USING HEATED EFFLUENT FROM A 835 MWe NUCLEAR POWER REACTOR FOR SHELLFISH AQUACULTURE*

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ABSTRACT

Aquaculture of shellfish (*Crassostrea virginica* and *Mytilus edulis*) has been studied for the last four years using heated effluent from the 835 MWe Maine Yankee Nuclear Power Reactor in Montsweag Bay, near Wiscasset, Maine. The effects of the heated and moving effluent on growth and product quality of the rafted shellfish is presented for several stations at various distances from the reactor. A station in the nearby unheated Damariscotta estuary was used as a control. Descriptions of the growth at these stations will be presented.

The measured rate of uptake of reactor released radionuclides ^{58}Co, ^{60}Co, ^{137}Cs, ^{134}Cs, and ^{54}MN by shellfish is compared with the mathematical models (24) used to understand the variations of these radionuclides with position and time. A dynamic estuary computer program (25) is used to understand the position dependence (26) and a pulsed relaxator model (23) is used to understand the time variation of the radionuclides in shellfish.

INTRODUCTION

The increased demand for electricity by our civilization and consequent construction of additional generating facilities in coastal areas will dramatically increase the number of thermal releases available for application in marine aqualcuture systems.

Since 1973 we have been involved in a study directed toward an evaluation of the use of the thermal effluent and waters surrounding the Maine Yankee Atomic Power station, located at Bailey Point on Montsweag Bay, Wiscasset, Maine, for the culture of the American oyster (*Crassostrea virginica*) and the blue mussel (*Mytilus edulis*). We have considered two major factors governing the potential use of these waters. First, the growth and quality of the animals and second, the retention of gamma-ray emitting radionuclides by the animals.

The use of thermal effluents for the culture of marine organisms has been duscussed by many authors: Nash (1), Burns (2), Coutant (3), Mather and Stewart (4), Strawn (5), Yarosh (6), Huguenin and Ryther (7), and others.

Studies of accumulation and depuration of radionuclides in a number of marine organisms have been undertaken. Measurements have been made of ^{58}Co in the mussel *Mytilus edulis* (8), ^{137}Cs and ^{60}Co in the clam *Mya arenaria* (9), and ^{137}Cs and ^{60}Co in the oyster *Crassostrea gigas* (10). Studies by Seymour (11), Jeffries and Preston (12), Naidu and Seymour (13), Wolfe (14), and Lowman, Rice and Richards (15) are also relevant to our work.

We have examined the annual physiological cycles of glycogen, percent total solids, shell growth and the uptake and dupuration of gamma-ray emitting radionuclides in American oysters (*C. virginia*) cultured directly in the effluent of the Maine Yankee nuclear power reactor, three other points in Montsweag Bay, and at a control site in an adjacent esturine environment; the Damariscotta River.

METHODS

Site Locations

The Maine Yankee Nuclear Reactor at Wiscasset, Maine, is a pressurized water reactor rated at 835MWe. The plant is cooled by pumping up to 960 cubic feet of water per second from Montsweag Bay over its condensers and then discharging the water into Bailey Cove. Tray stations containing oysters were located in the intake channel (S-1), directly in the effluent (S-2), above the effluent point in Bailey Cove (S-3), and below the effluent point off of Long Ledge in Montsweag Bay (S-4), (Fig. 1). The control site was located at the marine laboratory on the Damariscotta River; and adjacent estuary. One hundred fifty oysters to be examined for glycogen content, percent total solids and shell growth were distributed between two trays at each site. Additionally, twenty four oysters were placed in a separate compartment of one tray of each site to be measured monthly in a longitudinal study of the accumulation of gamma-ray emitting radionuclides. One hundred and forty mussels were rafted at the outflow (S-2), Long Ledge (S-4) and at the control site in the Damariscotta River.

Environment

A Beckman field salinometer (Model RS5-3) was used to monitor salinity and temperature every two weeks during high tide at all stations. For one year water samples were taken every other week at high tide at all stations to evaluate the food available to the oysters. These samples were used in the determination of chlorophyll and particulate oxidizable carbon (16). In this manner, we were able to gain some knowledge of the variation in environmental parameters which have been shown to influence oyster growth and condition (17).

Biological

Monthly a random sample of twelve oysters was collected from each field site. Fouling organisms were removed, each oyster was weighed and measured. Measurements (height, length and width) were of the maximum dimension of a given parameter. New shell growth was measured on the right and left valves and the larger value used in calculating the average shell growth at a given station.

The condition of oyster meats was determined by shucking the oysters taking care not to pierce the meats. Meats were allowed to drain for one minute on a plastic mesh and then weighed. All twelve oyster meats from a given station were then homogenized and glycogen extracted from the homogenized meats according to the method of Burklew (1971). The percent total solids of the oyster tissue were calculated from the average of three, five gram aliquots of the homogenate, employing the following calculation;

$$\text{Percent solids} = \frac{\text{dry weight of meats}}{\text{wet weight of meats}} \times 100$$

Mussels were measured monthly for growth.

Radionuclear Apparatus and Calibration

The gamma-ray measurements are carried out using an Ortec Ge(li) detector with a 2400 pound low background lead shield. The detector pulses are amplified with an Ortec 452 spectroscopy amplifier and the detector bias is provided by an Ortec 459 high voltage supply. The amplified detector pulses are processed by a Northern Scientific NS-700 multichannel analyzer. A typical gamma-ray spectrum for live oysters is shown in Fig. 2. The memory of the multichannel analyzer is outputted onto magnetic tape using a Northern Scientific NS-408C magnetic tape controller and a Wanco tape transport. The data thus recorded is then processed using the University of Maine IBM 360/370 computer system. The computer program analyzes the peaks by Compton continuum subtraction (18). The number of counts in each peak is then converted from counts per second into disintegrations per second by using the efficiency determined for the sample geometry employed. Both branching ratios and the variation of efficiency with energy are taken into account. From disintegrations per second, the number of picocuries per gram is determined for each of the gamma-ray peaks which exceed a statistical criterion for significance above background. Picocuries per gram of those radionuclides in our library of branching ratios are computed automatically and new or unidentified peaks are processed by hand calculations. The efficiency versus energy curve for the detector is determined by placing several standard sources from the Environmental Protection Agency Analytic Quality Control Laboratory, Las Vegas, Nevada, in a solution of demineralized distilled water in a 1.0 liter Nalgene cylindrical bottle which is our standard sample geometry. All quantitative measurements are made using this geometry. The peaks from the standard sources are analyzed

in the same way as the unknown peaks in a sample. Graphical analysis of the efficiency versus energy is plotted on log-log paper and tested for linearity and consistency. Results of these periodic calibrations are used to update the computer program. New branching rations are entered into the program as required.

Procedure

Previous experience involving radionuclide assessment of marine organisms (19) suggests that monthly measurement of the specific activity is sufficient and convenient for studies of this type. Two species of mollusca (*C. virginica* and *M. edulis*) are cultured at several rafting sites near the outflow and one control site. For each species, one kilogram samples of living organisms is randomly selected from populations of organisms of similar age and genetic background at each rafting site. High resolution gamma-ray spectrographic measurements are made as soon after collection as practical and the specimens are returned to the approporate raft sites within twenty four hours. The spectra are computer processes as discussed. Monthly specific activities for each species are graphed and compared for five reactor associated radionuclides (^{60}Co, ^{58}Co, ^{137}Cs, ^{134}Cs and ^{54}Mn) and for the natural occurring radionuclide ^{40}K.

Marine sediment from several sites at selected distances from the outflow are collected to a depth of 5 millimeters over an area sufficient to yield 2 kilogram wet samples. A monthly sampling schedule is employed. High resolution gamma-ray spectrographic measurements are made.

Control site

In May of 1973 oysters at the control site in the Damariscotta River exhibited shell growth as the temperature rose above 8°C, (Fig. 3). During June and July gametogenesis occurred and is reflected in a characteristic decrease in glycogen, increase in percent total solids and decrease in the rate of shell growth. Shell growth resumed in August but ceased to be measureable in September. This correlates with a decrease in food available to the oysters, as the standing crop of phytoplankton dropped out during this period. The following spring, with adequate food available in April and the water temperature rising to 8°C, shell growth resumed. This cycle of growth has continued.

Measurements taken to detect the accumulation of gamma-ray emitting radionuclides of reactor origin in oysters at this site were negative. Mussel growth and survival was best at the control site (Figures 4 and 5).

Outflow Station

Oysters placed directly in the effluent (S-2) in April of 1973 showed shell growth after two weeks of exposure to the elevated temperatures found in these waters (Fig. 6). Glycogen levels decreased, and there was an increase in total solids which were correlated with gametogenesis. Shell growth decreased in May as the oysters spawned. During June shell growth resumed and continued through October. Water temperatures remained elevated throughout the winter except for brief plant shutdowns. Cessation of shell growth during the fall corresponds well with the decrease in the standing crop of phytoplankton. Shell growth resumed in March 1974 probably due to elevated temperatures and a spring bloom of phytoplankton found at this station. Again in the spring of 1975 shell growth was evident early in the year, February, and is attributed to elevated temperatures and a spring bloom of phytoplankton.

Mussels exhibited best growth at the control (SC) site in 1974 and 1975. In 1974 the outflow station suffered 100% mortality and warmer water sites show less growth than controls (SC) or Long Ledge (S-4) in 1975. (Fig. 4 and 5).

The uptake and loss of gamma-ray emmitting radionuclides predicted by our model is inn good agreement with levels measured in oyster from this station (Fig. 6B).

Upper Cove Station

Oysters placed in the upper cove station (S-3), showed signs of gametogenesis in April of 1973 with shell growth evident in May 1973. Oysters in the June 1973 sample were observed to have spawned and were recovering glycogen. Shell growth continued until November 1973 (Fig. 7A). The general features of the graph depicting the accumulation and loss of ^{58}Co, (Fig. 7B), is similar to that found at the outflow (S-2) station (Fig. 6A).

Other Stations

The general features of oyster growth and the uptake and loss of radionuclides at the intake (S-1) and Long Ledge (S-4) stations (Fig. 8 and 9) are observed to be generally similar to those found at the outflow (S-2) and the Upper Cove (S-3). Oysters at the intake (S-1) are lower in their accumulation of ^{58}Co by a factor of five and by a factor of three at Long Ledge (S-4). This is a result of their distance from the discharge point, the thermal differences existant at these sites, the consequent variations in oyster metabolism, and their exposure to radionuclides.

The magnitude of cumulative shell growth at each station was, upper cove (S-3) 58.0 mm, S.D. 8.92 the outflow site (S-2), 55.2mm, S.D. 6.13, the intake (S-1) 32.0 mm, S.D. 5.16, Long Ledge site (S-4), 34 mm, S.D. 4.33 and the control site (sc), 23.4 mm, S.D. 2.26. All stations in Montsweag Bay showed significantly greater shell growth than controls, with the warmer water sites (S-2 and S-3) significantly greater than the cooler sites (S-1 and S-4), (Fig. 10).

Oysters of excellent market quality were observed during the fall and winter of 1973-1974 at the intake (S-1) and Long Ledge (S-4) sites. The meats of oysters at the upper cove site (S-3) and the outflow (S-2) were comparable to controls. Mortalities at all oyster stations were less than 5% and there was no significant difference between mortalities at the different oyster stations. Mortality was highest in the mussels at the outflow station (98%) in 1974 and always decreased as distance from the outflow increased.

