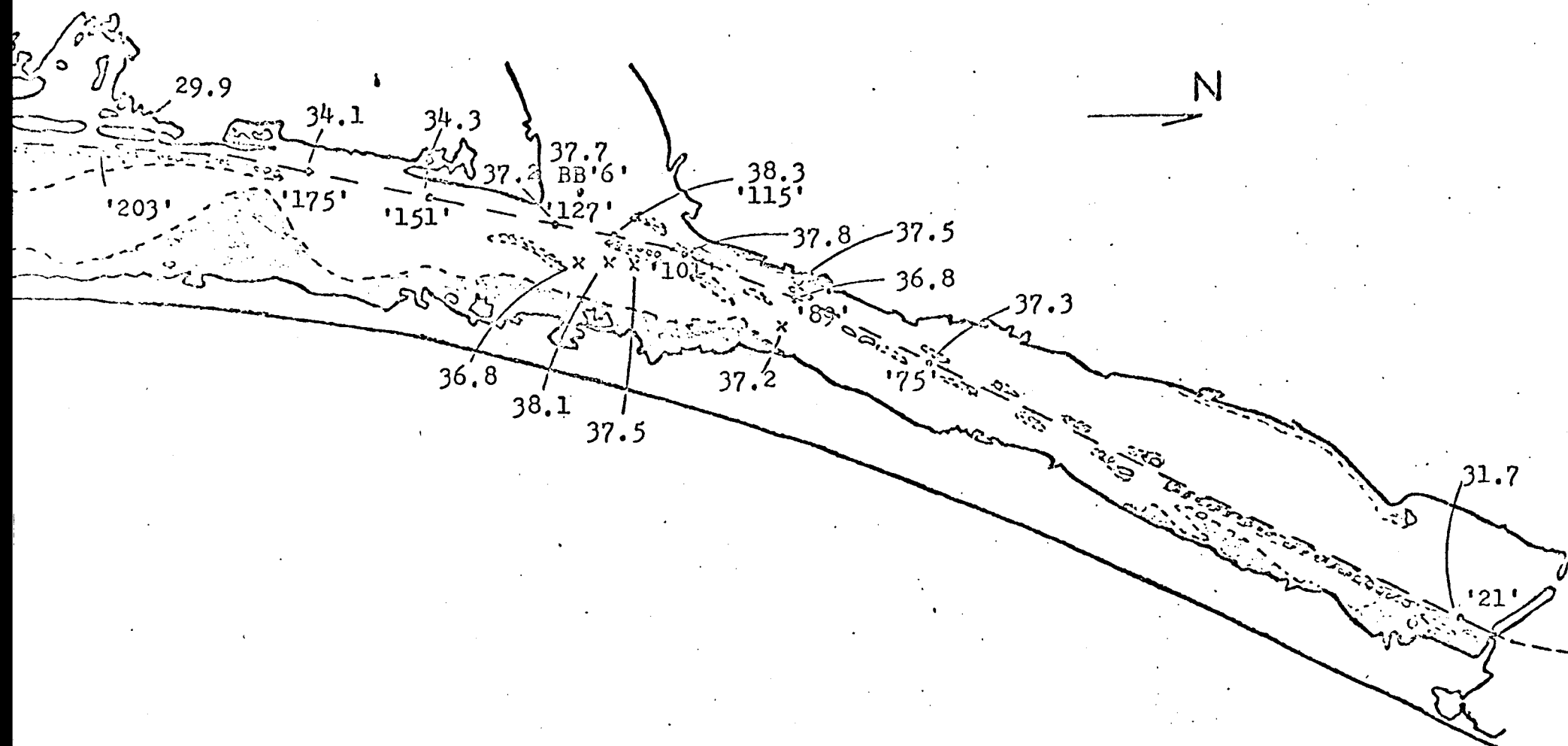
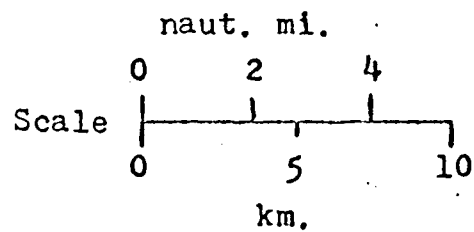


Fig. R6.2 (B). Salinities, in parts per thousand, 6 November, 1975. Marker numbers enclosed in apostrophes.



Wind drift currents were measured at several locations using a surface float on a 10 meter long tether line. The time interval required for the float to drift to the end of its tether was used to calculate the surface current speed. When the current direction was not parallel to the axis of the channel, the direction was determined using a sighting compass. Currents of about 1/2 knot (26 cm/sec) were found moving to the south through the Land Cut in the early afternoon of the first day. Movement was still to the south the following morning, but speeds had decreased to about 8 cm/sec. Current measurements made in the channel connecting The Hole with the Land Cut near Marker 201 again showed water moving at nearly a half a knot (24 cm/sec), leaving The Hole on the afternoon of the first day. This lateral channel, cut for the purpose of improving the exchange of water between the Land Cut and The Hole, appears to be serving well in this capacity. Within The Hole itself, wind drift measurements were substantially weaker. A speed of under 7 cm/sec was measured in mid afternoon of the first day.

