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Running Head: Effect of Drill Mud on Coral

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OF THE REEF-BUILDING CORAL, *MONTASTRAEA ANNULARIS*

Abstract

Possible effects of drilling mud on the growth of *Montastraea annularis* were evaluated in the following separate studies: (1) short-term recovery and subsequent growth of this species exposed to drilling mud on a Florida reef, and (2) long-term growth record of these corals from East Flower Garden Bank, an area of possible exposure to drilling mud from nearby exploratory drilling operations that took place during 1974 and 1977.

In the short-term experiment, eight *M. annularis* head corals were heavily dosed with drilling mud and left with 10 untreated control corals on the reef for six months to recover and grow. All corals were then collected and analyzed using X-radiography to determine post-treatment growth rates. Barium and chromium levels incorporated in the coral skeleton before and after the experiment were determined by emmission spectroscopy. Barium levels ranged from 11 ppm (background) in pre-treatment skeletal areas to as high as 1,200 ppm in skeletal areas deposited during and after treatment. Chromium concentrations were at or below background levels in all samples. In the second study, cores taken by divers from large *M. annularis* heads at East Flower Garden Bank were analyzed in the same manner as those in the first experiment. Annual growth rates averaged 8.9 mm over a 50 year period (1907-1957). In 1957 average yearly growth declined sharply and has remained 1.7 mm below previous long-term growth averages. Concentrations of barium and chromium were at or below background levels in skeletal material from both pre-drilling growth periods and growth periods during drilling operations.

Introduction

The continuing search for new oil and gas deposits in the oceans has in recent years expanded to include exploratory drilling adjacent to coral reefs, such as East Flower Garden Bank, located in the northern Gulf of Mexico about 200 km south-southeast of Galveston, Texas (Fig. 1).

An often highly visible feature at such sites is the presence of a drilling mud plume trailing downstream from the drilling platform. A major function of barium-base drilling mud is to flush out material (cuttings) excavated by the drill mud, which is recirculated. Most of the mud-coated cuttings are discarded into the water. Periodic cleanout of sand and silt traps also contributes additional mud to the water column. Bulk discharge of drilling mud at the completion of drilling can amount to several thousand barrels of mud being dumped into the water over a period of hours (Ayers *et al.*, this volume). To what extent these expended drilling muds affect corals has been the subject of considerable debate and, until recently, minimal research. The work of Thompson (1979) has documented the tolerance of certain reef corals to specific concentrations of drilling mud under controlled, but of necessity short, time periods. The present study attempts to determine possible effects of drilling mud on the growth rate of *Montastraea annularis*.

Field Study #1

Short-Term Exposure of *Montastraea annularis* to Drilling Mud

Materials and Methods

Data for this study was provided in part from an unpublished study conducted by Texas A & M University researchers in 1975 at Carysfort Reef in the Florida Keys (Fig. 1).

Twenty small (10-20 cm) knobs of *Montastraea annularis* were collected by divers from a single large coral head at the reef. Random pairs of coral were secured to 10 numbered cement tiles with a non-toxic lime-base cement (Hudson, in press). This procedure immobilized each specimen and provided a convenient and positive means of identification. The heavy, 5-cm-thick by 50-cm-square tiles also served as excellent anchors by maintaining the corals in normal growth position on the bottom. The corals were placed in three meters of water on the lee side of the reef (Fig. 2) and treated in the following manner. An 18 ppg (18 lb/gal = 2.2 kg/ℓ) fresh-water lignosulfate/lignite drilling mud was prepared by weight in the following proportions: 11,280 mℓ fresh water, 270 g AQUAGEL (bentonite), 1,080 g Glen Rose shale, 540 g Q-BROXIN (ferrochrome lignosulfate), 540 g CARBONOX (lignite), 108 g caustic soda (sodium hydroxide), 16 g CELLEX (sodium carboxymethylcellulose), and 27,000 g of BAROID (barite).* The drilling mud was metered into plastic whirlpac bags in 200 mℓ doses. Divers applied drilling mud directly to all upper surfaces of each of the two corals being treated until the surfaces were coated with as much material as would remain there (usually a 2-4-mm-thick layer). This treatment, termed a maximal dose, was repeated four times at 2½ hour intervals.