In addition to the effects of heated moving effluent on the growth and product quality of rafted shellfish, one must consider the uptake, accumulation and depuration by the organism of the trace amounts of radionuclides in the effluent. In order to take full advantage of the heated effluent, and minimize the accumulation of radionuclides, the spatial distribution of these radionuclides in the estuary is also needed. Both the filter feeding of the organisms and sedimentation tend to reconcentrate the radionuclides providing pathways for the radionuclides into the shellfish. In the discussion below, we describe a field study designed to measure the parameters governing these processes and two mathematical models: a pulsed relaxator model for the temporal behavior, and a "Dynamic Estuary" computer program for the movement and spatial behavior of radionuclides in the water column and sediments. These modesl describe the processes in a detailed enough way to make practical predictions possible.

Models of Uptake of Radionuclides By Shellfish

Constant concentration theories have been suggested in laboratory studies by Polycarpov (20), Ruzic (21), and Davis and Foster (22). In such theories, the radionuclide concentration in the oysters, C_o, is related to the radionculide concentration in the sea water C_w, by a concentration factor K.

$$C_o = K\, C_w$$

This factor K becomes larger with time until it reaches an equilibrium value, if the concentration C_w may be found by dividing the released radioisotope in curies, f_i, by the volume of water used for the release V_w.

$$C_w = \frac{f_i}{V_w}$$

Using this equation in a dynamic situation, as in the case of reactor releases, will give values of K which are considerably less than the equilibrium value for K as found in a laboratory situation. We find that calculations based upon laboratory values of K in the case of reactor releases inaccurately estimates the radionuclide concentration (19).

To develop a dynamic model of variations in the uptake and depuration of radionuclides by the oysters, the release rates of radionuclides by the reactor was used as the driving source of a multimode pulsed relaxator system. The resulting differential equation may be solved by integration to give exact solutions if appropriate simplifying assumptions are made (19). These assumptions are that the reactor releases monthly by injecting the nuclides into the estuary in a short time (several hours). The nuclides are then accumulated by the oysters, and are slowly reduced by radioactive decay and by biological cycling, depuration, in the oysters. Initially we assumed that the oysters had constant depuration over the entire year. Later these assumptions were modified to include: a) variation in nuclear reactor plant operations (shut-downs, plant discharge rate, power output, etc.), b) oyster biological parameters (growth rate, glycogen content), and c) estuarial parameters (temperature, salinity, current velocities, standing crop, etc.) (23). As our understanding has improved we have found that by using this radionuclide uptake model, predictions can be made to establish an optimum release pattern for the reactor in order to minimize oyster uptake of radionuclides.

A full development of this new model is discussed in detail in references (19) and (24). Reference (23) describes how to use the model. The essence of the model is the calculation of the rate of change of concentration of radionuclide in the organism. This calculation uses the differential equation given below

$$\frac{dN(t)}{dt} = R(t) - \lambda_b N(t) - \lambda_p N(t)$$

where

$N(t)$ = the concentration of radionuclide in the organism at time t.
$R(t)$ = the rate of introduction of radionuclde into the marine environment from an external source (i.e., the nuclear reactor effluent).
λ_b = biological turnover, biological decay or depuration constant
λ_p = physical or nuclear decay constant

and $R(t)$ may be written

$$R(t) = \sum_i U_i F_i \delta(t - t_i)$$

The results of integration is given below for the intervals between release times

$0 \leq t \leq t_1 \qquad N(t) = C\, e^{-\lambda t}$

$t_1 \leq t \leq t_2 \qquad N(t) = U_1\, f_1\, e^{-\lambda(t - t_1)} + C\, e^{-\lambda t}$

$t_2 \leq t \leq t_3 \qquad N(t) = U_2\, f_2\, e^{\lambda - (t - t_2)} + U_1\, f_1\, e^{-\lambda(t - t_1)} + C\, e^{-\lambda t}$

The releases of radionuclides are made into the marine environment at a sequence of m time (t_1, t_2, t_3 . . . t_m) and the amount released is given by a function $f_i(t)$, which for times greater than or equal to t_1 but less than t_2, is given by f_1 $(t - t_1)$ and for times greater than or equal to t_2 but less than t_3 is given by $f_2(t - t_2)$ and so on up to times greater than t_m. A scaling parameter U determines the availability of radionuclides for uptake by the organism and depends on the distance from the discharge point to the aquaculture rafting station in question, and the pumping rate or efficiency of collection of the organism. It is called the retention ratio.

We first discuss the case of ^{58}Co at the outflow rafting station (S-2), the closest site to the discharge point. The theoretically predicted values are scaled to the experimentally measured values to determine U at this site for ^{58}Co to be 10.0×10^{-12} g^{-1}. Assuming U constant has given fairly good agreement between theory and experiment, however, it is known that below 8°C the American oyster stops pumping water and hybernates. It is also know that this phenomena, combined with the available standing crop of phytoplankton results in a step shaped shell growth curve. If one assumes that during times of hibernation or zero shell growth the oyster is shut down, i.e. neither pumping water nor feeding, then, during this period, $\lambda_b = 0$ and $U = 0$ and the organism gains no radionuclides from the environment and loses them only by physical decay. Results shown in Figure 11 including all biological parameters, i.e., λ_b, temperature and shell growth. One can still observe some departures of the theoretical prediction from experiment. These have been traced to gametogenesis and/or spawning, (19) and result from the associated changes in oyster metabolism and the ratio of shell mass to soft part mass, refinements which could be included in λ_b and U. However, since these variations represent effects comparable to the error resulting from counting statistics, it is felt that for the radionuclide levels involved and the 5000 second count employed, the effort is not warranted. In (Fig. 12) the results are given for ^{137}Cs in oysters. The list of parameters used is given in (Table 1) for all rafting stations. Notice the interesting result that U does not depend on the chemistry of the radionuclides. This implies that for the concentrations encountered in the environment near a nuclear power reactor, the major uptake mechanism is physical rather than chemical. It has been suggested that the radionuclides attach to particulate are filtered out essentially non-chemically by the oyster.

The biological decay constant, λ_b, is not site specific and indeed the same values of λ_b were found at all sites. The U values decrease monotonically with increasing distance from the discharge point. U values are shown (Fig. 13) as a function of water path distance from the discharge point for the four aquaculture raft station sites employed in this study. The fact that the curve came out to be a straight line is probably fortuitous, however, the point being made is that the major factor which determines the value of U is proximity of the rafting station to the source of radionuclides.

In order to further understand the nature of the retention ratio U and its dependence of position relative to the outflow location it is necessary to measure radionuclide content in the sediment settling out of the water column. Sediment sampling, as described in the Procedure Section was carried out along tidal transects with a total of 72 samples being taken on one low tide. Isocuric plots are drawn by fitting radionuclide concentration versus sampling site on each transect line to a cubic equation. The location of the intersection of an isocuric line with a transect line was found using this fitting procedure. All radionuclides in this survey were distributed in nearly the same manner as indicated by the isocuric maps for ^{58}Co and ^{137}Cs, (Fig. 14 and 15). Both isocuric maps display very high concentration near the outflow, while somewhat cross-stream there is a low concentration "valley". In the upper cove both maps depict a broad region of high concentration near the outflow side of the cove. Down-cove from the outflow both maps indicate a narrow high concentration band adjacent to the east shore line. The concentrations are generally higher up-cove than down-cove from the outflow, indicating a substantial portion of the releases were carried into the upper cove during the flood tide.

A dynamic estuary model is used to simulate the above behavior. Complete and extensive descriptions of this model, developed for the Federal Water Quality Administration for San Francisco and San Diego Bay systems, is given in reference (25). The model can represent flow and dispersion characteristics of an estuary where vertical stratification is slight. It consists of two separate but compatible computer programs. The first, DYNHYD, models the hydraulic behavior of an estuary. It computes tidal heads and flows and stores this information on magnetic tape. The second program,DYNQUA, uses this tape to describe the dispersion of a pollutant introduced into the estuary. Both programs use the finite difference method, and apply one-dimensional equations to one-dimensional channels which are laid out in a two-dimensional framework. Water velocity patterns are calculated for various stages of the tidal cycle. The result for the last slack high tide on May 13, 1975 are shown in Fig. 16. Two eddies are observed, one elongated from the outflow up into the northern portion of the cove and the other at the southern mouth of the cove. Notice that from the isocuric maps we observe high concentrations of radionuclides in these regions. Similar observations can be made for other portions of the tidal cycle. The second program DYNQUA is used to calculate the concentration of radio-

nuclides in the sediment, using the tidal heads and flows as calculated by DYNHYD. The final predictions by the model are presented as dot maps. (Fig. 17 and 18 for ^{58}Co and ^{137}Cs respectively.) Both figures show very high concentrations near the outflow and relatively high concentrations adjacent to the east shore line of Bailey Cove, with concentrations being slightly higher in the upper cove than in the lower cove. Correlation coefficients between the isocuric maps (experimentally measured concentrations) and the dot maps (mathematically calculated concentrations) are about 0.75, indicating very good agreement between experiment and theory (26).

CONCLUSION

Our data suggest that one limiting biological factor in using the thermal effluent from this power plant is the availability of food for the oysters. The thermal additions by the power plant has been seen to provide a sufficient increase in water temperature to allow the oysters at the warmer sites to take advantage of the food available in the early spring. The growth of oysters had ceased by November as the amount of food available decreased in the fall, even though temperatures remained warm enough to permit growth.

An additional limiting factor in the use of the effluent waters was the proliferation of the marine worm *Polydora ligni* and *websteri* which adversely effected the commercial value of oysters from the warmer water sites.

The importance of intelligent selection of the species for cultivation is shown by the high mortality found amoung mussels placed in the effluent in 1974 (Fig. 4).

We have found that the concentration factor model does not adequately describe the dynamic nature of the uptake and loss of radionuclides for the case in which the source of these nuclides varies with time. The model we have described, which utilizes the release schedule of an atomic power plant to describe the true variation of the source of radionuclides, is in good agreement with values as measured in the oysters located at various distances from the discharge point.

The oysters do not take up radionuclides during their hybernation (when shell growth is stopped, and the biological decay constant is zero). Radioactivity is taken up independent of the chemistry of the nuclides, suggesting a physical process such as filtration of particulates. The radionuclides concentration in oysters decreases with increase of the distance from the discharge point. The values of radionuclides in the associated sediments can be described by a dynamic estuary model and these calculations correlate with sediment transect measurements.

The application of this model allows one to predict accumulations of radionuclides in shellfish, and based on their physiology suggests a release schedule that will minimize the concentration of radionuclides by the oysters, and permits optimum choice of sites for future aquaculture efforts.

