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FALLOUT Mn-54 ACCUMULATED BY BAY SCALLOPS *ARGOPECTEN IRRADIANS* (LAMARCK) NEAR BEAUFORT, NORTH CAROLINA

Written and

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Revised Abstract

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Bay scallops were collected in estuarine waters near Beaufort, North Carolina, during the period of January 1963 to June 1966 and analyzed for gamma radioactivity originating from fallout. Most of the gamma radioactivity was Mn-54, with scallops containing 30 times more Mn-54 than other lamellibranch mollusks collected at the same time. Concentrations of Mn-54 were largest in December 1963 and October 1964 and declined after October 1964, with a half-life of approximately 240 days. Concentrations of Mn-54 in the 75 samples collected were a function of collection sites in the estuary, size of the scallops, and tissue type.

Amounts of Mn-54 were determined in seven different tissues. Kidneys contained the greatest concentrations, about 100 times more than adductor muscle, gills, mantle, gonad, visceral mass, and liquid. Maximum concentrations in kidneys were 100 pCi/g wet weight. Kidneys are a small fraction of the total weight, so concentrations in the combined soft parts are about a factor of 100 lower than the kidney. Stable element content of scallop tissues was determined

also, and kidneys again contained at least 100 times more stable manganese than any of the other tissues. Variations in specific activities (pCi Mn-54/µg Mn) among the different tissues were greater than could be explained by physical decay and possible turnover rates in the organism.

Mechanisms of Mn-54 and stable manganese accumulation are postulated from data on specific activity of different tissues, mode of scallop feeding, and results of laboratory experiments in which scallops were fed phytoplankton labelled with Mn-54. These data are important because kidneys of bay scallops concentrate Mn-54 more than any other biological system presently known. Public health implications are minimized because only the adductor muscle is sold as seafood.

FALLOUT MN-54 ACCUMULATED BY BAY SCALLOPS ARGOPECTEN IRRADIANS (LAMARCK) NEAR BEAUFORT, NORTH CAROLINA [1]

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Estuarine systems near Beaufort, North Carolina include Bogue Sound, Newport River, North River, and Core Sound with a combined area of approximately 400 km^2 (Fig. 1). These estuaries are shallow and turbid with most areas being less than 2.0 m deep at low tide. The mean tidal range is 0.8 m near the inlets (1). The estuaries are highly productive, a characteristic of estuaries in the southeastern part of the United States. Part of the productivity is due to marsh grasses, primarily Spartina alterniflora, which enter aquatic food chains as detritus. Production of cord grass, Spartina alterniflora, was about one-third the production of phytoplankton in these systems (2), where zooplankton standing crops have been measured also (3).

Studies of fallout radioactivity in these North Carolina estuaries indicated that bay scallops could be used as a biological indicator of Mn-54 (4). Scallops contained more Mn-54 and Cs-137 than three other species of filter feeding molluscs, hard clams, American oysters, and marsh mussels collected in the same area (5). Benthic feeding fish from these estuaries also accumulated more Mn-54 than fish with other feeding habits (5).

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Bay scallops are an ideal biological indicator of radioactivity in the environment because they are easily collected in large quantities and are sessile, so collection location can be accurately related to sources of accumulated radioactivity (4). Scallops also have a one-year life cycle so the time span when radioactivity can be accumulated is restricted largely to the year preceeding collection. Near Beaufort, scallops spawn from late summer until early winter and are harvested commercially before they are 16 months old (6). Most of the harvested scallops are one year old or less (6).

The biology of bay scallops in Bogue and Core Sounds has been described (6). Scallops are filter feeders with filtering rates as great as 16 liters/hr (7). Food sources are not well known. Food of the Pacific mud flat scallop, Pecten circularis, is reported to be detritus (8). Materials eaten by these scallops were studied by cutting a hole in the animal's shell and mantle and closing the opening with a glass cover slip so materials ingested could be observed directly. Other workers have found that bay scallops feed primarily on phytoplankton in a discrete epibenthic layer (9). General aspects of suspension feeding have been reviewed by Jorgensen (10).

Two species of scallops can be collected near Beaufort, North Carolina. The bay scallop, Argopecten irradians (Lamarck), occurs in the shallow estuaries and the calico scallop, Argopecten gibbus (Dall), occurs in the offshore waters at depths ranging from 20 to 90 m. In addition to being found in different habitats, the two species can be separated by morphological characteristics (11). My paper is concerned mainly with bay scallops, and I use "scallops" to denote this species.

METHODS AND MATERIALS

Scallops were collected in Core and Bogue Sounds near Beaufort, North Carolina (Fig. 1) from January 1963 to August 1966. Tissues from 6 to 12 scallops were pooled for measurements into the following fractions: liquid, gill, mantle, adductor muscle, visceral mass, kidney, and gonad. With the exception of the visceral mass, the soft tissues were readily and distinctly separable into the above named organs or organ systems. The visceral mass contained the digestive tract, with the exception of the rectum and associated digestive organs. In some samples the rectum was not separated from the adductor muscle. The rectum, a small fraction of the soft parts, and the shell were counted, but the amounts of radioactivity were so low that exclusion of the data was not significant. More than 70 sets of tissue samples were analyzed for gamma radioactivity.

Gamma-emitting radionuclides in the tissues were measured with a low-background counting system. The 512-channel analyzer (Nuclear Data 130) was equipped with an oscilloscope, IBM typewriter, and paper punch for readout. A solid 10-cm x 10-cm NaI (Tl) crystal mounted on a 7.5-cm phototube was housed in a large shield, inside dimensions of .61 x .61 x .91 m high with 15-cm steel sides lined with 6 mm of lead and 1.5 mm of stainless steel.