7. 11 December, 1975

The seventh survey was carried out following the first few frontal passages of the season. Surface temperatures, reflecting the cooling effects of the fronts, were narrowly confined to between 17.2 and 18.6°C. Values generally increased to the south, with lowest temperatures found near the Causeway (Fig. R7). A substantial fraction of this change, however, was likely in response to diurnal heating, and thus a temporal and not a spatial variation. Salinities similarly increased to the south. A fairly

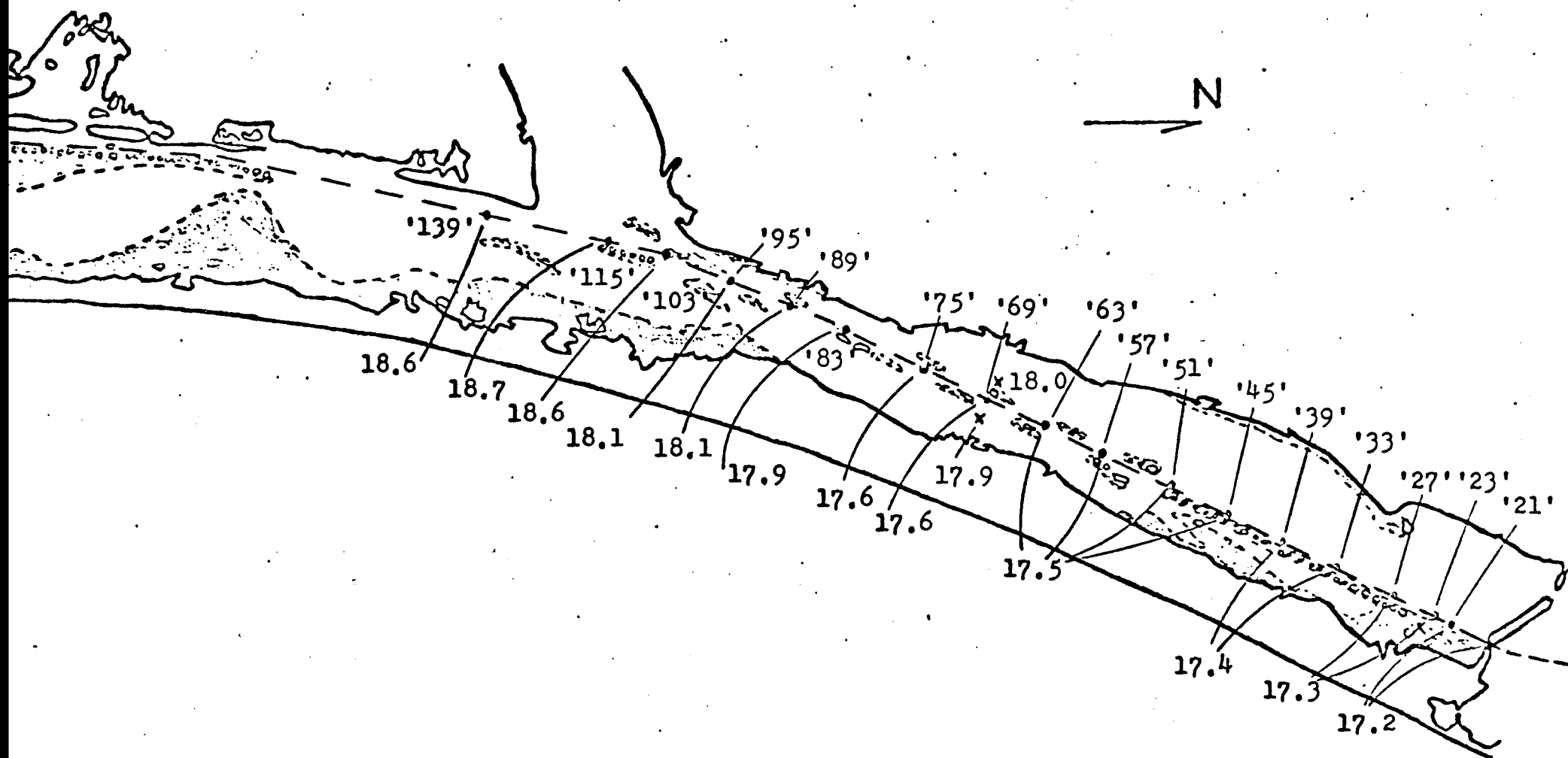
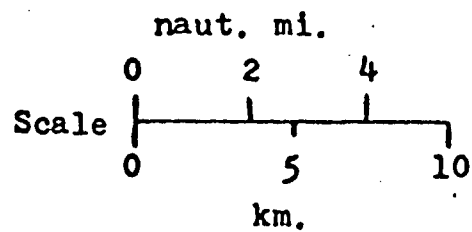


Fig. R7 (A). Temperatures, in $^{\circ}\text{C}$, 11 December, 1975.
Marker numbers enclosed in apostrophes.