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TABLE 1 INPUT INFORMATION

RAFT STATION	PHYSICAL HALF-LIFE, $t_{½p}$, days					BIOLOGICAL HALF-LIFE, $t_{½b}$, days					$U \times 10^{-12} g^{-1}$
	^{58}Co	^{60}Co	^{54}Mn	^{134}Cs	^{137}Cs	^{58}Co	^{60}Co	^{54}Mn	^{134}Cs	^{137}Cs	
S-1	71.3	1902	303	748	10950	35	35	1500	250	250	1.7
S-2	71.3	1902	303	748	10950	35	35	1500	250	250	10.0
S-3	71.3	1902	303	748	10950	35	35	1500	250	250	7.4
S-4	71.3	1902	303	748	10950	35	35	1500	250	250	3.4

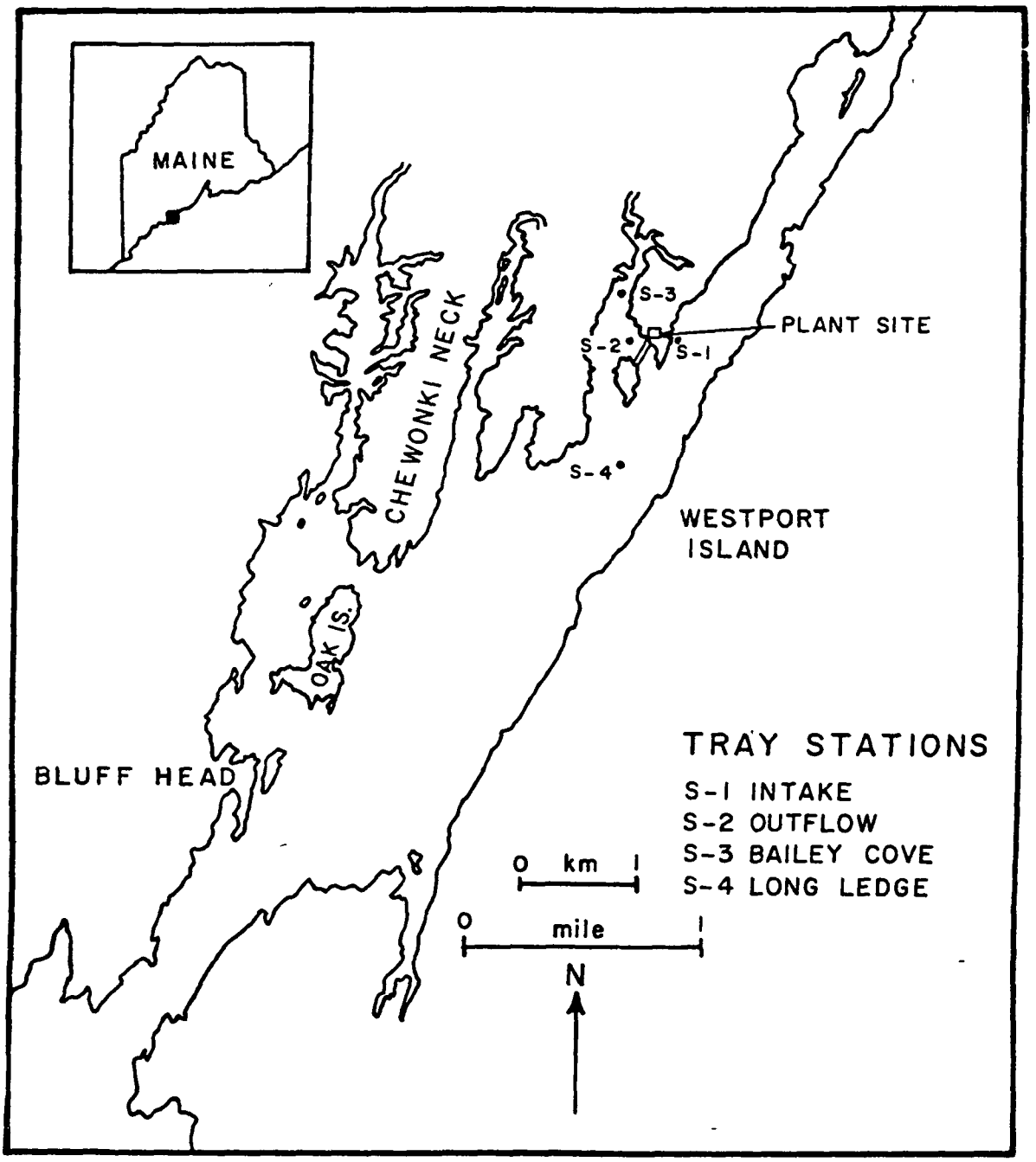

Fig. 1. Map of Montsweag Bay showing location of tray stations.

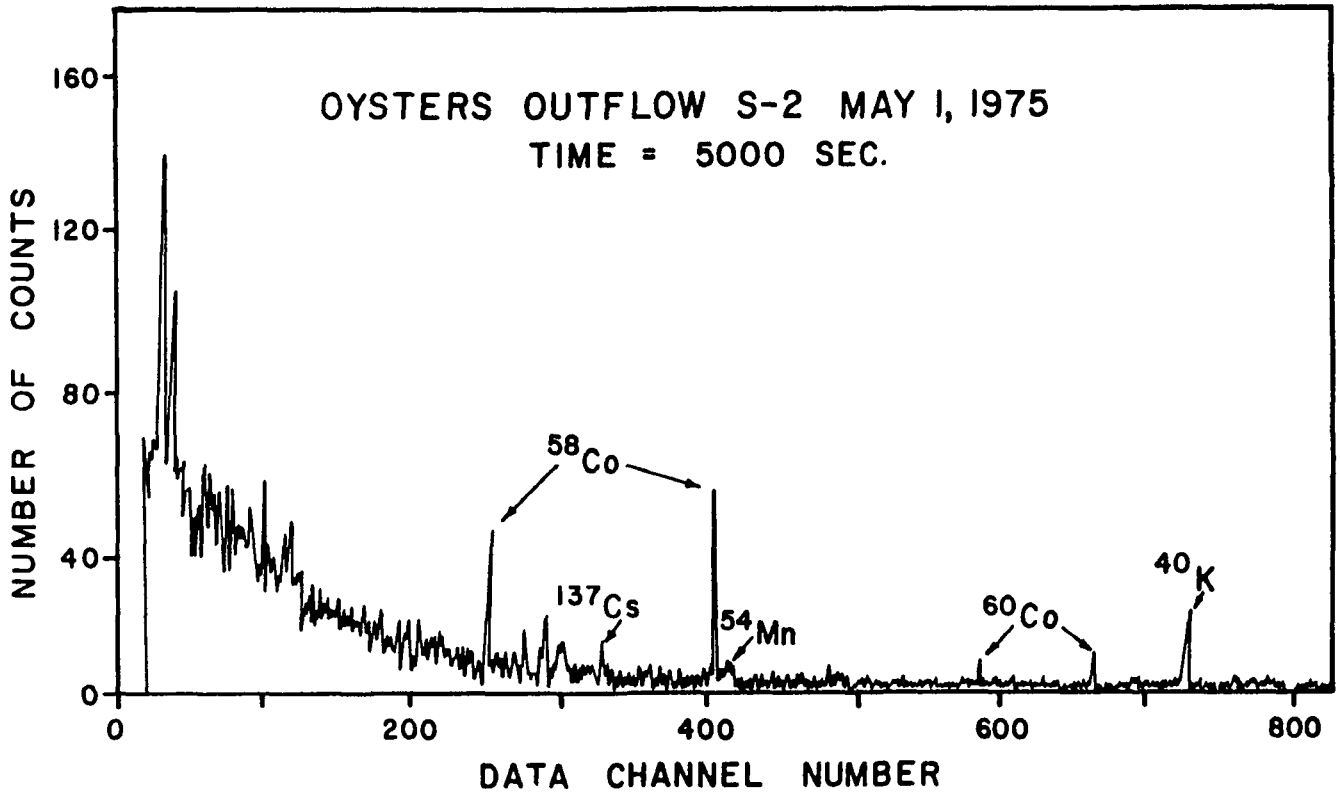

Fig. 2. Gamma-ray spectrum of oysters from the outflow station (S-2) with data channel number versus number of counts in 5000 sec.

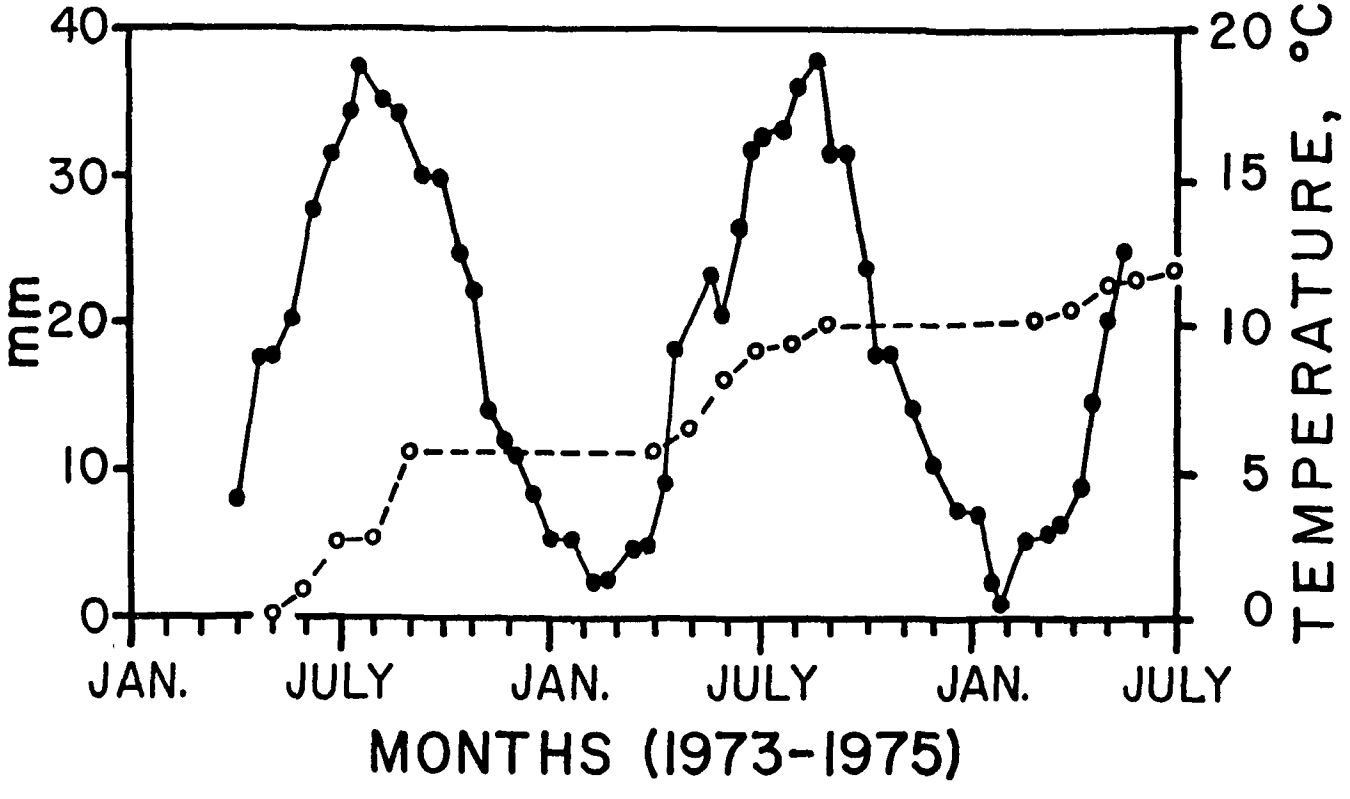

Fig. 3.a. Oyster shell growth in mm at control site (SC) versus month of year for 1973-1975 (O---O). b. Temperature in ^{o}C versus month of year (●—●).