Treatment was scheduled so that the last dose was usually applied near midnight to allow exposure during daylight and darkness. Reactions of test corals and controls were monitored and recorded on sound track video tape cassettes.

Three coral pairs were treated with drilling mud in this manner and one pair with a mixture containing only barite (barium sulfate). Wave current surge at various times dislodged much of the drilling mud coating the corals.

In general, removal of drilling mud particles was accomplished by a combination of coral tentacle cleansing action, mucus secretion, and water movement (wave-induced) that would lift thin lumps and sheets of mucus-agglutinated drilling mud particles off the coral. At the conclusion of the experiment, all test corals and controls were placed in a 3-m-deep protected area on the reef (Fig. 2) and allowed to remain undisturbed for six months.

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*The use of brand names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Results

At the end of six months, all *Montastraea annularis* used in the experiment were recovered by the senior author. One tile (used as a control) had been overturned, and the upper surfaces of both corals killed by sediment burial. Consequently, it was excluded from analysis. The remaining nine coral pairs appeared healthy, as indicated by normal appearance and coloration of polyps, with no observed tissue lesions or discoloration on growth surfaces. The surviving specimens were treated in the following manner.

Corals were detached from their cement tiles with hammer and chisel, then slabbed along their growth axis to produce a 4-mm-thick slice suitable for X-radiographs. A Torrex 120 61-CM X-ray unit was set at 3MA/60KVP on type M film. Contact prints were made on high contrast paper to facilitate accurate measurement of growth bands. Growth increments were measured with a precision caliper to the nearest 1/10th mm. Measurements were made along the axis of growth from the upper edge of a high density band to the upper edge of the next high density band.

Measurements and comparison of 6-month growth increments after exposures to drilling mud components suggest that treated corals grew less and at a more uniform rate than untreated ones (Fig. 3). Testing of growth rate means by t-test (Zar, 1974), however, indicated a difference at only the 10-20 percent level ($0.2>p>0.1$). Testing of the variance by F-test, on the other hand, revealed a significant difference between variance at about the 1 percent level ($.02>p>.01$). Although these findings must be considered tentative, they do suggest that heavy concentrations of drilling mud applied directly to *M. annularis* over a period of only 7½ hours may not only reduce growth rates in this species but also suppress variability in growth as well. Whether these effects are temporary or longlasting will have to be determined by future research. It is notable that other workers (Dodge *et al.*, 1974) found a similar relationship in natural populations of *M. annularis* growing in areas having a high level of resuspended bottom sediments. They found a significant decline both in growth rate and variability in growth of corals from environments having high sedimentation rates.

Analyses of pre- and post-treatment sections of coral material for barium are shown in Table 2A. Typical pre- and post-treatment sample areas within a coral slab are shown in Figure 4. Pre-treatment samples show only average background levels (11-13 ppm), normally found in *M. annularis* (Livingston and Thompson, 1971). Several post-treatment samples, however, were higher than normal. The coral treated with barite showed the highest concentration (1,200 ppm). This abnormally high level is probably the result of contamination at the time of drilling mud treatment. Close examination of X-radiographs revealed a network of small boring sponge galleries that penetrate the living surface of both treated and untreated corals (Fig. 4). Due to the method of drilling mud application, it is highly likely that many of these voids trapped and retained some of the applied material despite thorough washing of coral surfaces during sample preparation. Washing was accomplished by spraying water coolant on the sample and rock saw blade as the sample was cut from the coral slab.