Samples were counted using 127 channels of the analyzer calibrated at 20 keV/channel. Samples were counted from 20.0 to 80.0 minutes which was usually enough time to obtain sufficient counts for a counting error no greater than ± 5.0%. The background in the 6 channels used to measure Mn-54 was about 18 cpm. Counts of Mn-54 were corrected for background but were not corrected for Compton scattering from radionuclides with gamma energies greater than 0.84 meV, primarily Zn-65 and K-40. These two isotopes were present in small proportions relative to the Mn-54 activity (5), so not correcting for their activity was insignificant for the tissues with higher activities, and represented an overestimation of Mn-54 by no more than 10% for the adductor muscle, a tissue with a low activity.

Dissected samples were put in plastic cups which were placed directly on the detector for counting. Three series of tissue samples were counted, dissolved in nitric acid and counted again in 50 ml of liquid. Ratios of the counts of the wet samples to the counts of the liquid samples were used as a geometry factor in the calculation of activity present in each tissue.

After the samples were counted, the data were punched on paper tape, transferred to IBM cards, and analyzed with a computer program. Results were obtained for each tissue as pCi/gram wet weight and pCi/animal.

Scallops for laboratory experiments were collected in the vicinity of the Radiobiological Laboratory at Beaufort. Animals were maintained in large fiberglass tanks for the experiment in which uptake in Millipore filtered water and cotton filtered water was compared. In this experiment the water was not changed, and other lamellibranch molluscs, clams, oysters, and mussels were present in the tank (5). Under these conditions cycling of radioactivity would be expected.

In the other laboratory experiments, animals were maintained in running sea water except for the periods required to label them with radioisotopes. Sea water was provided from the laboratory system, pumped from the estuary into settling tanks, fed into the laboratory experiments, and discharged, eliminating cycling of radioactivity for all practical purposes.

In one experiment accumulation of Mn-54 from phytoplankton, Chlamydomonas, and sea water was compared. Phytoplankton were labelled while growing in a medium containing Mn-54 and were separated from the radioactive medium for use in the experiment. Activity added directly to sea water in the ionic form would have been adsorbed on particles and possibly absorbed by phytoplankton in the water; however, some of the activity may have been accumulated by scallops from the added ionic phase. In this experiment, to avoid problems of determining available quantities of Mn-54 from different sources, amounts in tissues were based on percentages of the total accumulated.

Animals in the laboratory experiments were dissected and counted as described above. Activity of live animals was measured by wrapping them in Saran wrap, counting them in a Packard Armac counter, and then returning them to holding tanks. This procedure made it possible to use the same animals for studies of uptake or loss of radioactivity.

Concentrations of stable zinc and manganese were measured with atomic absorption spectrophotometry using a Perkin Elmer 190. Tissues were dissected and prepared for analysis as follows: digested with nitric acid, evaporated to dryness, and then dissolved and diluted to volume in 4% hydrochloric acid. Four samples of one scallop each were used in the analysis.

FALLOUT MN-54 IN SCALLOP TISSUES

Mn-54 was measured in tissues of scallops collected from December 1963 to June 1964 (Table 1). Large ranges in variances of the arithmetic data for concentrations indicated the need to transform data prior to statistical analysis. A log transformation provided data with much more uniform variances or standard deviations, and Bartlett's test indicated homogeneity of variances.

Analysis of the transformed data revealed significant differences among the samples, either on the basis of concentration per unit weight or on the basis of amount per animal (Table 1). An analysis of variance (F-values) showed a highly significant difference among the means for different tissues and the least significant difference between means for each group (12). On a weight basis, all the tissues except the mantle and liquid contained significantly different concentrations of Mn-54, whereas amounts per animal were not significantly different for the tissue pairs of gonad-mantle and liquid-gills.

The most outstanding feature of the distribution of Mn-54 among different tissues was the amount and concentration in kidneys. On a weight basis, kidneys contained 100 times more Mn-54 than the other tissues, except the visceral mass, and about 70 times more Mn-54 than the visceral mass (Table 1). Even though the kidney represented only 2% of the wet weight, it contained nearly 80% of the average amount of Mn-54 in the soft tissues.

Based on these data, it seemed logical that the amounts of fallout Mn-54 in scallops could be studied from measurements of kidneys alone without measuring amounts in other tissues. Starting in June of 1965 a sampling program was instituted to continue the study of Mn-54 accumulated by scallops from measurements of kidneys.

YEARLY VARIATION OF FALLOUT MN-54 IN KIDNEYS

From the available data there was no apparent seasonal distribution of Mn-54 concentrations in scallop kidneys (Fig. 2). Two peaks of concentration occurred in December 1963 and November 1964 in samples collected in Bogue Sound. Data for Dog Island in 1964 indicate that concentrations for this location were similar to those for Salterpath, and that scallops contained as much Mn-54 in 1964 as in 1963.

Concentrations of Mn-54 in kidneys varied according to sampling location. Even though data were variable, they could be divided into two groups (Fig. 2). Samples from Bogue Sound (above the solid line) had

larger concentrations than samples from Core Sound. All the points from the two main collecting sites, Salterpath in Bogue Sound and Whitehurst Island in Core Sound, were separated by this division. Four collections from Bells Island in Core Sound contained concentrations large enough to be grouped with Bogue Sound, and one from the Biltmore Hotel was in the Core Sound group. Data for samples collected prior to the fall of 1964 also seemed to differ according to location. Collections from Emerald Island in the western part of Bogue Sound appeared to contain less Mn-54 than the other samples collected from the eastern part of the sound.