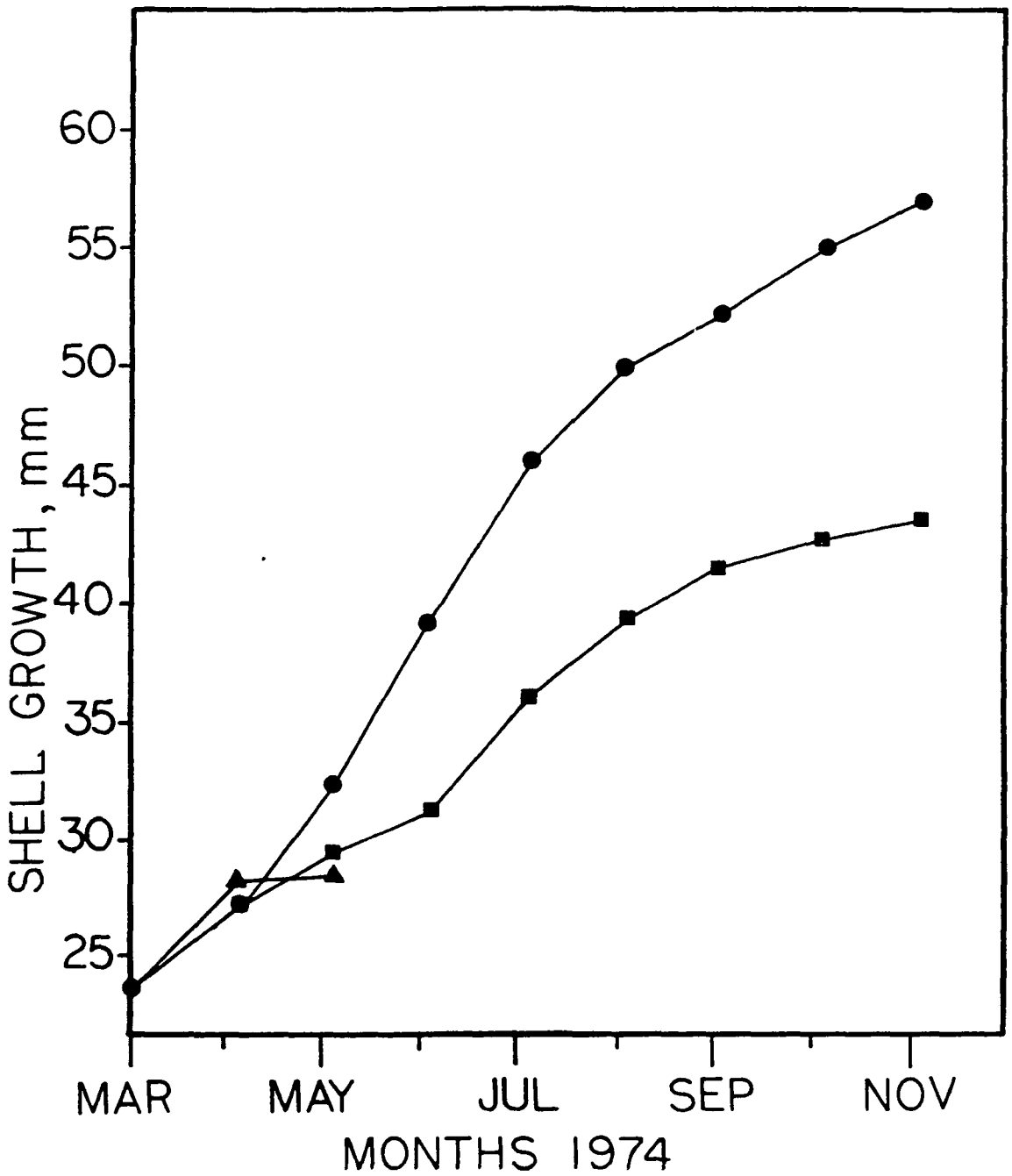

Fig. 4.a. Mussel shell growth in mm at control site (SC) versus months for 1974 (●—●) b. Mussel shell growth in mm at longledge (S4) versus month of year (■—■) c. Mussel shell growth in mm at outflow (S2) versus month of year (▲—▲).

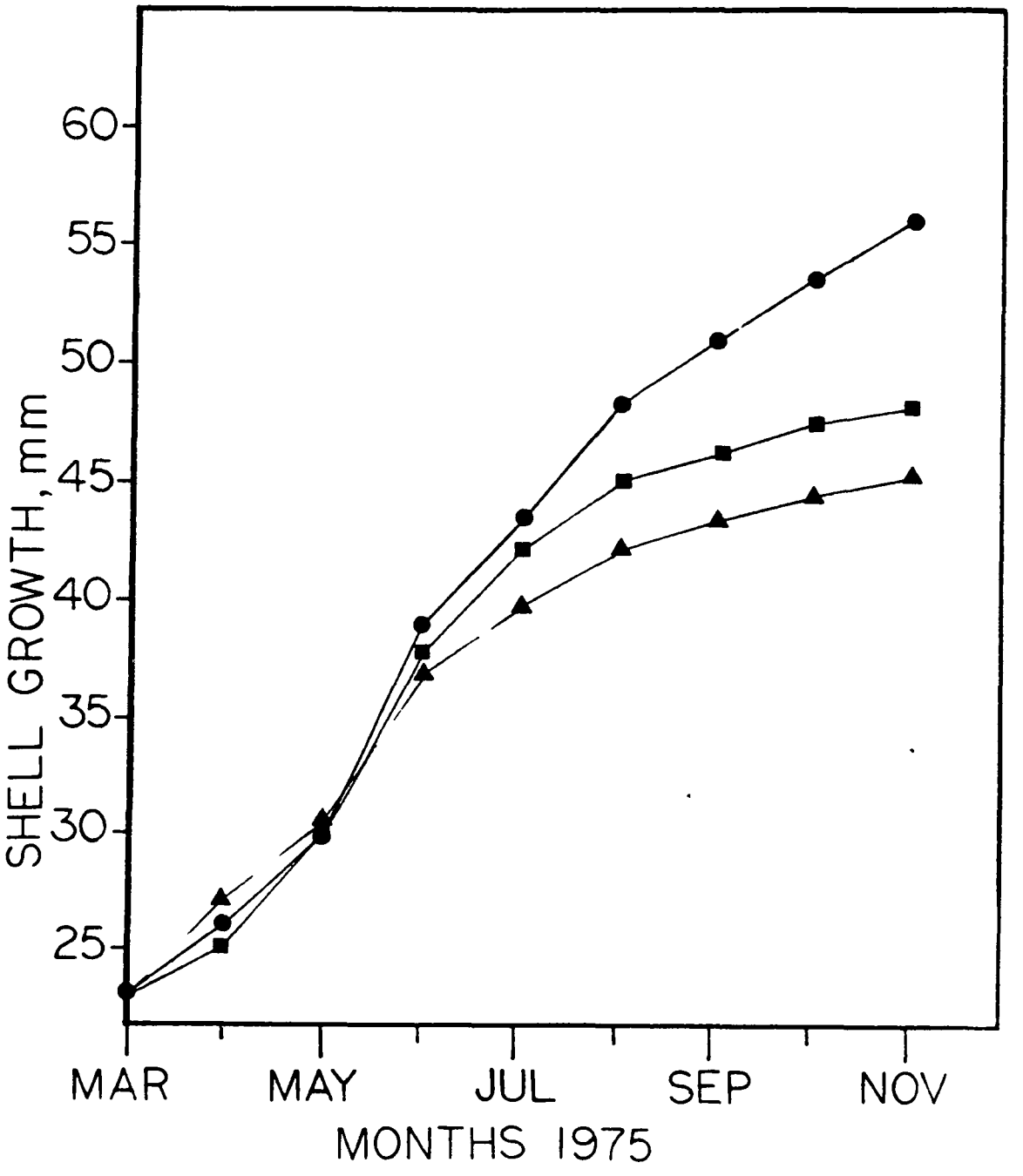

Fig. 5. Mussel shell growth in mm as shown in Fig. 4. versus month of year 1975.

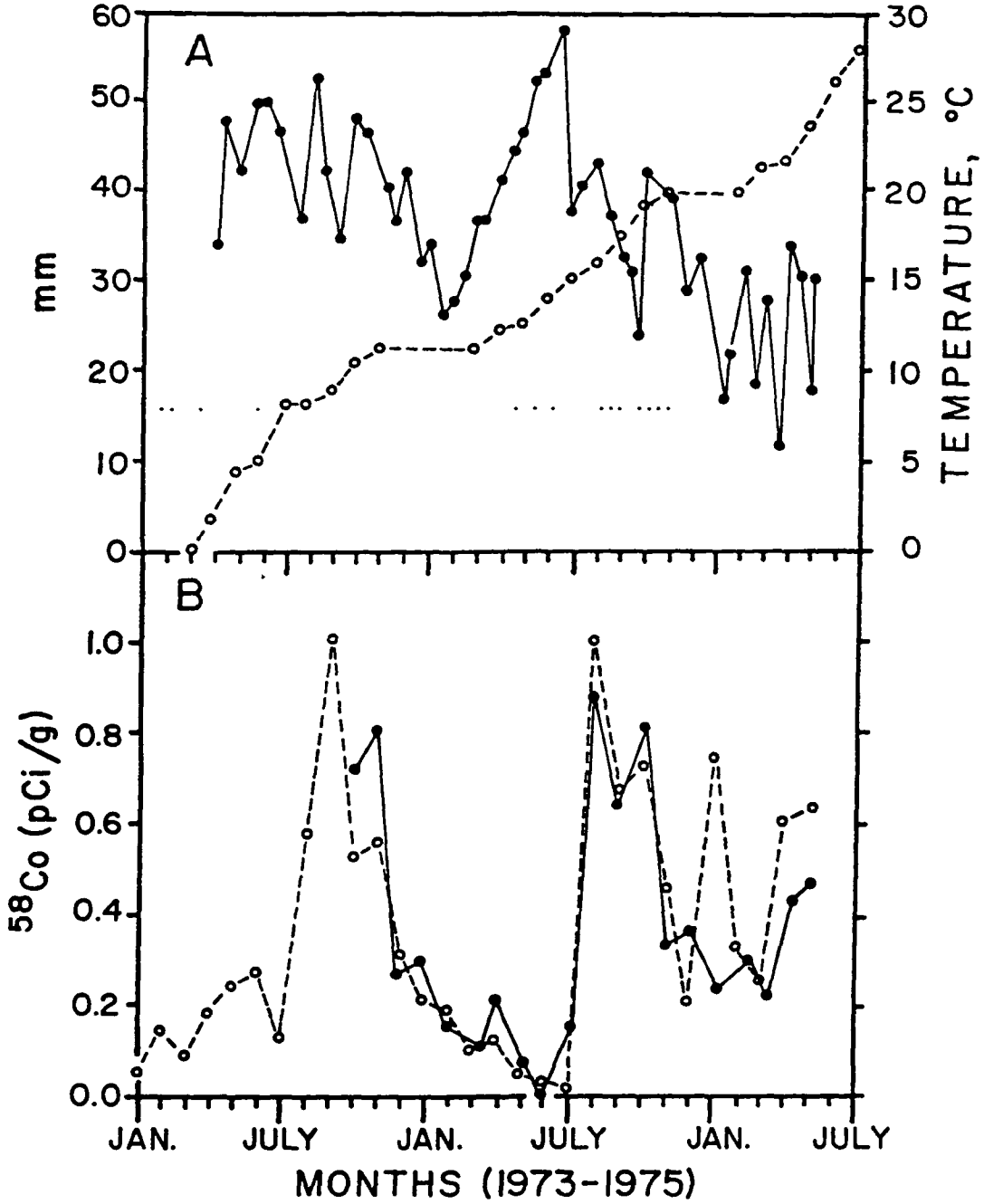

Fig. 6. Oyster shell growth at the outflow station (S2) versus month of year for 1973-1975. (O---O). Ab. Temperature in ^{o}C at outflow versus months of year (●—●) Ba. Radionuclide concentration for ^{58}Co in oysters from the outflow versus month (●—●). Bb. Theoretical radionuclide concentration for ^{58}Co in oysters versus month (O--O).