Field Study #2

Long-Term Growth Study of *Montastraea annularis* from East Flower Garden Bank

Materials and Methods

In August 1979, the authors collected core samples from 12 massive (1-2-m diameter) *Montastraea annularis* head corals at East Flower Garden Bank (Fig. 5), a large salt dome structure located in the northern Gulf of Mexico at 27°54'37" North latitude, 93°35'55" West longitude, about 200 km south-southeast of Galveston, Texas (Fig. 1). Cores were taken by divers at depths of 19-20 m using a rotary hydraulic drill fitted with a diamond-tipped core barrel. This device is similar to the one described by Macintyre (1975). A plywood template secured to each coral facilitated accurate positioning of the drill bit by preventing undue damage by "wandering" of the bit over living coral surfaces. After being drilled, cores were "broken out" of coral heads by driving a tapered metal bar down alongside each core.

This procedure cleanly breaks off the sample at the bottom of the core hole, allowing it to be removed by the diver. All cores were labeled, packed in boxes and returned to the laboratory, where they were slabbed and X-radiographs made to determine growth rates. Samples of core material were also taken from pre- and post-drilling growth areas to detect possible contamination by barium and chromium. Procedures for determining annual growth rates and trace metal concentrations were the same as those used in field study #1.

Results

Average annual growth rates of *Montastraea annularis* at East Flower Garden Bank from 1888 to 1979 are shown in Figure 6. Due to variations in core lengths, growth data for all 12 corals extend only as far back as 1945. The data base is reduced to 10 corals by 1921, and to six by 1910. Only two corals were cored deeply enough to include a growth record earlier than 1900. Individual annual band measurements of all cores are presented in Table 3.

Together, these data indicate a past history of apparently stable growth conditions at East Flower Garden Bank that existed from 1907 to 1957, with growth rates averaging 8.9 mm per year. Prior to this (1888-1907), a brief decline in annual growth is indicated with a low growth rate average of 6.8 mm per year in 1899; however, this rate is based on only two cores. From 1957 to 1979, growth of these corals has averaged only 7.2 mm per year, a 1.7 mm reduction in average annual growth from the previous 50 years of average growth.

Barium concentrations in these corals (Table 2B) were at or below reported background levels found in *M. annularis* from two areas in Jamaica (Livingston and Thompson, 1971).

Discussion

Results of study #1 indicate that extremely high concentrations of unused drilling mud can affect growth of *Montastraea annularis*. Although upward growth of these corals at Carysfort Reef continued after treatment with drilling mud, the increase was not as great as that of the untreated control corals. The difference in subsequent rate of growth between treated and untreated specimens is sufficient to suggest that exposure to drilling mud caused a decrease in growth rate of the treated corals. Had the treated corals been allowed to continue growing, it is possible that their growth rates would have returned to normal levels within a year. This assumption is based on previous observations of reduced and subsequent resurgence of growth in this species following periods of environmental stress (Hudson *et al.*, 1976). It could not be determined if the experimental procedures caused the corals to deposit a high-density stress band (Hudson *et al.*, 1976), since they were exposed to drilling mud at a time when they normally begin depositing high-density skeletal material. These regularly occurring annual bands, used to age *M. annularis*, are formed between July and October on Florida reefs.

Trace element analysis suggests that neither barium nor chromium were incorporated into coral skeletal material during drilling mud treatment. However, test results do indicate that at least one specimen was probably inadvertently contaminated by barium during treatment.

Results of study #2 clearly demonstrate that growth rates of *M. annularis* sampled at East Flower Garden Bank declined abruptly in 1957 and have remained depressed over the last 22 years. No evidence, however, was found to link this decline to drilling mud from nearby drilling operations that took place between 1974 and 1977. To the authors' knowledge, there has been no drilling activity in the vicinity of East Flower Garden Bank since 1977. Analysis of coral skeletal elements deposited before and during exploratory drilling operations adjacent to East Flower Garden Bank (Table 2B) revealed only background concentrations of barium and chromium, levels normally found in this species. No attempt was made to determine if detrital material other than drilling mud components was present in skeletal cavities (Barnard *et al.*, 1974). A separate study has been initiated to determine chemical and mineralogical composition of skeletal elements and any entrapped sediment particles.