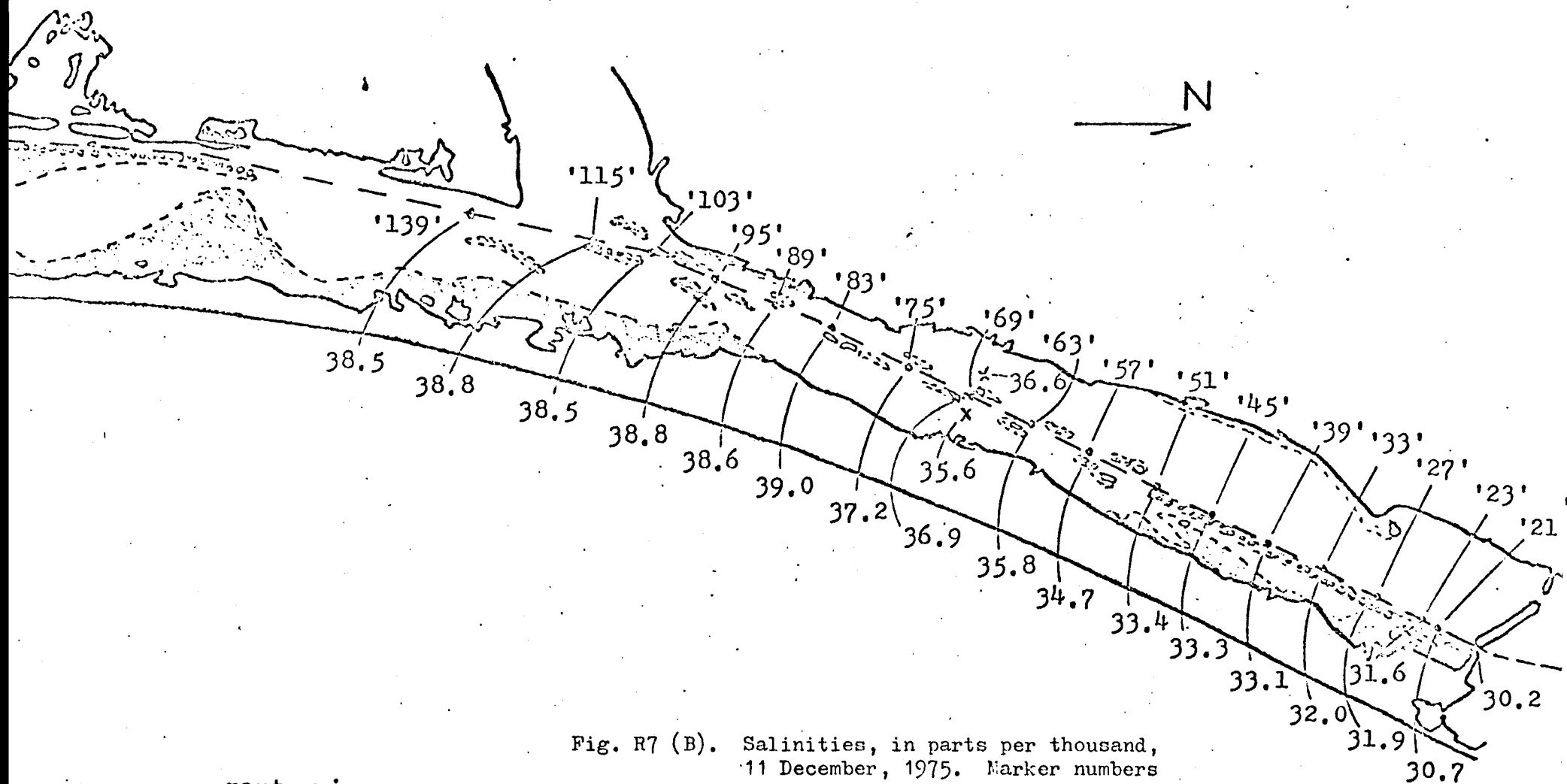
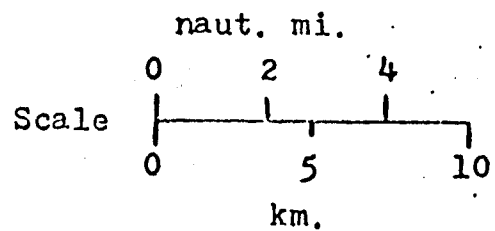


Fig. R7 (B). Salinities, in parts per thousand, 11 December, 1975. Marker numbers enclosed in apostrophes.



steady increase in salinity was found from near 30 ppt at the Causeway to over 36 ppt at the entrance to Baffin Bay.

Currents recorded on this survey were flowing into Upper Laguna Madre from Corpus Christi Bay. Current speeds, however, were quite low--generally less than 10 cm/sec.

9. U. S. Geological Survey Synoptic Data

A limited amount of similar, synoptic survey data was obtained in the form of annual reports prepared by the Texas Water Development Board. Surveys were conducted by the U. S. Geological Survey through the study area on 27-28 August, 1968; 16-17 September, 1969; and on 16 July and 6 August, 1970. The results will be summarized here where pertinent, but will not be presented in map form.

The August, 1968 survey shows a great homogeneity in temperature. Measurements were made along five tracks perpendicular to the Intracoastal Waterway, approximately equally spaced between the Kennedy Causeway and Marker 89, a total distance of just over 22 nautical miles (41.2 kilometers). The temperature varied only between 27.9° and 29.5°C , with the exception of two 31°C readings recorded near the entrance to Baffin Bay. Salinities varied from 27.0 ppt at the edge of Corpus Christi Bay to 34.2 ppt north of the entrance to Baffin Bay at about Marker 89. No salinity measurements were made in the flats east of the spoil islands. In the shallow waters west of the Intracoastal Waterway near Marker 49, salinities were 28.4 ppt, compared to just over 30 ppt in the Waterway itself.

The September, 1969 survey revealed quite high salinities, with values increasing from 44.0 ppt at the Causeway to 51.5 ppt in the Waterway at Markers 49 and 69, and again in the flats just east of Marker 89. Temperatures were at about their annual maximum, ranging from 28.2°C at the Causeway to just over 31°C in the shallow waters west of Marker 49.

The July and August, 1970 surveys were restricted to sampling at the edge of Corpus Christi Bay and at the Kennedy Causeway. Though sampling was spread out over nearly three weeks, temperatures varied only between 28.3° and 29.5°C. Slight temporal variability is characteristic of that time of year when temperatures have attained a seasonal high, just prior to the first cold fronts of the fall and early winter. Salinities showed a slight decrease over this time interval, dropping from approximately 33-34 ppt in July to values of just under 31 ppt recorded in August.

The synoptic surveys provide the data required for answering the questions: (1) are there significant T-S variations occurring laterally across Upper Laguna Madre, between the Intracoastal Waterway and the nearby flats? (2) do the T-S distributions suggest that the spoil islands along the Intracoastal Waterway are substantially inhibiting the lateral circulation and thus the renewal of water in areas removed from the Waterway? and (3) are the measured T-S differences significant in affecting local plant and fish populations?

Temperature and salinity distributions reflect the long-term, net effect of internal circulation patterns, and thus

provide a better indicator of the local circulation than do spot measurements of wind-drift currents. Results obtained from available historical surveys and from the 1975-76 field program suggest that T-S variations between the Waterway and the adjacent flats are characteristically less than $2-3^{\circ}\text{C}$ and 2-3 ppt. The available data are not adequate for defining a trend, however it is safe to assume that these small variations are deviations from a somewhat more stable physical environment along the Intra-coastal Waterway. For example, in mid to late summer, temperatures in the flats would be characteristically $2-3^{\circ}\text{C}$ warmer than in the Waterway, and at times of lowest winter temperatures, the flats would be on the order of a few degrees cooler. Little information is available to support this latter statement, however. Similarly, but depending primarily upon recent rainfall in the area, the salinity of water in the flats would decrease slightly during periods of high rainfall, and increase relative to values recorded in the Waterway at times when rainfall did not compensate evaporative losses.