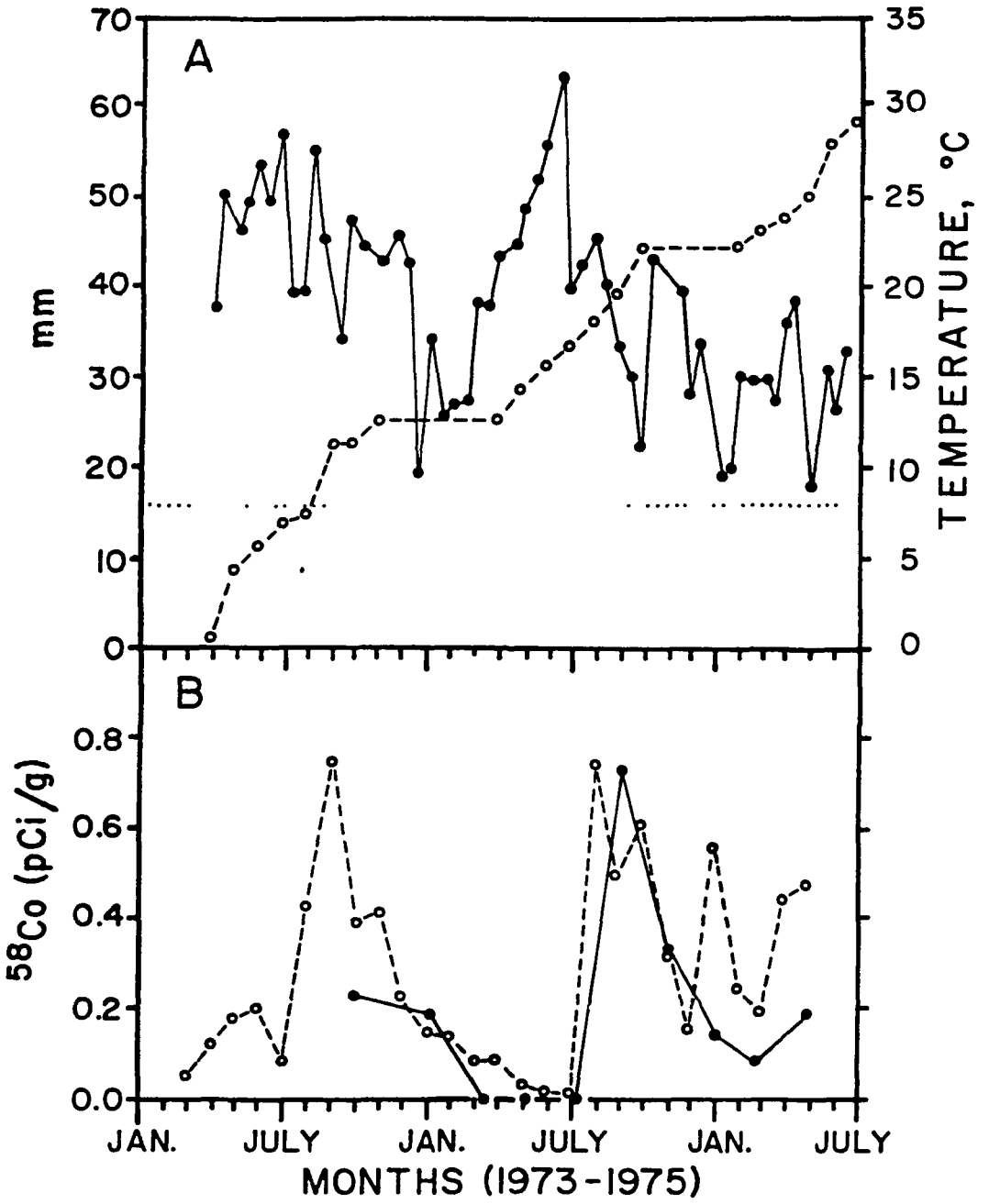

Fig. 7.Aa. Oyster shell growth, Ab. Temperature in ^{o}C, Ba. Radionuclide ^{58}Co concentration, and Bb. Theoretical ^{58}Co radionuclide concentration versus month of year as in figure 6. for Upper cove site (S3).

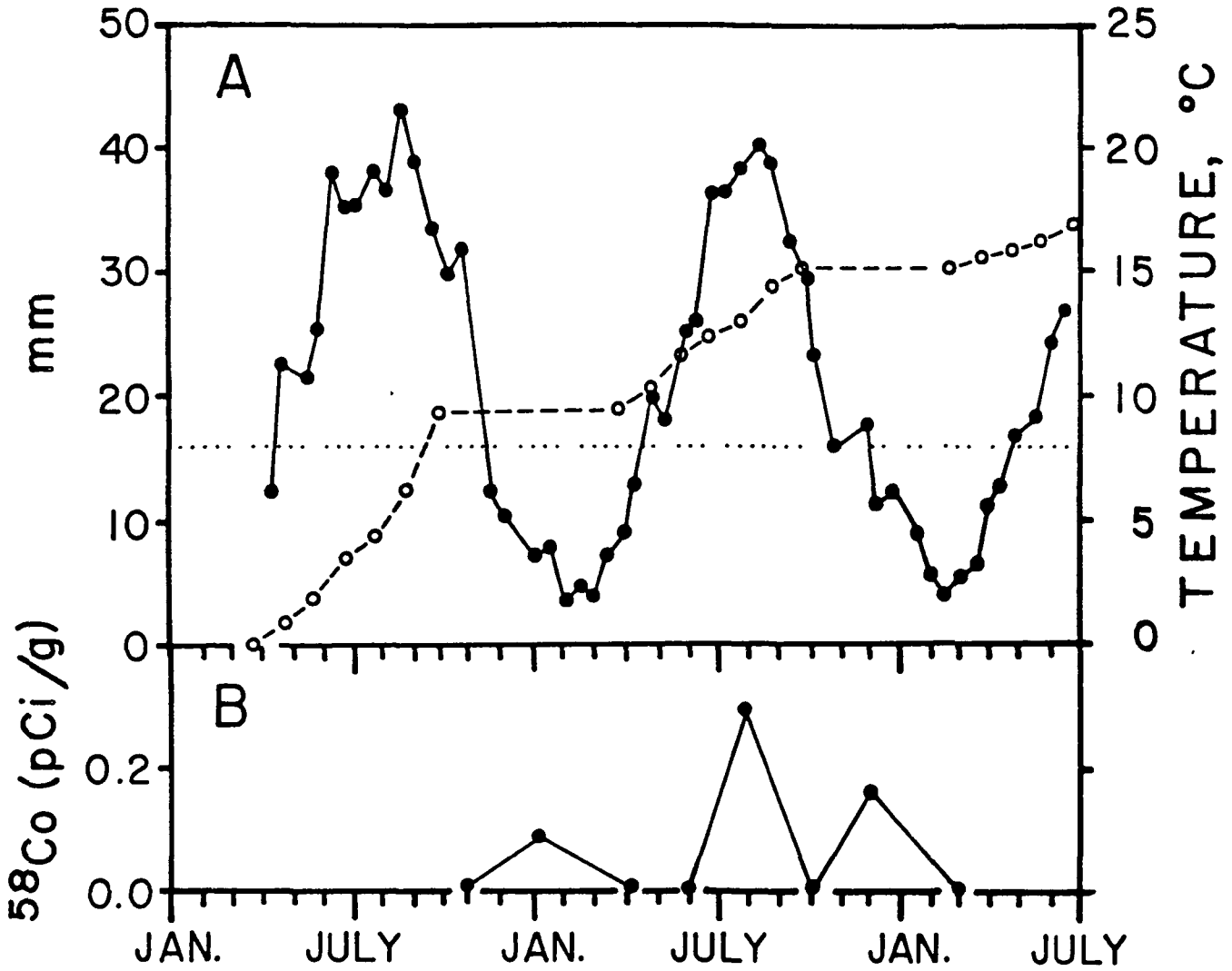

Fig. 8 Aa. Oyster shell growth, Ab. Temperature in ^{o}C, Ba. Radionuclide ^{58}Co concentration, and Bb. Theoretical ^{58}Co radionuclide concentration versus month of year as in figure 6. for longledge site (S4).

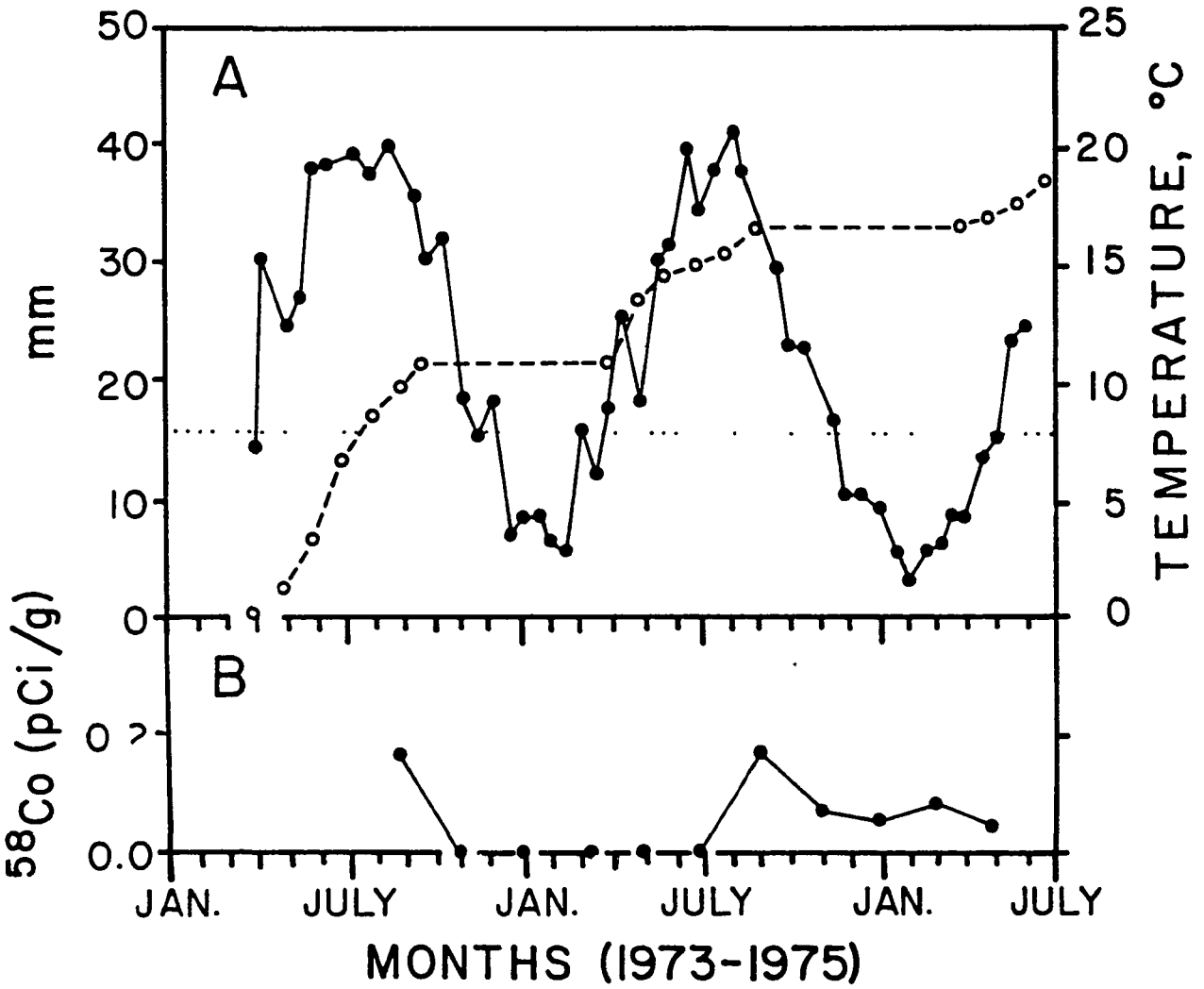

Fig. 9. Aa. Oyster shell growth, Ab. Temperature in ^{0}C, Ba. Radionuclide ^{58}Co concentration, and Bb. Theoretical ^{58}Co radionuclide concentration versus month of year as in figure 6. for intake site (S1).