High and low density skeletal elements from growth intervals before, during and after the decline in growth will be analyzed.

It should be noted that oceanographic conditions at East Flower Garden Bank are characterized by exceptionally clear oceanic water and bottom tidal currents of up to 25 cm/sec (David McGrail, oral communication). Strength and direction of these currents are highly variable and can be attributed in part to the complicated topography of the bank. In effect, net transport of water across the bank is probably of sufficient strength to prevent most fine particulate materials, such as those found in drilling mud, from settling out on the reef. This assumption is borne out by the lack of clay- and silt-size particles in reef sediments on this bank (J.H. Hudson and Eugene A. Shinn, personal observation), and at nearby West Flower Garden Bank (Edwards, 1971).

Possible causes of coral growth decline, other than drilling mud, need to be examined. Some of these possibilities include:

(1) Resuspension of bottom sediments. Sedimentation from resuspended bottom sediments has been related to reduced growth rates in *Montastraea annularis* (Dodge *et al.*, 1974). Huge quantities of bottom sediments are stirred up by commercial shrimp trawlers inshore of East Flower Garden Bank during summer and early fall (June-October). Most fishing effort is on sand-mud bottom in depths of 19-36 m. Although shrimping off the Texas coast began to flourish in the late 1950's (Bureau of Commercial Fisheries, 1969), it is considered unlikely that sediments put into suspension by shrimp trawlers would rise above the so-called nephloid layer, a highly stratified layer of turbid bottom water found throughout the northern Gulf of Mexico. In addition, trawling could not have occurred within 30 km of this bank due to excessive water depth.

(2) Dumping of chemical wastes. A chemical dump site within 60 km of the Flower Gardens has been in existence since the 1950's (Hann *et al.*, 1976). The chemicals dumped include papermill waste, chlorinated hydrocarbon wastes, and by-products of

the tetraethyl lead production. This dumping was largely stopped in 1973 and the site has since been moved farther offshore and is regulated by the Environmental Protection Agency. No noticeable improvement in coral growth rate has occurred since 1973 (see Fig. 6), however, nor does it seem likely that chemical dumping, which undoubtedly began gradually and increased into the 1960's, would have caused such a sudden and dramatic growth reduction in 1957.

(3) Temperature changes. It is known that sudden drops in water temperature cause stress and growth rate reduction (Shinn, 1966; Hudson *et al.*, 1976). It is virtually impossible, however, to know if major changes in water temperature began in 1957 due to lack of long-term data.

(4) Reduced light levels. Corals at the Flower Gardens are probably growing near the threshold depth for reef-building corals because of reduced light penetration. Any slight change in either (or both) atmospheric clarity or water transparency might cause a significant change in light levels at water depths where corals grow at the Flower Gardens. Again, however, it is unlikely that such perturbations would increase suddenly in 1957. It is more likely that unfavorable conditions would slowly intensify over a much greater time period, causing a gradual rather than an abrupt reduction in coral growth.

From the above discussion, it should be clear that no single cause for growth rate reduction in *M. annularis* can be pointed out. Hopefully, additional research can determine the cause of coral growth rate decline at the Flower Gardens. Such work is deemed necessary, because other reefs in the Caribbean could be the benefactors of such research.

Conclusions

Study #1: Experimentally treated *Montastraea annularis* at Carysfort Reef.

(1) Highly concentrated doses of unused drilling mud reduced growth rate and growth rate variability of *M. annularis*.

(2) Barium higher (i.e., 17, 31 and 1,200 ppm) than normal background levels

was incorporated into three of eight treated coral skeletons of *M. annularis*. The barium is thought to have been trapped in voids caused by boring organisms.