Some of the variability among the different samples was due to differences in sizes of scallops. Larger concentrations of Mn-54 were usually present in the paired sample containing larger animals than in the sample with smaller animals (Fig. 2). Differences were greater for amounts per animal, where size is a greater factor, than for concentrations per unit weight, indicating that Mn-54 was accumulated during growth of the animal. No attempt was made to model amounts or concentrations as a function of size, location, and time because there seemed to be insufficient data for this purpose.

The decrease in amounts of Mn-54 during 1965 and 1966 can be used to calculate an environmental half-life. In the absence of a refined model, it appears, either from the solid line separating the two groups or from the dashed line for the best fit of the Bogue Sound data, that the concentration of Mn-54 decreased exponentially during the two-year period with a half-life of approximately 240 days (Fig. 2).

SPECIFIC ACTIVITY OF FALLOUT MN-54 IN TISSUES

Concentrations of stable manganese were measured to determine whether scallops accumulated stable manganese and fallout Mn-54 differently. When kidney samples were dissolved, they had a pink color characteristic of the manganous sulfate reagent used by aquatic ecologists for oxygen determinations. Manganese concentrations in kidneys averaged 7 mg Mn/g wet weight (Table 2). Kidneys contained more stable manganese than any of the other tissues with an average concentration 100 times greater than the gonads and more than 1000 times greater than the mantle (Table 2). Concentrations of manganese in gills and visceral mass varied more than in the other tissues, but concentrations of zinc also varied more among these tissues. It is possible that these tissues may have been contaminated during dissection and handling in the laboratory, but they might actually have contained greatly different concentrations, since the visceral mass contains the digestive tract and materials ingested by the animal.

Concentrations of stable zinc in kidneys, like stable manganese, were also greater than in any of the other tissues, but only about 50 times larger than concentrations in gonads (Table 2). Kidneys contained about 100 times more zinc than the mantle which had the lowest average concentration.

Concentrations of stable manganese were not measured routinely in tissue samples analyzed for fallout Mn-54. Specific activities were therefore calculated from average concentrations of fallout Mn-54 (Table 1)

and average concentrations of stable manganese from another sample of scallops (Table 2). Specific activities ranged from 8.3 pCi Mn-54/mg Mn in gonads to 66.9 pCi Mn-54/mg Mn in the adductor muscle (Table 3). The large range cannot be explained entirely by variations in stable manganese because gonads and mantle with relatively little variation in stable manganese represent the two extremes. The low value for kidneys may be due partly to errors in weighing the relatively small mass of kidneys compared to other tissues. Kidney weight for fallout Mn-54 data averaged 0.5 g (Table 1), and weights for stable manganese data averaged 0.3 g (Table 2), indicating a possible error of 60%. Calculating specific activities from two sets of data assumes no seasonal or areal difference in stable manganese concentration. As indicated in the discussion, additional data are needed to answer some of the questions raised by the calculated variations in specific activities among the tissues.

DISTRIBUTION OF MN-54 IN LABORATORY EXPERIMENTS

Laboratory experiments were run to measure amounts of activity accumulated and for comparison with data from environmental samples. Kidneys contained nearly 80% of the fallout Mn-54 accumulated in the soft parts of scallops collected in the field (Table 4). In laboratory experiments, kidneys also accounted for 80% of the Mn-54 in soft parts, but apparently only after 65 days, when the amounts in different tissues were at some steady state condition (Table 4). After 3 days smaller amounts were present in the kidneys. Because data from only two days are available, it is not possible to determine rates of transfer and quantities for the different tissues or compartments. It is evident, however, that the kidney is a sink for accumulated activity.

Gills and visceral mass contained a larger percentage of the radioactivity at 3 days than at 65 days, indicating that in this experiment these tissues functioned in the transfer of activity from the environment to the animal (Table 4). In the Millipore-filtered water, the liquid also contained a large percentage of the accumulated Mn-54. Data on the specific activity of Mn-54 (nCi/g) are essential if one is to model the transfer and storage among the compartments. For example the muscle contained 5 or 6 times more stable manganese than the mantle due to differences in weight and concentration of manganese (Table 2); therefore, after 3 days the specific activity of Mn-54 in the mantle was probably greater than in the muscle, indicating that the pool of manganese in the mantle had a greater rate of turnover than the muscle, or that activity was transferred to the mantle before it was transferred to the muscle, or some combination of the two.

A second experiment was run in which Mn-54 was added to unfiltered sea water and in the form of labelled Chlamydomonas cells. In this experiment (Table 5), the added Mn-54 was taken up much more rapidly by the visceral mass, muscle, and kidney than in the previous experiment (Table 4). At 21 hours more than 85 per cent of the accumulated activity was present in the three tissues. Within 21 hours kidneys of the scallops from the tank containing Mn-54 labelled phytoplankton accounted for 80% of the activity in the experimental animal. These results suggest that the

scallops filtered all the labelled phytoplankton and transported the Mn-54 to the kidney within 21 hours. Comparing the percentages of activity accumulated from sea water and labelled phytoplankton indicates that the pathways or mechanisms of accumulation are different for the two sources, since when Mn-54 was added to sea water about 94 hours elapsed before the kidneys contained 80% of Mn-54 in the animals.