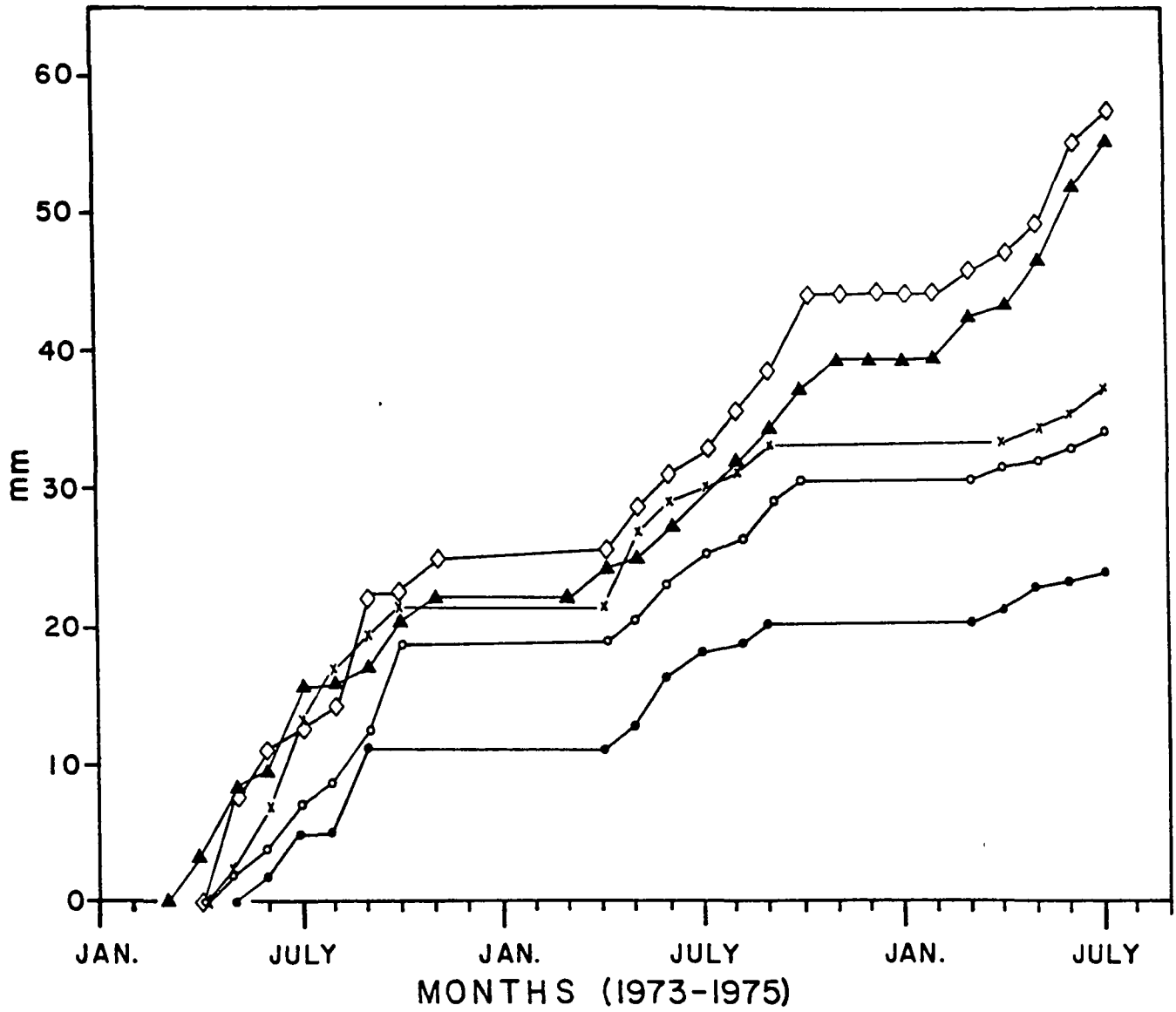

Fig. 10. Comparison of oyster shell growth for all stations versus time of year for 1973-1975. Controls (●——●), Intake (0——0) Long Ledge (x——x) outflow (▲——▲) Upper Cove (◊——◊).

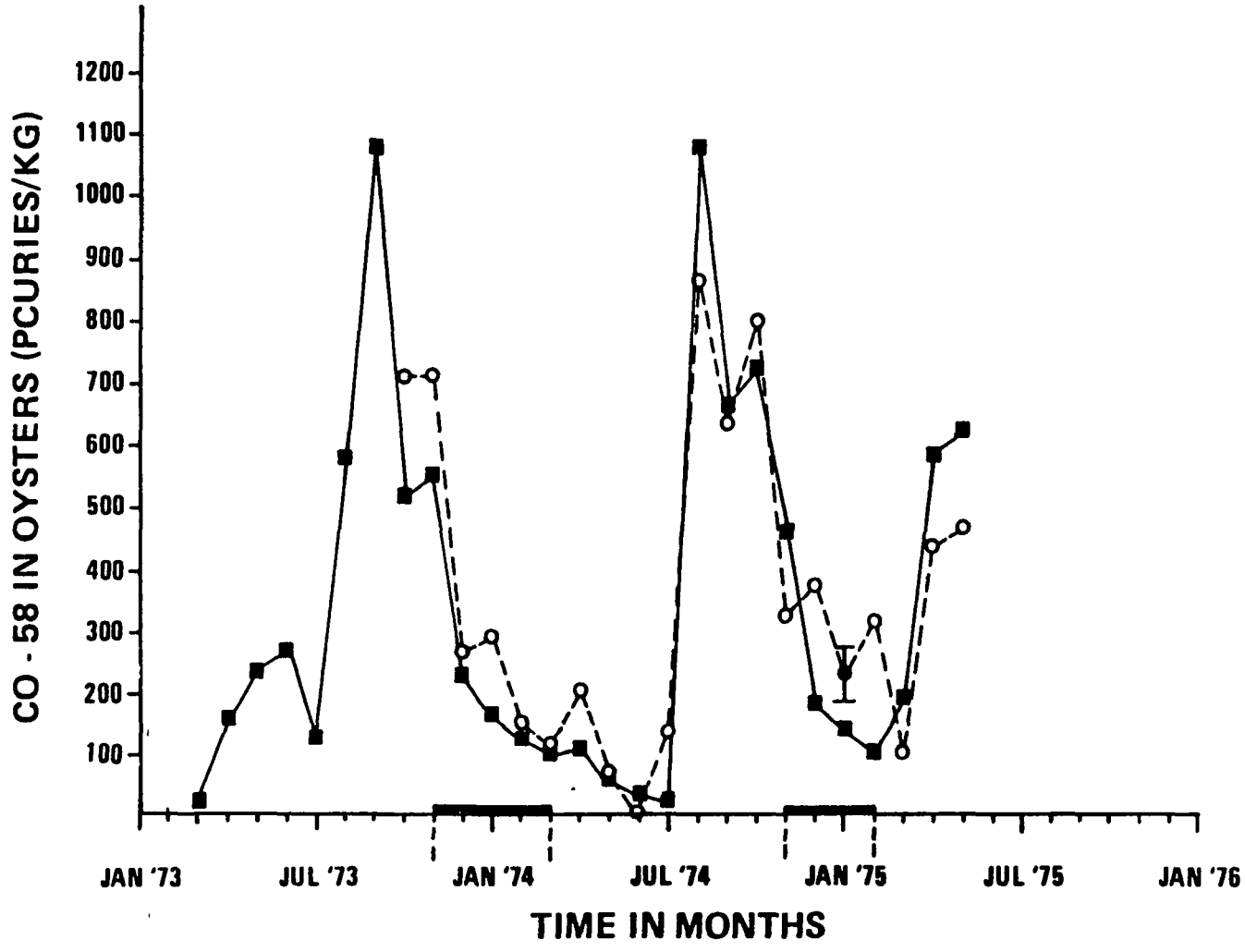

Fig. 11.a. Theoretical calculations for ^{58}Co for changing U, and $t_{\frac{1}{2}b}$ U = 1 x 10^{-8}Kg, $t_{\frac{1}{2}b}$ = 35 days, with no black bar and U = 0.0 $t_{\frac{1}{2}b}$ = ∞ with black bar (■—■).

b. Experimental results for ^{58}Co in oysters (0---0).

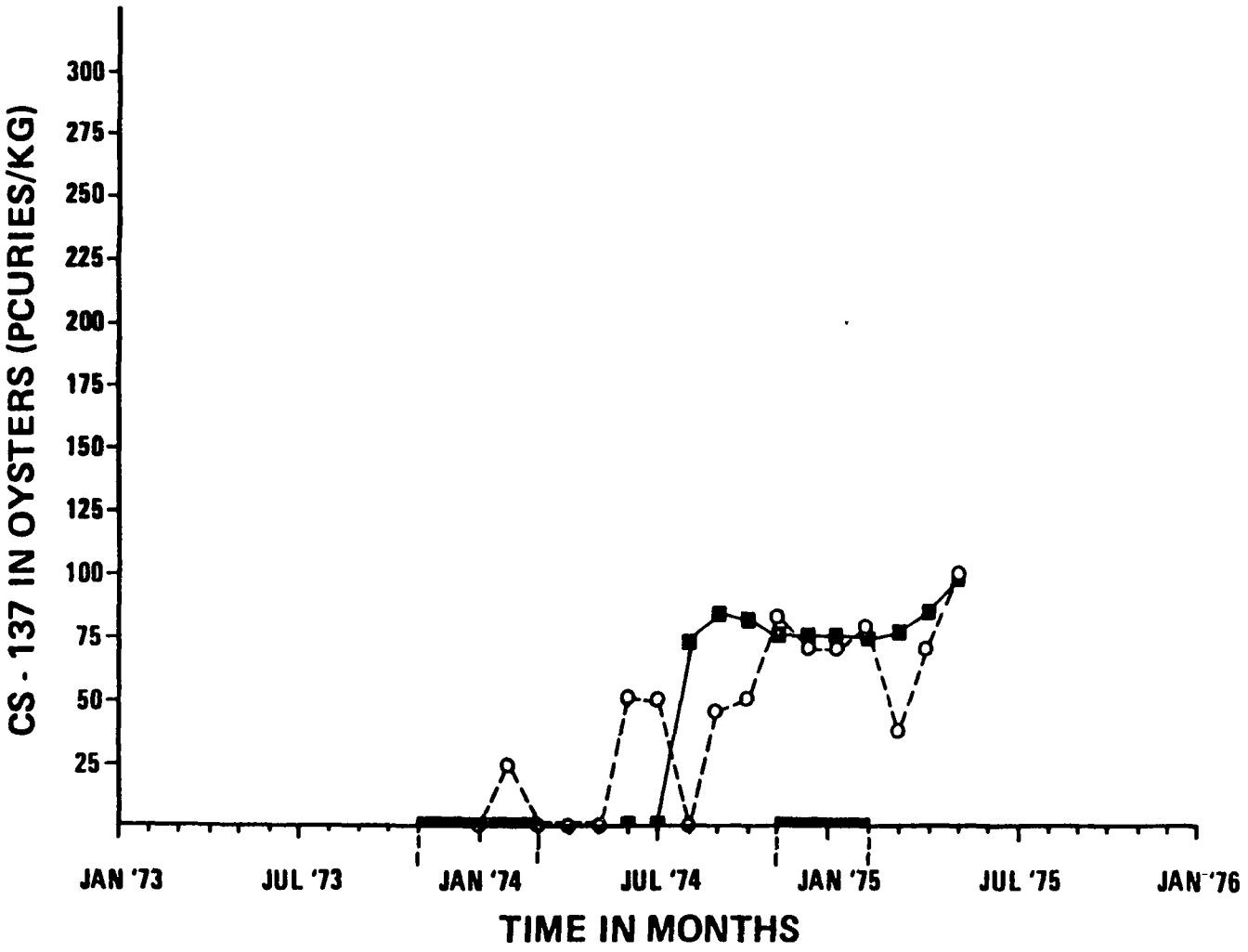

Fig. 12.a. Theoretical calculations for ^{137}Cs changing U and $t_{\frac{1}{2}b}$: U = 1 x 10^{-8}Kg., $t_{\frac{1}{2}b}$ = 250 d with no black bar and U = 0.0 $t_{\frac{1}{2}b}$ = ∞ with black bar (■—■)

b. Experimental results for ^{137}Cs in oysters (0---0).