Study #2: East Flower Garden Bank.

(1) Growth rate of *M. annularis* dropped from a 50-year average of 8.9 mm to an average of 7.2 mm in 1957. The reduced growth rate has persisted until present.

(2) Barium and chromium were not detected in skeletal material representing time before (1969-1974) nearby drilling or in skeleton deposited during (1974-1979) time of nearby drilling.

(3) Cause of reduced growth rate starting in 1957 is not known.

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References

Barnard, L.A., I.G. Macintyre, and J.W. Pierce. 1974. Possible environmental index in tropical reef corals. Nature 252(5480):219-220.

Bureau of Commercial Fisheries. 1969. Gulf of Mexico Shrimp Atlas. U.S. Dept. of Interior Circular 312 (May). 20 p.

Dodge, R.E., R.C. Aller, and J. Thomson. 1974. Coral growth related to resuspension of bottom sediments. Nature 247(5442):574-577.

Edwards, G.S. 1971. Geology of the West Flower Garden Bank. Dept. of Oceanography, Texas A & M University. NOAA Sea Grant Program. TAMU-SG-71-215. 199 p.

Hann, R.W., Jr., T.F. Zapatka, M.C. Zapatka, and C. Baskin. 1976. History of Ocean Dumping in the Gulf of Mexico. Environmental Engineering Division, Civil Engineering Dept., Texas A & M University, College Station, Tex. NOAA Sea Grant Program No. 53466. 87 p.

Hudson, J.H. 1979. A quick-setting cement for use on submerged substrates. *In* J.W. Miller, ed., National Oceanographic and Atmospheric Administration Diving Manual, U.S. Dept. of Commerce, U.S. Government Printing Office, Rockville, Md.

Hudson, J.H., E.A. Shinn, R.B. Halley, and B. Lidz. 1976. Sclerochronology - A tool for interpreting past environments. Geology 4:361-364.

Livingston, H.D. and G. Thompson. 1971. Trace element concentrations in some modern corals. Limnol. and Oceanog. 16(5):786-796.

Macintyre, I.G. 1975. A diver operated hydraulic drill for coring submerged substrates. Atoll Res. Bull. 185:21-25.

Shinn, E.A. 1966. Coral growth-rate, an environmental indicator. Jour. Paleo. 40(2):233-240.

Thompson, J.H., Jr. 1979. Effects of drilling mud on seven species of reef-building corals as measured in field and laboratory. Final Report to the U.S. Geological Survey. Grant No. 14-08-001-1627. Texas A & M University, College of Geosciences, College Station, Tex. 58 p.

Figure Captions

Figure 1. Map showing location of study area #1 (Carysfort Reef) and study area #2 (East Flower Garden Bank).

Figure 2. Thirty-meter-high lighthouse at Carysfort Reef showing locations of drilling mud treatment site (A) and coral recovery site (B). Seaward margin of reef is at lower left of photograph.

Figure 3. Post-treatment growth rates of *Montastraea annularis* at Carysfort Reef, Florida. Graph depicts 6 months' skeletal growth of treated and untreated corals. To facilitate comparison, growth rates of the 8 corals treated with drilling mud are superimposed over the 10 untreated controls. Note reduced growth and lack of growth variability in treated corals.

Figure 4. Representative X-radiograph of treated corals from Carysfort Reef showing (A) sponge borings, in which barium is believed to have been trapped, (B) sample location for barium analysis of pre-treatment skeletal material (1973-1974), and (C) post-treatment band, which had begun forming at the time of treatment (1975-1976). Specimen was collected six months after band formation commensed, thus the band is only 1/2 normal width.

Figure 5. Detailed map of East Flower Garden Bank showing outline of live coral area, sample site within this area, and two exploratory wells drilled three km to the southeast of the sample site.