Regarding the effects of such T-S differences on the local ecology, Dr. Warren Pulich and Dr. D. E. Wohlschlag were consulted to learn of what effects might be reflected in local plant and fish populations, respectively. Both scientists have worked in, and are familiar with the region. Neither felt that the local species would be physiologically unable to cope with T-S variations this small.

The T-S data obtained from the shallow waters behind the spoil islands do not indicate that the blocking effect of the

islands is a major factor in explaining the observed spatial variations in temperature and salinity. In many cases, the T-S characteristics were similar around the islands, and variations were noted only with increasing distance from the Waterway. Often, variations with distance from the Waterway were similar both toward the east and the west. Thus, one can most safely conclude that T-S variations related to water depth are common, but relatively small in Upper Laguna Madre, and that these effects do not appear to be influenced by the existing array of spoil islands. This situation could, of course, be altered with additional dredging, but the circulation around the spoil islands seems to be adequate at present to prevent the significant deterioration of water quality.

B. Longitudinal Variations in Salinity

The amount of time required to sample T-S patterns along lateral lines into the flats on either side of the Intracoastal Waterway in most cases prevented any given survey from covering long distances along the axis of the Waterway. Also, the relatively short time available for the 1975-76 field program made it difficult to establish the local variability in salinity at any given point along the Waterway. To supplement the existing data, salinity measurements, made at 18 locations along the Intracoastal Waterway between Marker 1 at Corpus Christi Bay and Marker 115 at the entrance of Baffin Bay, were provided by Dr. E. W. Behrens for reanalysis in this study. The results of 31 synoptic surveys, carried out between 16 December, 1964, and 27 September, 1968, were used to compute long-term averages and standard

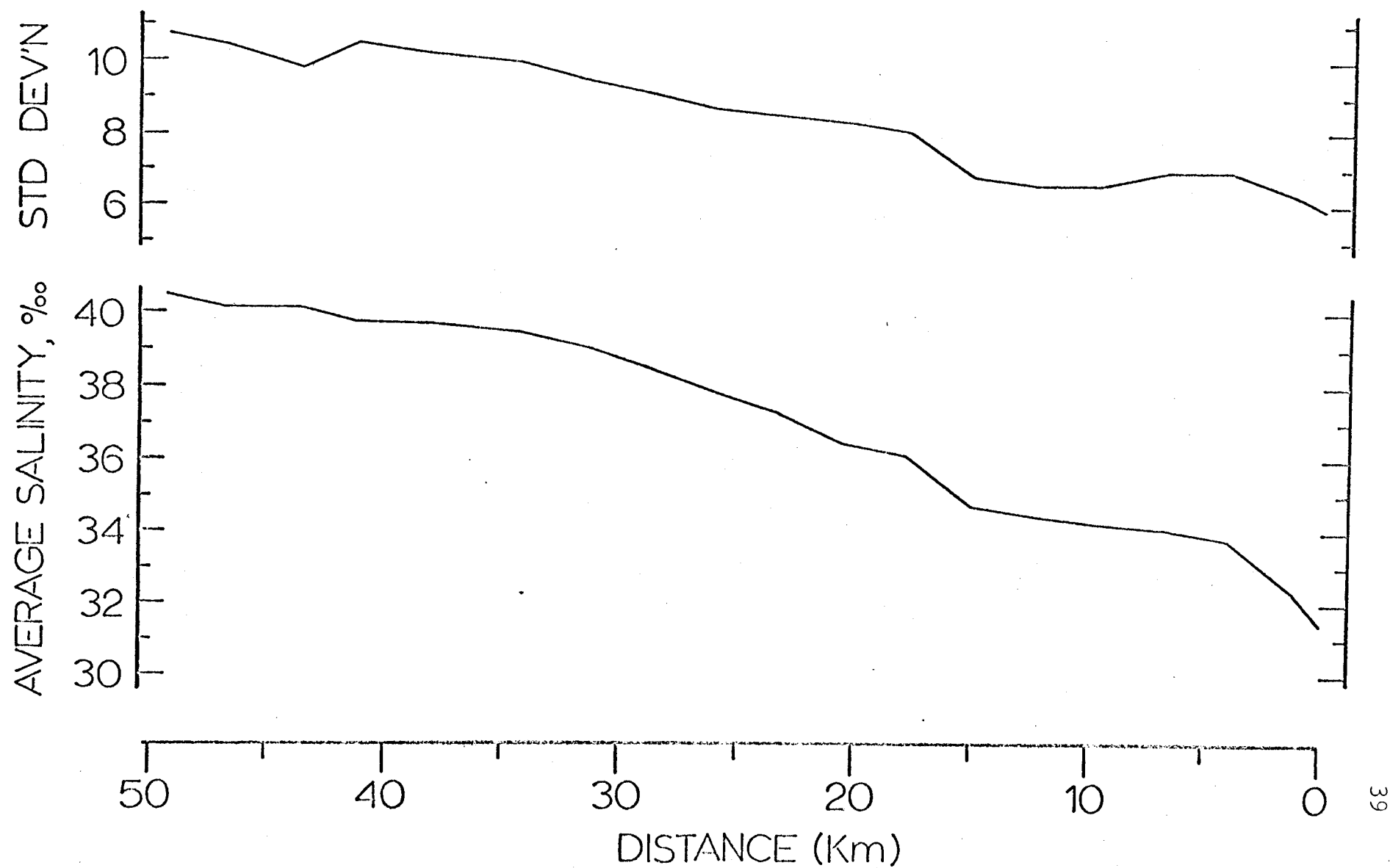


Fig. R9. Average salinities and standard deviations (in parts per thousand) from measurements along the Intracoastal Waterway, 16 December, 1964, to 27 September, 1968.

deviations as a function of distance from the entrance to Corpus Christi Bay. The results are useful both for understanding this aspect of the climatology of Upper Laguna Madre, and for inferring the characteristic tidal excursion of water moving southward through the Laguna from Corpus Christi Bay. Tidal exchanges will have the effect of buffering extremes in salinity, caused by alternate heavy rainfall and excessive evaporation in the shallow waters of Upper Laguna Madre. The portion of Upper Laguna Madre experiencing a regular renewal of water from Corpus Christi Bay should be identifiable in terms of salinity values closer to those characteristic of the bay itself, and a smaller standard deviation about the average salinity of the bay. In a region of generally high evaporation, but experiencing occasional heavy precipitation, that part of Upper Laguna Madre beyond the normal tidal exchange of water with Corpus Christi Bay should reflect the higher mean salinity and standard deviation associated with a dominant control of local processes.