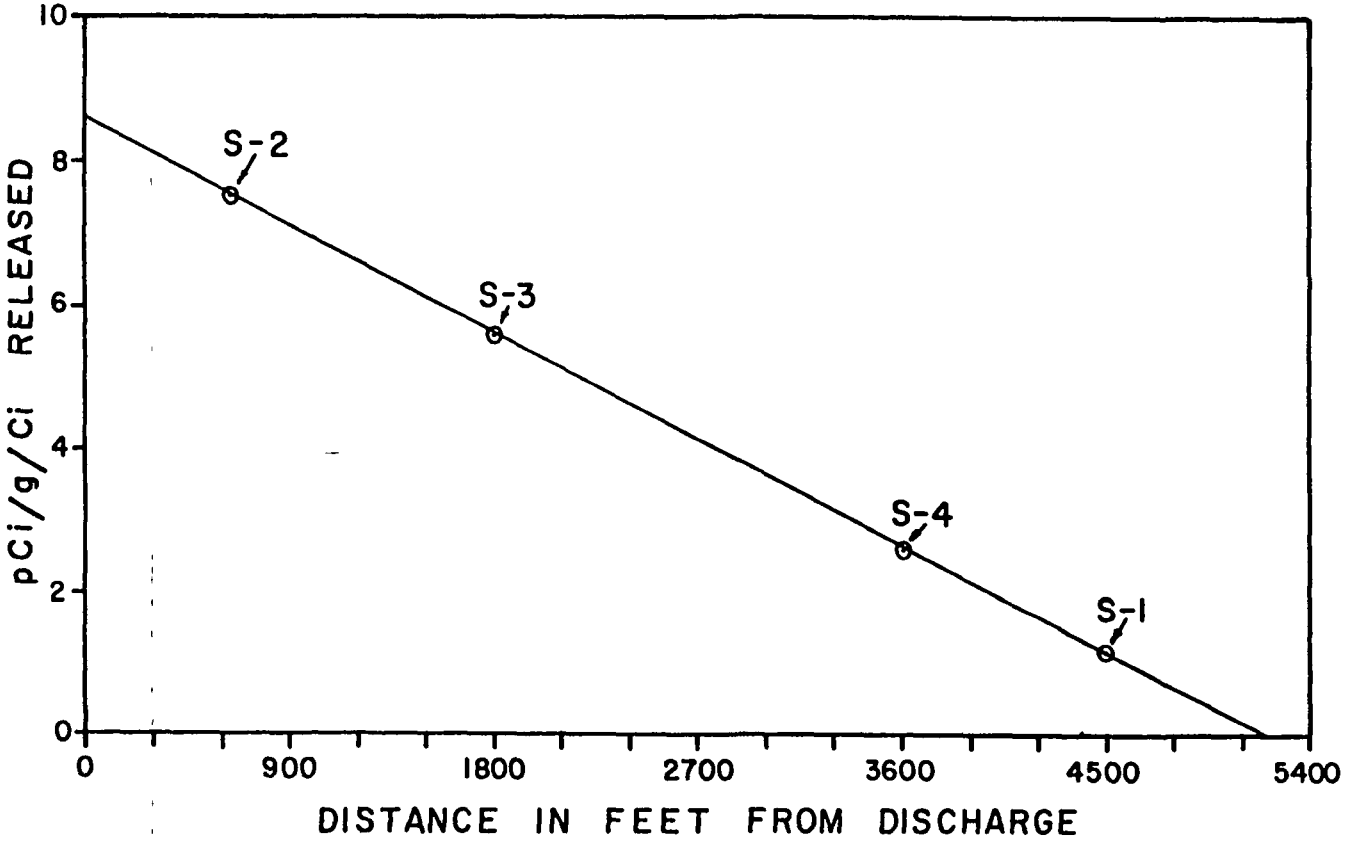

Fig. 13.a. Results of evaluation of U at each site S-1, intake site, outflow S-2 upper cove S-3 and Long Ledge S-4 versus distance in water from the release point.

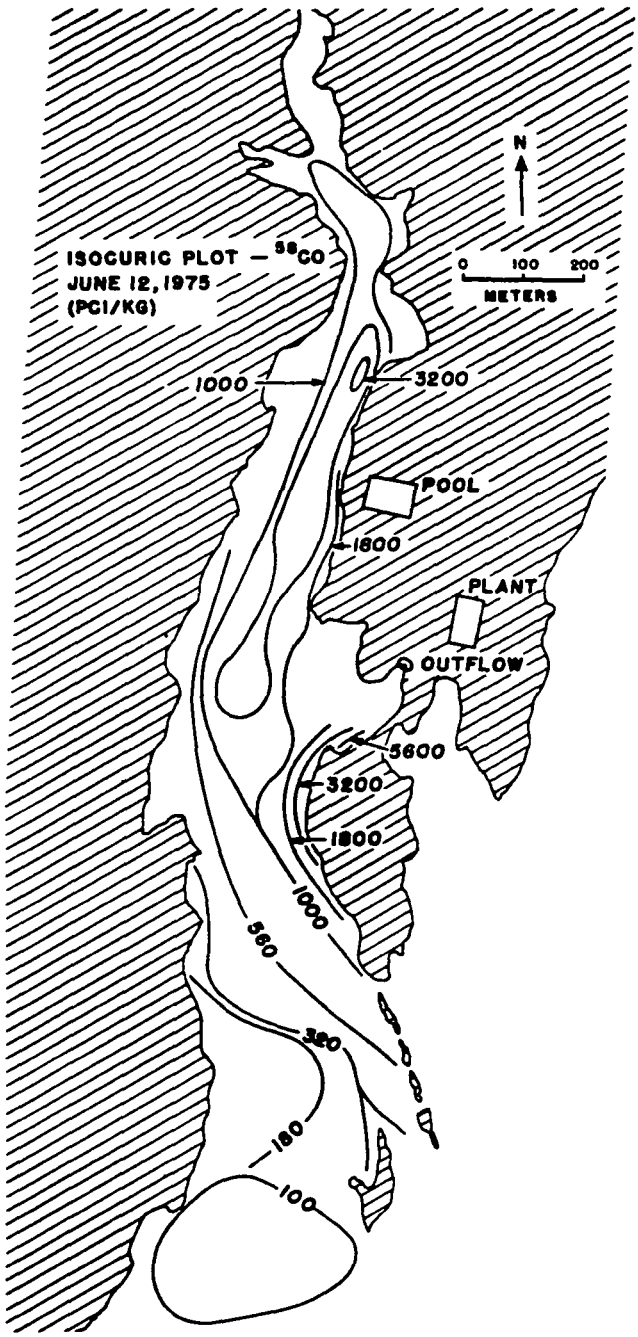

Fig. 14. Isocuric map of ^{58}Co concentration in sediment for the sediment survey; June 12, 1975.

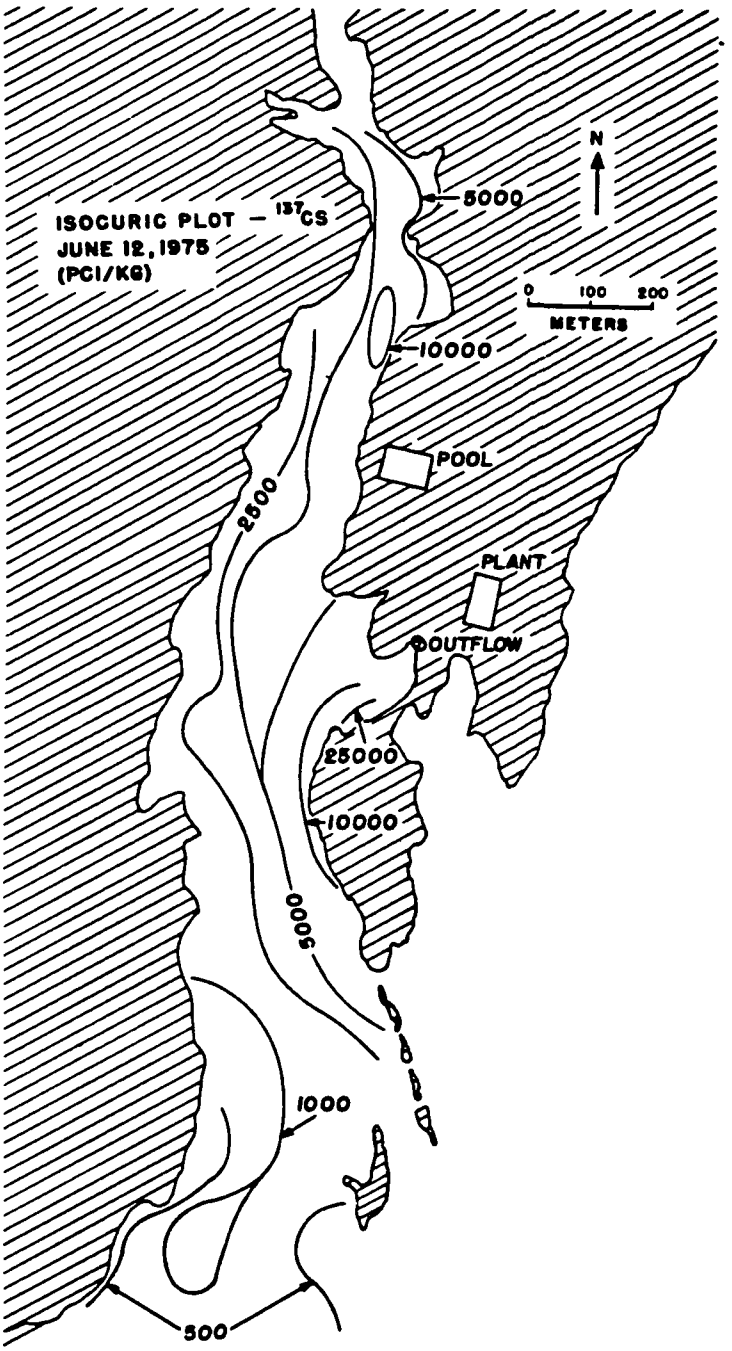

Fig. 15. Isocuric map of ^{137}Cs concentration in sediment for the sediment survey; June 12, 1975.