When Mn-54 was added as labelled phytoplankton it was not lost by scallops as rapidly as Mn-54 added directly to sea water (Table 5). In 21 days (506 hours) the amount of Mn-54 per scallop in the phytoplankton experiment was reduced 21%, whereas more than 50% of the activity was lost from scallops in the sea water experiment.

Zinc-65 accumulated from phytoplankton and sea water was distributed differently with time in the scallop tissues than Mn-54 (Table 5). It accumulated gradually in the kidney when added directly to sea water or when added as labelled phytoplankton. Zinc-65 accumulated under both conditions was retained as long as Mn-54 accumulated from phytoplankton and longer than Mn-54 accumulated from sea water.

RATE OF LOSS OF MN-54 IN THE LABORATORY

In laboratory experiments scallops lost Mn-54 with a biological half-life of 50 days or less. The loss rate between 16 and 57 days was greatest with a half-life of 30 days (Fig. 3). During the first few days of the experiment the half-life appeared to be greater, but was only 50 days. The increase in loss rate was coincident with higher water temperatures after 9 days, when water temperatures remained above 15°C and increased to 24°C by the end of the experiment. During the first 7 days of the experiment when the loss rate was least, water temperature was less than 15°C.

DISCUSSION

Fallout Mn-54 accumulated by bay scallops reached peak levels in 1964 (Fig 2), more than two years after the U.S.S.R. atmospheric tests in 1961 which have been reported to be the main source of fallout Mn-54 (13). Maximum amounts of Mn-54 in fallout were not detected, however, until the spring and summer of 1963 (13), presumably because the activity was associated with small particles and injected at high altitudes. Amounts of Mn-54 in fallout were a factor of 10 less in 1964 than in 1963. Amounts of Mn-54 in scallop kidneys also increased during 1963, presumably after the spring maximum in fallout, but as tabulated below, were as large in 1964 as in 1963. These data indicate that scallops in 1964 accumulated Mn-54 from an environmental reservoir and not from recently deposited fallout, which had decreased to low levels. Levels of Mn-54 in freshwater clams in 1963 were also much greater than in 1962 (14).

Mean concentrations of Mn-54 in kidneys of bay scallops:

	pCi/g	pCi/animal
Jan. 1963 (8)	30.8 ± 5.3	13.1 ± 3.6
Dec. 1963 - June 1964 (15)*	97 ± 40	49 ± 32
Jan. 1965 (8)	128 ± 35	52 ± 21

* from Table 1

Large amounts and concentrations of Mn-54 in scallop kidneys do not pose a problem from the standpoint of public health. In the United States only the adductor muscle is eaten and sold commercially. According to commercial fishery records, 2.4×10^5 lbs, or 1.0×10^8 g, of scallop muscle were harvested from Bogue Sound in 1964, the year when concentrations of Mn-54 appeared to be greatest (Fig. 2). If the concentration was 1.0 pCi/g (Table 1), the harvest contained 1.0×10^8 pCi or 0.1 mCi Mn-54. If 10% of the total Mn-54 in scallops was present in muscle tissue (Table 4), then 1.0 mCi Mn-54 would be a conservative estimate of the total activity in scallops harvested from Bogue Sound in 1964.

The combined soft tissues of bay scallops contained at least 10 times more Mn-54 and stable manganese than other lamellibranch molluscs collected in the estuaries near Beaufort. Average concentrations of two undissected scallop samples were 4.8 pCi Mn-54/g wet weight and 55 µg Mn/g wet weight (5), which are comparable to calculated concentrations for combined soft parts (Tables 1, 2). Other workers have found large concentrations of stable manganese and zinc in scallop kidneys (15). Concentration factors for Mn-54 could not be calculated because data on Mn-54 concentrations in sea water were not available. Concentration factor for stable manganese, assuming a manganese concentration of 5 µg Mn/l in sea water, would be 11×10^3 for the combined soft parts and 14×10^5 for scallop kidneys. A mechanism other than accumulation directly from sea water is suggested by the relatively large concentration factor for kidneys.

Possible pathways of accumulation of trace elements by filter feeding molluscs can be from ingested particles including food or from uptake of ionic forms. Brooks and Rumsby (15) concluded that particulate ingestion or adsorption of particulate matter was the most likely mechanism for trace element uptake by marine bivalves in New Zealand. My data suggest that scallops obtained Mn-54 more readily from labelled phytoplankton and retained it longer than Mn-54 added in other forms. The rate of uptake and retention of manganese measured as percent Mn-54 in kidneys (Tables 4, 5) indicated that both increased as the amount of particulate matter in the water increased. The least amount was accumulated from Millipore filtered water, and the greatest percentage was accumulated in the shortest time from labelled phytoplankton.

More of the added Mn-54 in Millipore and cotton filtered water was probably in the ionic or colloidal form than in any of the other experimental conditions. Under these conditions, larger amounts of activity were accumulated by gills, mantle, and liquid (Table 4) than when added activity

was associated with particles in sea water or labelled phytoplankton (Table 5). Mn-54 added as labelled phytoplankton was transferred to the kidney within 21 hours, presumably via absorption in the digestive tract, in proportions that were representative of what are presumed to be equilibrium values for field samples. Because this condition was achieved most rapidly when labelled phytoplankton were used as food, I concluded the mechanism for manganese accumulation is from food.

Data on specific activities of Mn-54 among different tissues were variable and cannot be used to interpret mechanisms of manganese uptake. Possibly mechanisms could have been determined if stable and radioactive manganese had been measured conjunctively in a large set of samples, so that Mn-54 could have been used as a tracer. Relatively low specific activities in gills indicate that fallout Mn-54 was not absorbed by the gills from the water as would be expected because fallout enters the environment as particles, and most of the manganese in sea water is also in the particulate form.