Figure R9 shows a general increase in both average salinity and standard deviation with increasing distance from Corpus Christi Bay. A distinct jump in both the average salinity and the standard deviation is apparent between Markers 33 and 39. It is suggested that the tidal transport of water originating in Corpus Christi Bay is characteristically to a point somewhere between these two sampling stations, and the tidal excursion is therefore between approximately 15 and 18 kilometers.

The implications associated with the analysis of these salinity data are important. It becomes apparent that the region

Markers 33 and 39 should be thought of as the average limit of tidal oscillations between Upper Laguna Madre and Corpus Christi Bay. That is, this point represents the boundary between the area regularly reached and buffered by tidal exchanges with Corpus Christi Bay, and the area further to the south which experiences more extreme environmental conditions due to natural, local processes. It would seem then, that there should be greater concern shown in this further removed portion of Upper Laguna Madre for man-induced activities which would tend to decrease natural exchange mechanisms. For example, while the effects of spoil islands on the local circulation does not presently appear to result in diminished water quality, the creation of new spoil islands, or the expansion of existing spoil islands would have a greater effect on water quality south of Marker 39, where tidal motions are less efficient in removing hypersaline water.

The long-term salinity variations along the axis of the Intracoastal Waterway also provide a valuable comparison for the lateral variations of salinity observed during the 1975-76 synoptic surveys. In particular, salinity differences on the order of 2-3 ppt between the Waterway and the adjacent flats is small relative to the 7-10 ppt standard deviation characteristic of most points along the Waterway itself. It is thus difficult to assign significant importance to small spatial variations relative to a region which is itself highly variable.

C. Temperature Variations Characteristic of Shallow Grass Flats

The temperature patterns observed during the 1975-76 synoptic surveys should not be thought of as static or slowly

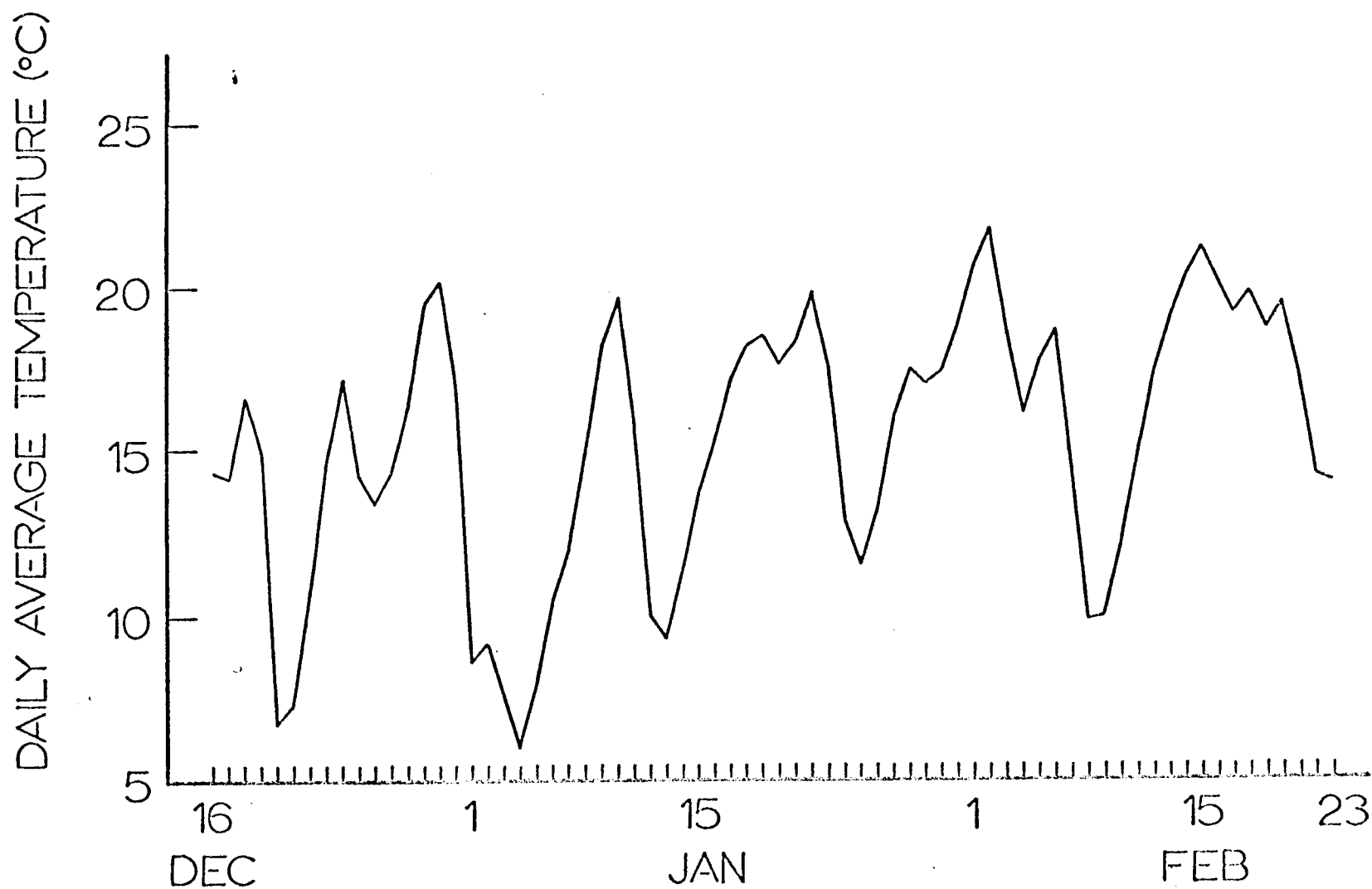


Fig. R10. Daily average temperatures, in °C, computed from hourly measurements, 16 December, 1973, to 23 February, 1974.

changing. Superimposed onto the long-term, seasonal temperature variations are shorter-period changes occurring in response to wind shifts, especially frontal passages, and daytime heating. The spot measurements obtained on the synoptic surveys are part of a constantly-changing pattern, and their representativeness in time can only be estimated from time series measurements of temperature from a recording device in a fixed position.