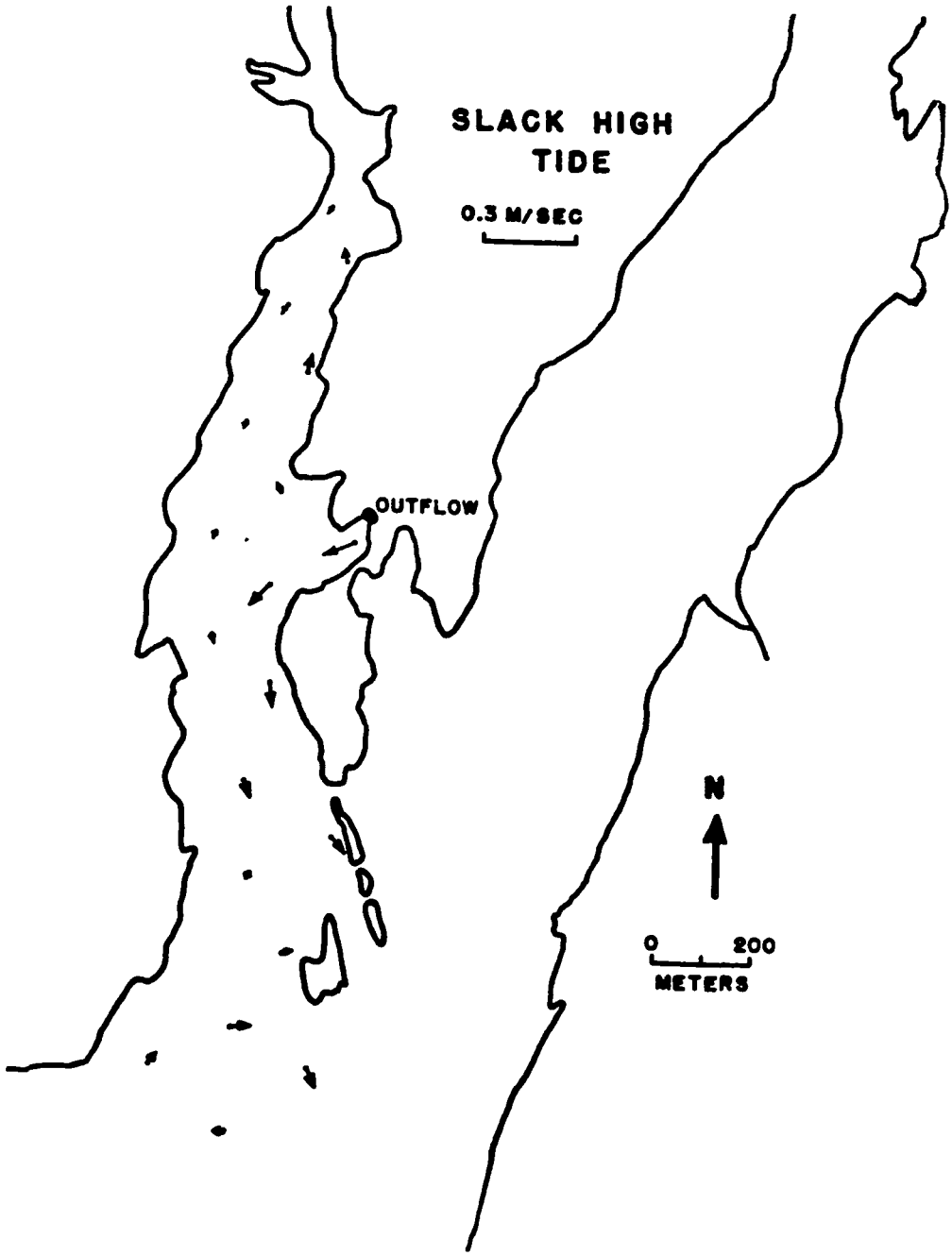

Fig. 16. Computer calculated water velocities at slack high tide.

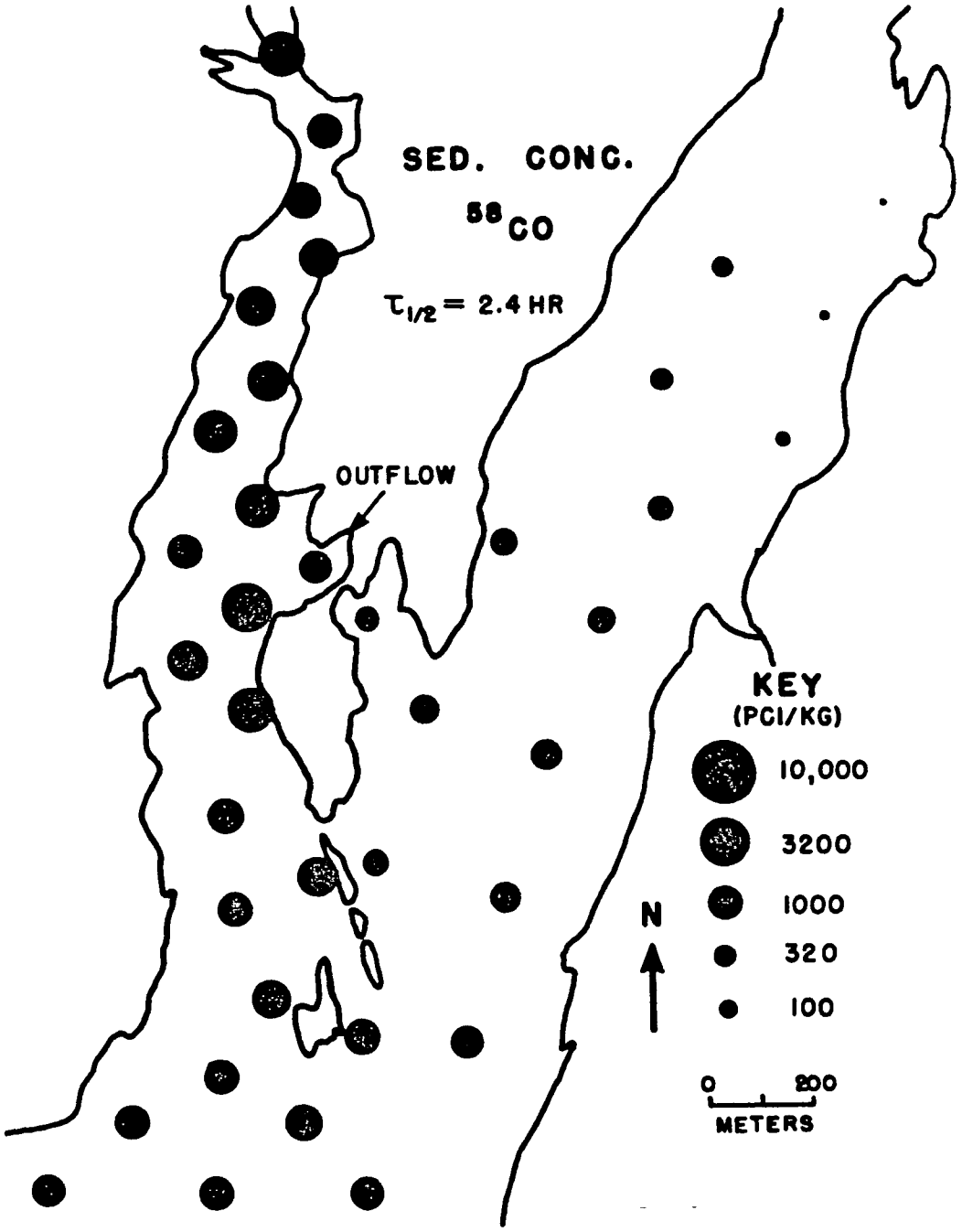

Fig. 17. Computed concentrations of ^{58}Co in sediment measured in pCi/kg, for $t_{\frac{1}{2}b}$ = 2.4 hr.

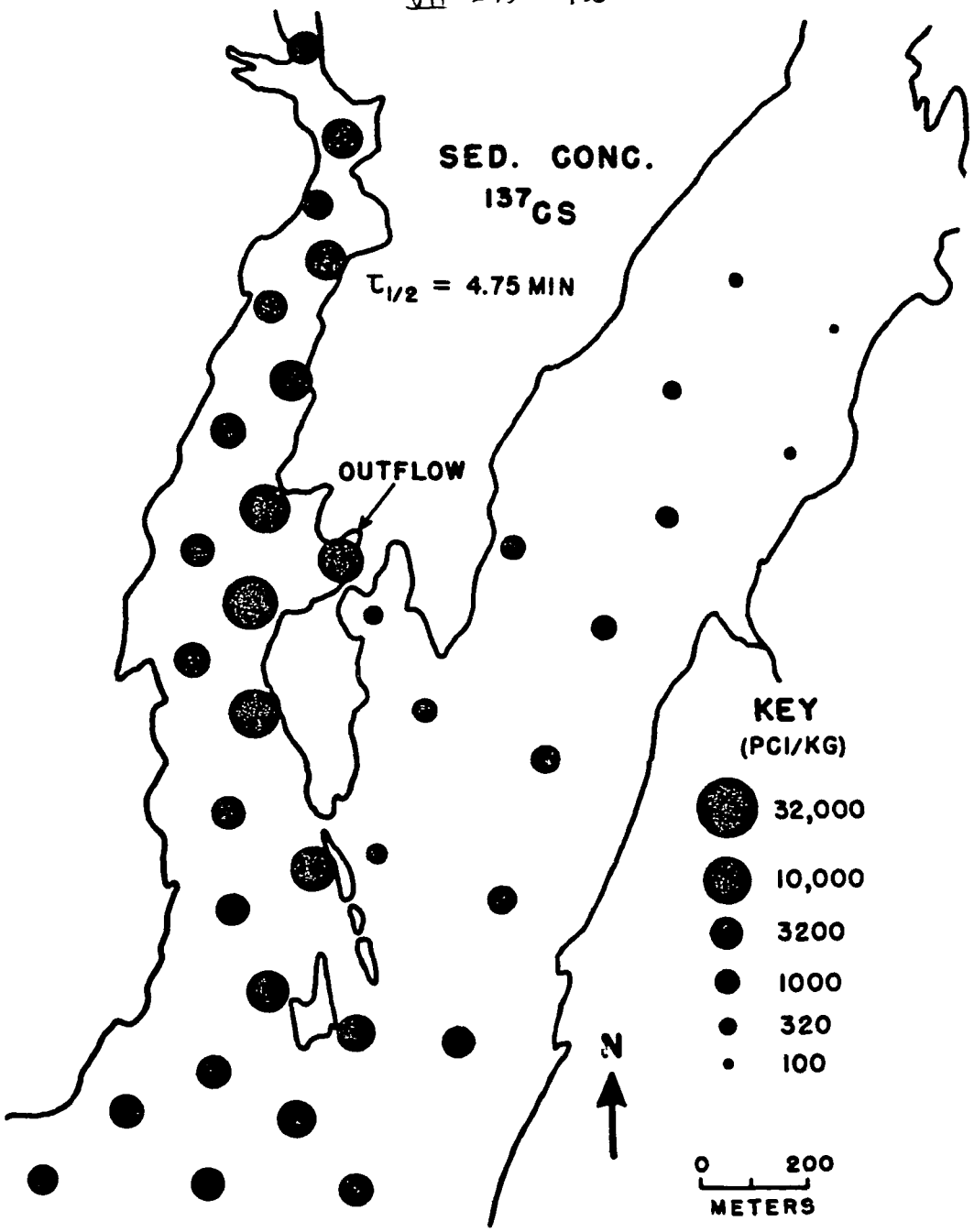

Fig. 18. Computed concentrations of ^{137}Cs in sediment measured in pCi/kg. $t_{\frac{1}{2}b}$ = 4.75 min.