After the inputs of Mn-54 decreased in 1964, the concentrations in scallop kidneys decreased exponentially with an estimated environmental half-life of 240 days (Fig. 2). In one laboratory experiment, the biological half-life of Mn-54 ranged from 30 to 50 days and seemed to vary with water temperature (Fig. 3). The difference in the rate of loss between the environmental and biological half-life is undoubtedly a function of the supply of Mn-54 in the environment. The large difference indicates a relatively large reservoir of Mn-54 with an input that was not adequate to compensate for physical decay half-life of 300 days.

Ecologically, interpretation of data on accumulation of Mn-54 by scallops poses some interesting questions. Amount of radioactivity accumulated by bay scallops was apparently related to sampling location, indicating that different amounts of fallout Mn-54 were available for uptake at the different locations. Gutsell (6) reported that the growth of bay scallops in Bogue Sound decreased from east to west as amount of tidal action decreased. Marshall (16) has also indicated that relatively large tidal action and high salinity are environmental characteristics favorable for scallop growth, possibly due to supplies of phytoplankton provided from offshore waters. Concentrations of Mn-54 in samples from Bogue Sound also decreased with collecting location from east to west, but bay scallops collected in Core Sound contained less Mn-54 than those collected in Bogue. Calico scallops collected off the coasts of North Carolina and Florida contained less than one per cent of Mn-54 concentrations found in bay scallops. In laboratory experiments both species accumulated similar amounts of Mn-54 from sea water. These data indicate that environmental characteristics associated with shallow estuaries contributed to the large amount of Mn-54 accumulated by bay scallops.

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TABLE I

MANGANESE-54 IN SCALLOP TISSUES COLLECTED DECEMBER 1963 TO JUNE 1964.
DATA ARE MEANS ± ONE STANDARD DEVIATION.

Tissue	Number of Samples	pCi/animal		pCi/g wet weight	
		logarithmic	arithmetic	logarithmic	arithmetic
Liquid	15	0.1686 ± .3043	1.78 ± .98	-0.6811 ± 0.3605	0.28 ± .22
Gill	15	0.1824 ± .3261	1.57 ± .89	-0.3485 ± 0.3070	0.56 ± .27
Muscle	14	0.6865 ± .2238	5.50 ± 3.0	-0.1254 ± 0.2138	0.83 ± .36
Visceral Mass	15	0.5312 ± .1940	3.79 ± 2.2	0.1073 ± 0.1933	1.41 ± .75
Mantle	14	-0.1189 ± .1733	0.82 ± .32	-0.6695 ± 0.2499	0.25 ± .15
Kidney	15	1.6175 ± .2533	49 ±32	1.9537 ± 0.1707	97 ±40
Gonads	15	-0.04858 ± .2344	1.01 ± .50	-0.4302 ± 0.2561	0.44 ± .30
		Bartlett's test = 8.11 F = 84.6 (6,96 D.F.) LSD = T (.09466)		Bartlett's test = 11.08 F = 189 (6,96 D.F.) LSD = T (.09755)	

TABLE II

CONCENTRATIONS OF MANGANESE AND ZINC AND WET WEIGHTS OF SCALLOP TISSUES COLLECTED NEAR PIVERS ISLAND, AUGUST 4, 1965.

Sample	Kidney	Muscle	Gills	Gonads	Visceral Mass	Mantle
		µg Mn/g wet weight				
A	5080	34.5[1]	37.3	33.4	103	*
B	5090	11.4	*	72.0	29.0	4.10
C	7970	11.5	5.72	57.7	18.3	6.50
D	10060	14.3	60.6	49.3	51.2	3.92
Mean	7050	12.4	34.5	53.1	50.3	4.84
		µg Zn/g wet weight				
A	959	342[1]	119	22.4	163	*
B	1260	16.6	*	38.5	18.8	12.8
C	1640	14.4	22.0	26.9	419	11.3
D	1690	14.4	26.6	21.5	19.2	12.8
Mean	1390	15.1	55.9	27.3	155	12.3
		wet weight (g/tissue)				
A	0.32	5.68	3.24	2.72	2.29	3.03
B	0.29	4.62	2.07	2.73	2.09	2.99
C	0.39	7.17	1.37	2.79	2.21	3.75
D	0.29	6.80	1.58	2.15	2.91	3.13
Mean	0.32	6.07	2.07	2.60	2.38	3.23

* Sample lost.
(1) Value not used for calculation of the mean.

TABLE III

SPECIFIC ACTIVITY OF MN-54 AND CONCENTRATIONS OF MN-54 AND STABLE MANGANESE IN SCALLOP TISSUES. DATA ARE AVERAGES FROM TABLES I AND III.

Sample	Specific Activity pCi/mg Mn	Mn-54 pCi/g	Stable Mn µg Mn/g
Kidney	13.8	97	7050
Muscle	66.9	0.83	12.4
Gills	16.2	0.56	34.5
Gonads	8.3	0.44	53.1
Visceral Mass	28.0	1.41	50.3
Mantle	51.7	0.25	4.84

TABLE IV

DISTRIBUTION IN BAY SCALLOPS (ACTIVITY PER ANIMAL) OF MN-54 ORIGINATING FROM ENVIRONMENTAL ACCUMULATION OF FALLOUT AND FROM ACCUMULATION OF TRACER ACTIVITY IN THE LABORATORY. LABORATORY ANIMALS WERE HELD IN WATER CONTAINING ADDED MN-54 FOR 20 DAYS AND THEN PLACED IN RUNNING NON-RADIOACTIVE SEA WATER FOR AN ADDITIONAL 45 DAYS. DATA FOR ENVIRONMENTAL SAMPLES FROM TABLE I.