A total of 1,654 hourly temperatures were recorded between 16 December, 1973, and 23 February, 1974, in about two feet of water near the Laguna Ranger Station, just over one-half nautical mile northwest of Pita Island. Daily average temperatures for this nearly 69-day period are shown in Figure R10. The pattern shows a series of temperature maxima spaced at intervals of approximately 11-13 days, reflecting the effects of polar air outbreaks reaching the central Texas coast. Temperature drops on the order of 10-12°C in the shallow grass flats over a time interval of 2-3 days, before starting to rise again. Over the whole study period, there is a slow, seasonal warming. Lowest annual temperatures would be expected sometime in January or perhaps even early February, as meteorological seasons characteristically lag behind the calendar seasons by a month or more. Deviations from climatological patterns in any given year, however, may be substantial. These shorter-term variations in temperature must be kept in mind when looking at the long-term, annual temperature variations, as represented by the approximately monthly sampling of the synoptic surveys or by other investigators, or when considering smaller temperature differences found during

surveys extending over much of the daylight hours. Differences in the latter case may simply reflect diurnal heating, while seasonal patterns may be significantly masked by transient effects associated with unseasonably warm or cold weather.

D. Seasonal Temperature Variations in Upper Laguna Madre

The shorter-period variations in temperature noted above must be kept in mind when looking at annual temperature patterns, as brought out by less frequent sampling. Surface temperature data from Marker 21 was collected at approximately two-week intervals by the Southwest Research Institute of Corpus Christi for the Coastal Bend Council of Governments. The sampling program lasted from 9 April, 1971, through 14 May, 1972. While these data are not assumed to be representative of all years, they do put the temperature recorder data into a better perspective by providing information on the seasonal temperature variations

Upper Laguna Madre experienced a temperature range of nearly 21°C during this thirteen month period (Fig. R11). Highest temperatures of between 30 and 31°C were recorded between mid June and early September. Frontal passages, which characteristically start arriving at the coast in early fall, produced an irregular, stepwise cooling, which continued through late January. The minimum temperature of 9.1°C appears as a single and shortlived minimum, however the sampling frequency decreased somewhat during this time. Warming is rapid in the spring. Temperatures increase over 15°C within a two month period, and remain at approximately 25°C during the last one and a half months.

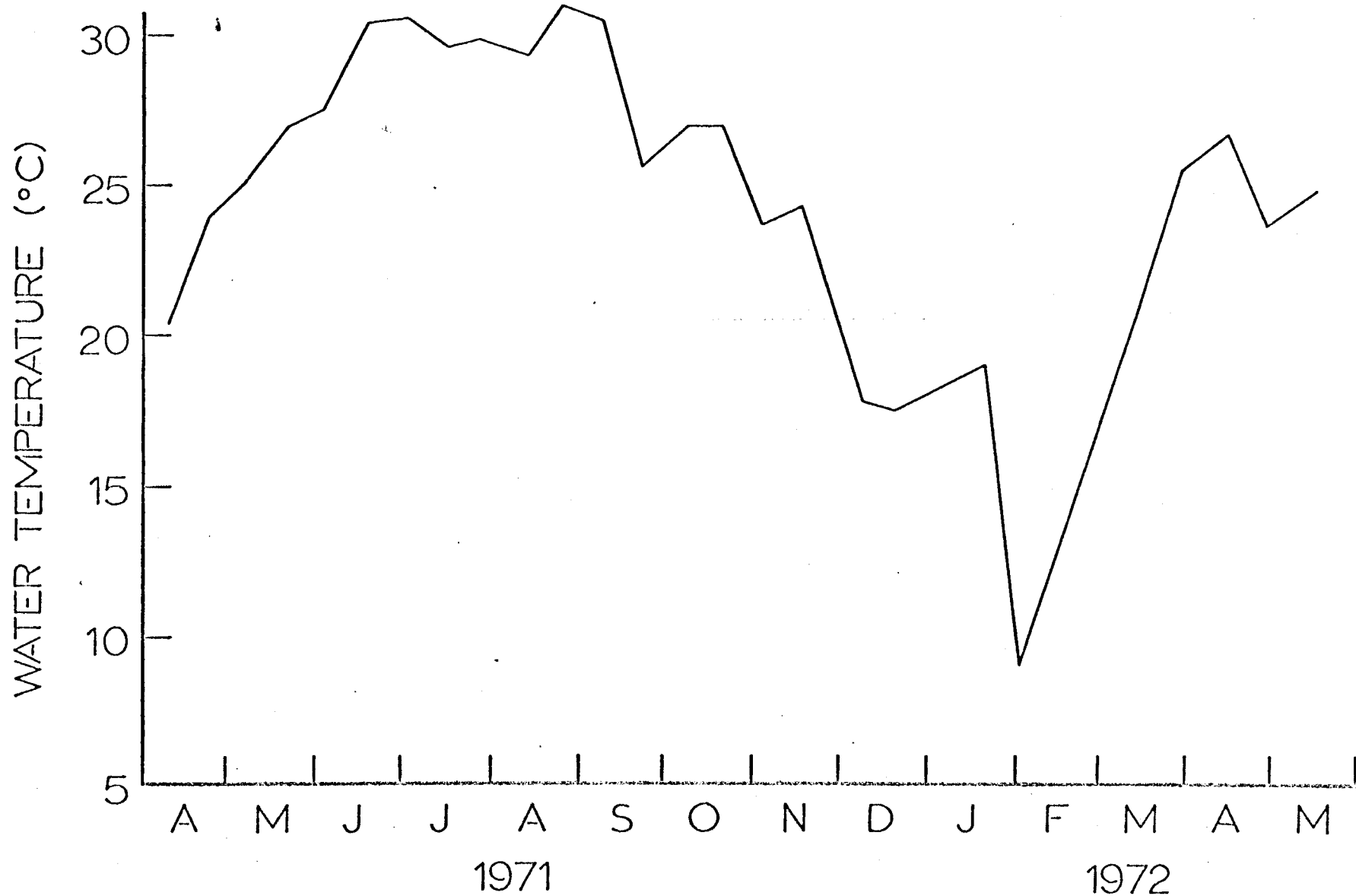


Fig. R11. Seasonal surface temperature variations recorded at Marker 21. Based on 26 measurements by Southwest Research Institute, April, 1971, to May, 1972.

In view of the 11-13 day variations characteristic of at least winter temperatures, the seasonal temperature variations shown in Figure R11 over the winter months must be treated with appropriate caution. The bi-weekly sampling was, in all probability, random with respect to the approximately bi-weekly variability, and temperatures on a given day may reflect unknown peaks or troughs in these shorter-period variations.

E. Long-period Water Level Variations

Results from both the two-year study of Upper Laguna Madre and related work in Corpus Christi Bay underline the importance of the non-tidal exchanges in maintaining water quality. While the inflow and outflow is as unpredictable as the variations in windstress that causes it, it is nevertheless important to investigate the relative importance of non-tidal exchanges.

In the 1974-75 study, it was shown by numerically filtering the data that tidal variations in water level account for only about 7% of the total in the northern part of Upper Laguna Madre. During this past year, analysis of water level data at Marker 115, at the entrance to Baffin Bay, produced a similar result. Again, only about 7% of the total variation was due to tidal effects. Tidal amplitudes are diminished somewhat, probably to statistical insignificance, and certainly to practical insignificance, but the longer-period, non-tidal variations are also reduced. Thus, the relative importance of the tides remains essentially the same. Results for Marker 115 are shown in Figure R12.

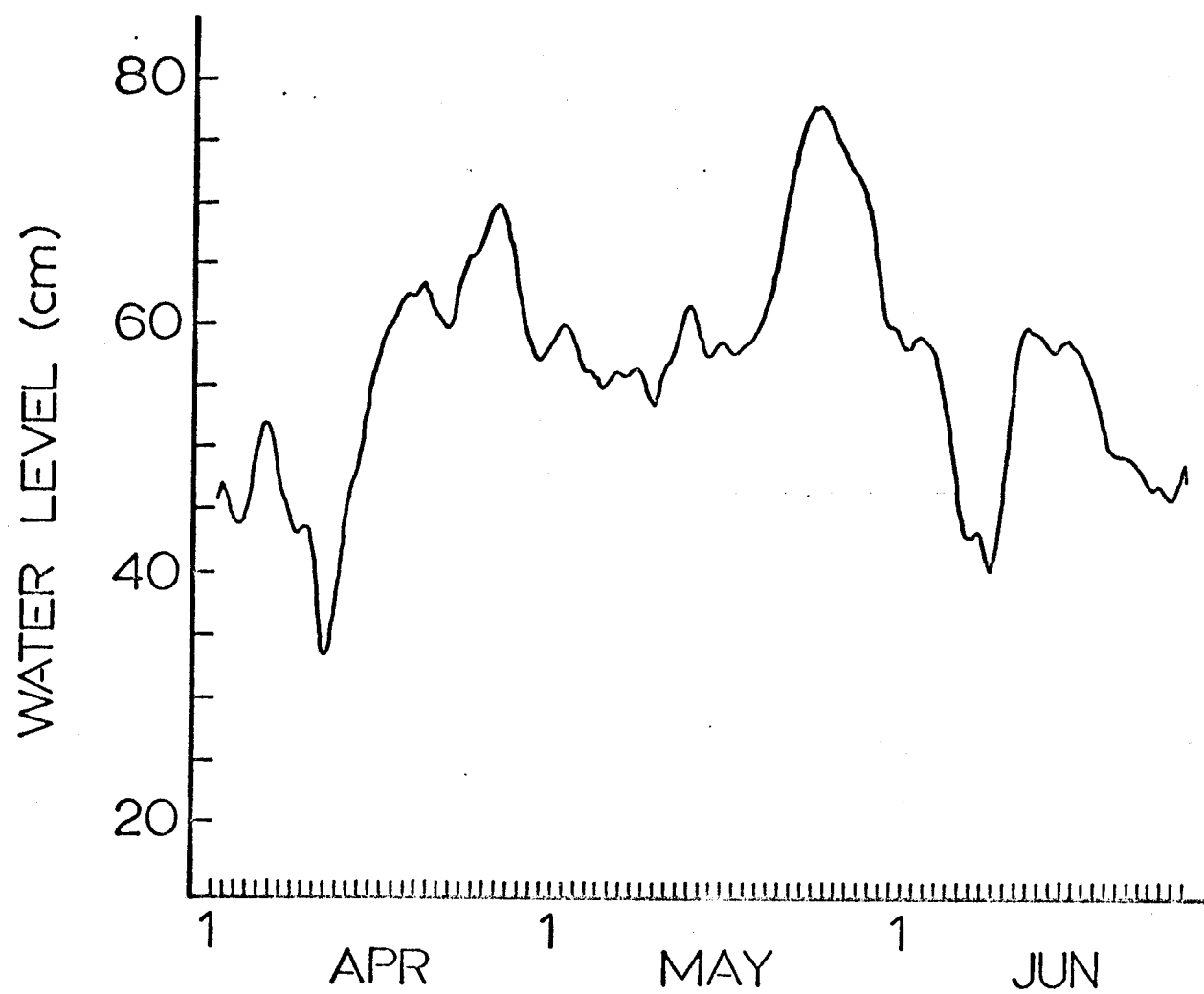


Fig. R12. Non-tidal water level variations recorded at Marker 115, 1 April through 25 June, 1974.