	Environment		Millipore-filtered water				Cotton-filtered water			
			After 3 days		After 65 days		After 3 days		After 65 days	
Sample	pCi	%	nCi	%	nCi	%	nCi	%	nCi	%
Liquid	1.8	2.8	.92	18	.34	1.8	.60	5.9	.86	3.4
Mantle	0.82	1.3	.34	6	.16	0.9	.45	4.5	.21	0.8
Gonads	1.01	1.6	.18	3	.03	0.1	.26	2.6	.33	1.3
Gills	1.57	2.5	.71	14	.38	2.0	1.22	12.1	.37	1.5
Visceral mass	3.79	6.0	.77	15	.30	1.6	1.07	10.6	.81	3.2
Muscle	5.50	8.6	.55	11	1.63	8.7	1.58	15.6	1.87	7.4
Kidney	49.1	77.2	1.71	33	15.9	85.0	4.90	48.5	20.8	82.2
Total	63.6		5.16		18.7		10.1		25.3	

TABLE V

ACCUMULATION OF MN-54 AND ZN-65 BY BAY SCALLOPS FROM SEA WATER AND FROM LABELLED CHLAMYDOMONAS. ANIMALS TRANSFERRED TO RUNNING NON-RADIOACTIVE SEA WATER AFTER 21 HOURS. VALUES ARE AVERAGES FOR THREE ANIMALS.

Mn-54 in Sea Water						
	Time (hours)					
Component	4	21	50	94	192	286
Visceral Mass[1]	7.8	9.4	4.6	3.4	7.8	4.2
Muscle[1]	4.7	3.9	5.9	7.8	9.3	4.5
Kidney[1]	46	60	74	81	76	66
Whole Animal[2]	0.35	1.00	0.78	0.85	0.65	0.41
Mn-54 Labelled Phytoplankton						
	Time (hours)					
	21	46	71	170	506	
Visceral Mass[1]	3.9	2.7	1.8	1.3	4.2	
Muscle[1]	2.5	2.6	13	5.1	1.8	
Kidney[1]	86	85	80	83	93	
Whole Animal[2]	1.00	0.98	0.99	0.95	0.79	
Zn-65 in Sea Water						
	Time (hours)					
	4	21	50	94	192	286
Visceral Mass[1]	24	17	12	8.8	8.7	4.2
Muscle[1]	3.8	8.5	16	16	9.2	8.9
Kidney[1]	7.9	27.1	39	51	51	77
Whole Animal[2]	0.45	1.00	1.02	1.04	0.84	0.71
Zn-65 Labelled Phytoplankton						
	Time (hours)					
	21	46	71	170	506	
Visceral Mass[1]	22	21	12	6.0	5.9	
Muscle[1]	8.6	8.9	24.7	13.0	4.9	
Kidney[1]	33	39	44	66	83	
Whole Animal[2]	1.00	.97	1.02	.74		

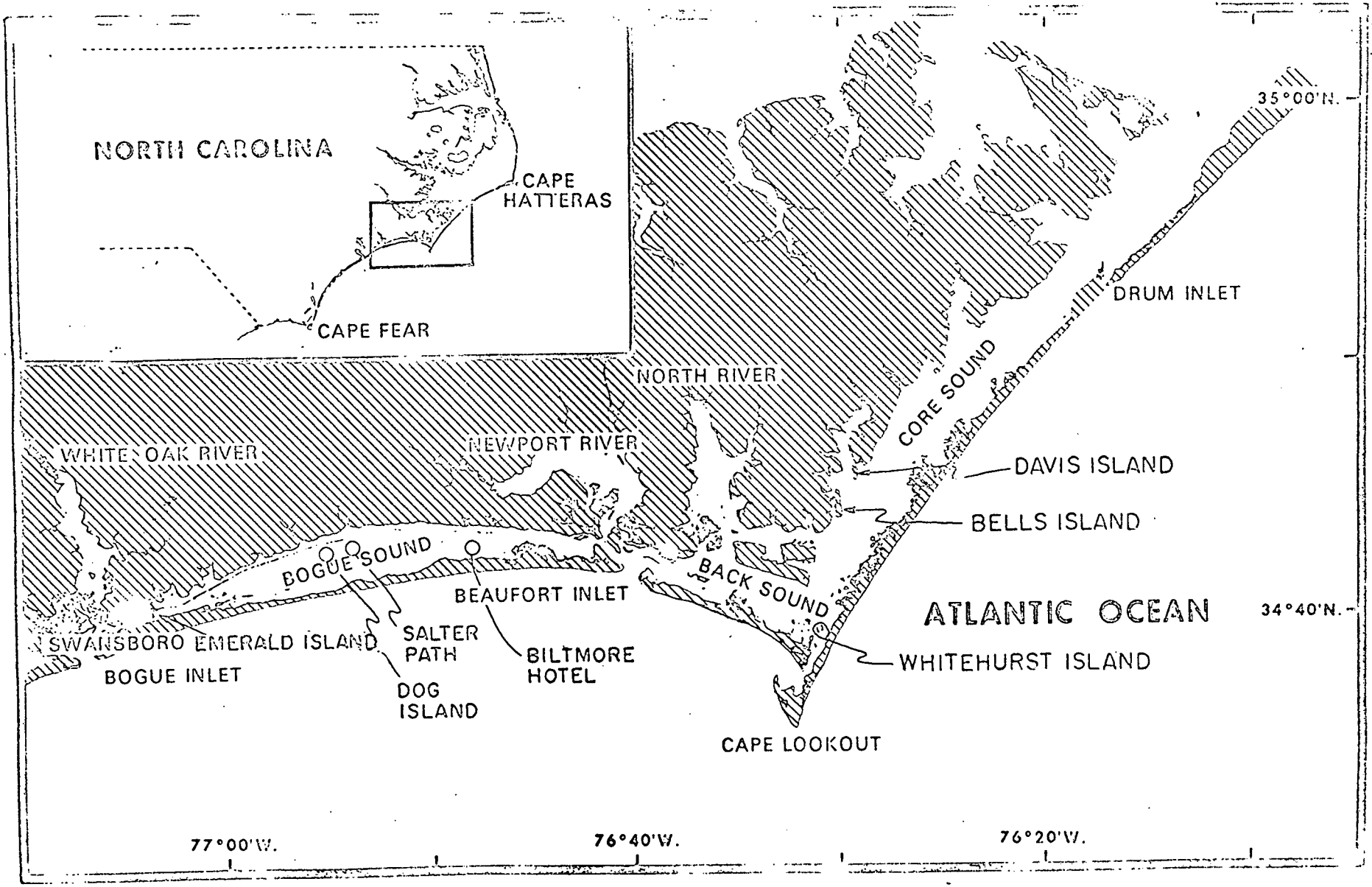
(1) Values are per cent of activity in soft tissues.
(2) Values are ratios of counts of live animals on each sampling time to that of sample at 21 hours.