The decrease in non-tidal water level variations is due to the greater distance from the Gulf. While part of the wind effect is local and involves a back-and-forth movement of water within Upper Laguna Madre, another part requires a net inflow from, or outflow of water onto the inner continental shelf at Port Aransas. The constricting effect of the Intracoastal Waterway on water movement, as well as the frictional effects of shallow water, tend to inhibit the net inflow or outflow and restrict its effects to the northern portion of the study area. One can conclude that both tidal and non-tidal exchanges are greatest, and thus the threat to water quality is least, in the northern part of Upper Laguna Madre.

Another consequence of non-tidal water level variations is to expose large areas of shallow water flats. The area between that which is permanently exposed and that which is permanently submerged is comparable to the intertidal zone, though this term is not strictly applicable in this case. The spatial extent of the "intertidal zone" is determined by the range in water level and the slope of the bottom across the area which is alternately exposed and submerged. While measurements of bottom topography were not within the scope of the study, the difference in non-tidal water levels recorded at Marker 21 during the 1974-75 study amounted to just over 1.3 feet (40 cm). During the same time interval, a range of 1.45 feet (44 cm) was found at Marker 115. A variation of approximately one and a half feet would presumably involve a significant area in the "intertidal zone", since Upper Laguna Madre shorelines have very gradual slopes.

There would also be a profound effect on the spatial distributions of plant and animal populations, primarily resident species of grasses and invertebrates, many of which may be closely identified with the supralittoral zone (above the high water line), the intertidal zone, or the infralittoral zone (below the low water line). Some species can withstand the temporary exposure or submergence associated with tidal processes. Non-tidal water level variations, however, characteristically occur over many days--beyond the tolerance limits of many of these species. Research in the intertidal zone ecology would provide an interesting extension of this aspect of the study.

F. Recording Current Meter Data

A General Oceanics recording current meter was installed at about mid depth near Marker 21 of the Intracoastal Waterway, about two kilometers south of the Kennedy Causeway. Current speeds and directions were sampled every half hour from 7 December, 1975, and 9 January, 1976. Data analysis revealed a resultant outflow of water from Upper Laguna Madre into Corpus Christi Bay of approximately 2.5 cm/sec. This corresponds quite well to observations made during field studies of a general lowering of water levels in the area. A semi-annual lowering of coastal water levels is characteristic of the northwestern Gulf of Mexico, with low water occurring during the month of January. As water levels drop at the coast, there is a resulting outflow of water from the bays which may be identified by averaging a sufficiently long time series of channel currents.

characteristic of the winter months. The central Texas coast has predominantly onshore, easterly or southeasterly winds of approximately 25 km/hour (15 mph). For one or two days following frontal passages, however, quite strong winds blow out of the northern quadrant. The associated reversal and increase in surface windstress is consistent with the strong but infrequent flood currents past Marker 21.

RECOMMENDATIONS FOR FUTURE WORK

Just as the 1975-76 study area was expanded to include all of Upper Laguna Madre between the Kennedy Causeway and the Land Cut, a logical continuation would now be to conduct similar studies in Lower Laguna Madre, between the Land Cut and the southern end of the National Seashore, near Port Mansfield. The location of this area, however, is at such a distance from Port Aransas that the study might better be carried out from the Port Isabel area. Pan American University operates a field station in Port Isabel, and the Texas Parks and Wildlife Department has a lab in Harlingen. These groups may be conducting related survey work in the area and should be contacted if the study is to be expanded into Lower Laguna Madre.

The historical data made available during the second year's study, and the synoptic survey data collected between June, 1975, and January, 1976, have provided data adequate to answer many of the Big Picture questions. Reliable information is available relating to the annual temperature cycle, the cooling effects of cold fronts, the long-term effects of tidal and meteorological

exchanges on the salinity along the Intracoastal Waterway, and the effectiveness of the internal circulation in preventing a significant build-up of extreme temperature and salinity conditions in locations removed from the Waterway. It is suggested that, within this framework, continued work in Upper Laguna Madre become more highly focused, either in a spatial sense, or in terms of the process under investigation. The personnel of the National Seashore are in the best position to identify many of the specific sites or problems which would contribute directly to management decisions. For example, particular locations which have been proposed as dredging sites or for some form of development. Such highly focused work becomes possible when attention is narrowed from a survey-oriented study covering all of Upper Laguna Madre.

Other possibilities for continued study have become apparent during the 1975-1976 field program. In particular, the inflow and outflow through the principal cut into The Hole, near Marker 201, could be monitored, and exchange rates could be estimated from recording current meter data obtained in the cut over a period of several weeks. Also, it is not yet possible to estimate the magnitude or the importance of water exchanges between Upper Laguna Madre and Baffin Bay. A study of this kind would be geographically somewhat removed from the western boundary of the National Seashore, but it may be necessary to include Baffin Bay as a temporary storage reservoir for water moving into and through Upper Laguna Madre. Water level data

are available from existing tide gages, and the associated survey work would be limited in a geographical sense and would not represent a major undertaking.

MANAGEMENT DECISIONS AFFECTING UPPER LAGUNA MADRE

Results of the two-year study of Upper Laguna Madre do not suggest that the existing array of spoil islands substantially affects the internal circulation between the Kennedy Causeway and Baffin Bay. Thus, on the basis of water quality considerations, there does not appear to be a need to place restrictions on further maintenance dredging. Nevertheless, as dredging continues, it would appear to be preferable to use existing spoil islands as the best sites for receiving additional spoil. Although existing spoil islands do not constitute a barrier resulting in hypersaline conditions and poor water quality, it should be recognized that increasing numbers of spoil islands would, at some point, create such a condition. Enlarging existing spoil islands would seem to be a reasonable compromise between the needs of Upper Laguna Madre for both industry and recreation.

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