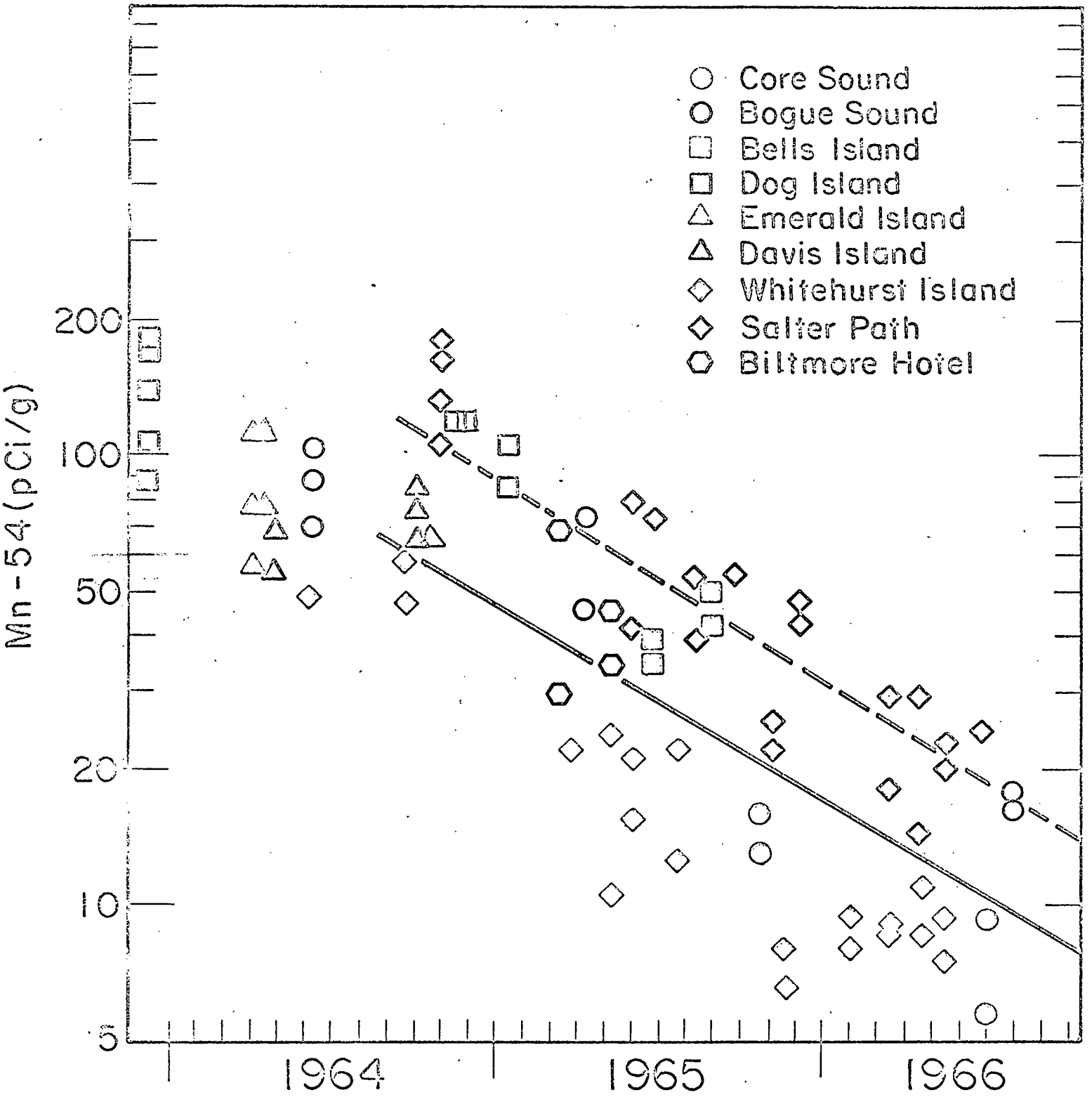
FIGURES

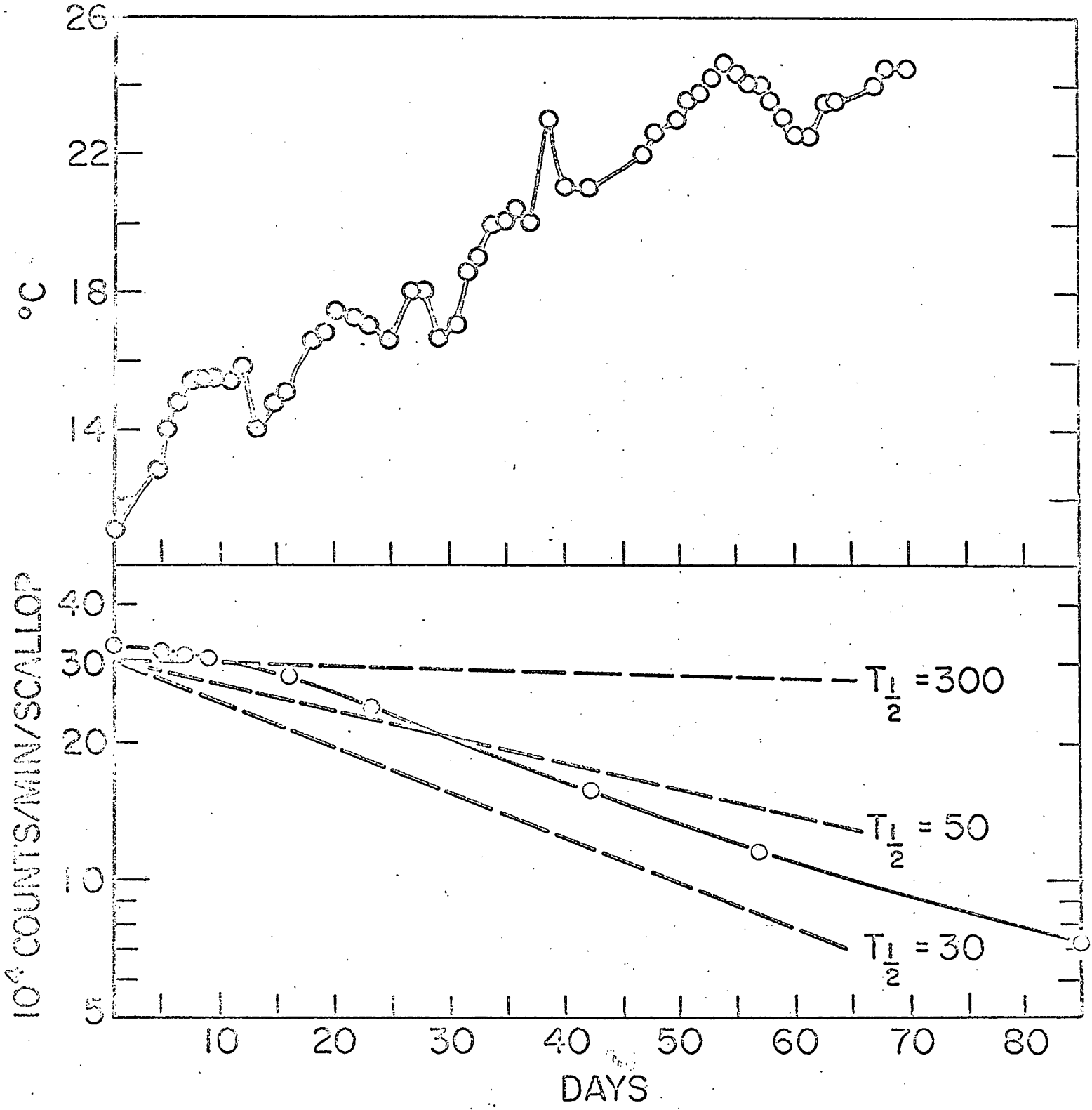
Fig. 1. Map of study area showing sampling locations

Fig. 2. Fallout Mn-54 in scallop kidneys collected from locations in Core & Bogue Sounds

Fig. 3. Retention of Mn-54 by bay scallops, Beginning April 1, 1965


NORTH CAROLINA
CAPE HATTERAS
CAPE FEAR
35°00'N.
DRUM INLET
NORTH RIVER
CORE SOUND
WHITE OAK RIVER
NEWPORT RIVER
DAVIS ISLAND
BELLS ISLAND
BOGUE SOUND
BEAUFORT INLET
BACK SOUND
ATLANTIC OCEAN
34°40'N.
SWANSBORO
EMERALD ISLAND
SALTER PATH
BILTMORE HOTEL
WHITEHURST ISLAND
BOGUE INLET
DOG ISLAND
CAPE LOOKOUT
77°00'W.
76°40'W.
76°20'W.


Core Sound
Bogue Sound
Bells Island
Dog Island
Emerald Island
Davis Island
Whitehurst Island
Salter Path
Biltmore Hotel
Mn-54 (pCi/g)
200
100
50
20
10
5
1964
1965
1966


26
22
18
14
°C
40
30
20
10
0
10^4 COUNTS/MIN/SCALLOP
$T_{\frac{1}{2}}$ =300
$T_{\frac{1}{2}}$ = 50
$T_{\frac{1}{2}}$ = 30
10
20
30
40
50
60
70
80
DAYS