Figure 6. Graph showing average annual growth rate of 12 *Montastraea annularis* heads cored at East Flower Garden Bank (see Fig. 5 for location). Dots show 5-year moving average and bars indicate one standard deviation. Note reduction of growth rate starting in 1957. Graph based on data in Table 3.

Table Captions

Table 1. Growth rates (in mm) of *Montastraea annularis* at Carysfort Reef, Florida, before and after exposure to drilling mud.

Table 2A. Barium concentrations (ppm) incorporated in skeletons of *Montastraea annularis*, 1973-1976, Carysfort Reef, Florida. See Figure 4 for explanation of analytical sample locations within coral bands.

Table 2B. Barium concentrations (ppm) incorporated in *Montastraea annularis* skeleton laid down before (1969-1974) and during (1974-1977) nearby exploratory drilling at East Flower Garden Bank.

Table 3. Growth rate data (in mm) from 12 cores of individual heads of *Montastraea annularis* at East Flower Garden Bank. Average used for construction of Figure 6 is shown in righthand column.

Table 1

	Treated Corals								Control Group									
Tile No.	#1		#2		#3		#4		#5		#6		#7		#8		#9	
Coral No.	1	1A	2	2A	3	3A	4	4A	5	5A	6	6A	7	7A	8	8A	9	9A
July/Jan.* 1975–1976	3.2	3.6	3.3	3.7	3.6	3.0	3.5	3.6	4.2	4.7	4.2	3.3	3.9	2.8	3.5	3.0	4.9	3.4
July 1975 - Drilling Mud Treatment																		
1974–1975	5.6	6.8	5.5	6.7	6.2	4.9	5.8	5.5	6.7	7.2	5.1	6.3	5.4	5.6	4.2	5.1	6.9	5.7
1973–1974	6.0	7.6	8.4	7.3	8.0	7.3	5.3	6.9	4.4	5.0	7.3	6.0	6.5	7.6	5.9	4.5	5.2	5.8
1972–1973	6.3	6.6	5.8	6.2	6.4	8.0	6.4	4.8	6.8	6.0	6.8	8.3	6.8	5.9	6.3	5.4	6.9	4.7
1971–1972	6.3	7.4	6.6	6.8	7.3	7.6	7.9	6.9	8.0	6.4	6.3	8.0	6.8	6.9	5.7	6.6	7.3	6.7
1970–1971	6.2	6.8	7.5	6.8	7.8	6.4	8.4	6.5	5.5	8.2	7.3	9.4	6.5	7.1	7.0	6.6	6.2	6.0

* Represents only 6 months of measured growth (July 1975 to January 1976). Remaining data based on yearly growth periods from July to July.

CORALS DOSED WITH DRILLING MUD

	Tile No. #1		#2		#3*		#4	
Growth Band Analyzed	Coral No. 1	1A	2	2A	3	3A	4	4A
	Barium (ppm)							
(Treated) 1975-1976	17	11	31	12	15	1200	12	12
(Not Treated) 1973-1974	13	12	12	12	19	12	12	12

* Corals on tile #3 treated with barite only.

CONTROL CORALS NOT DOSED WITH DRILLING MUD

	Tile No. #5		#6		#7		#8		#9	
Growth Band Analyzed	Coral No. 5	5A	6	6A	7	7A	8	8A	9	9A
	Barium (ppm)									
(Treated) 1975-1976	12	11	13	12	12	11	11	11	11	11
(Not Treated) 1973-1974	12	11	12	11	13	12	11	12	12	13

Table 2A.

EAST FLOWER GARDEN BANK

Year Bands From Which Skeleton Was Analyzed						Core No.						
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
						Barium (ppm)						
Years in Which Nearby Drilling Took Place (1974-1977)	12	11	13	13	11	11	11	11	10	11	12	11
Years When There Was No Nearby Drilling (1969-1974)	11	13	12	11	12	12	15	15	13	13	12	12

Table 2B.

Table 3*

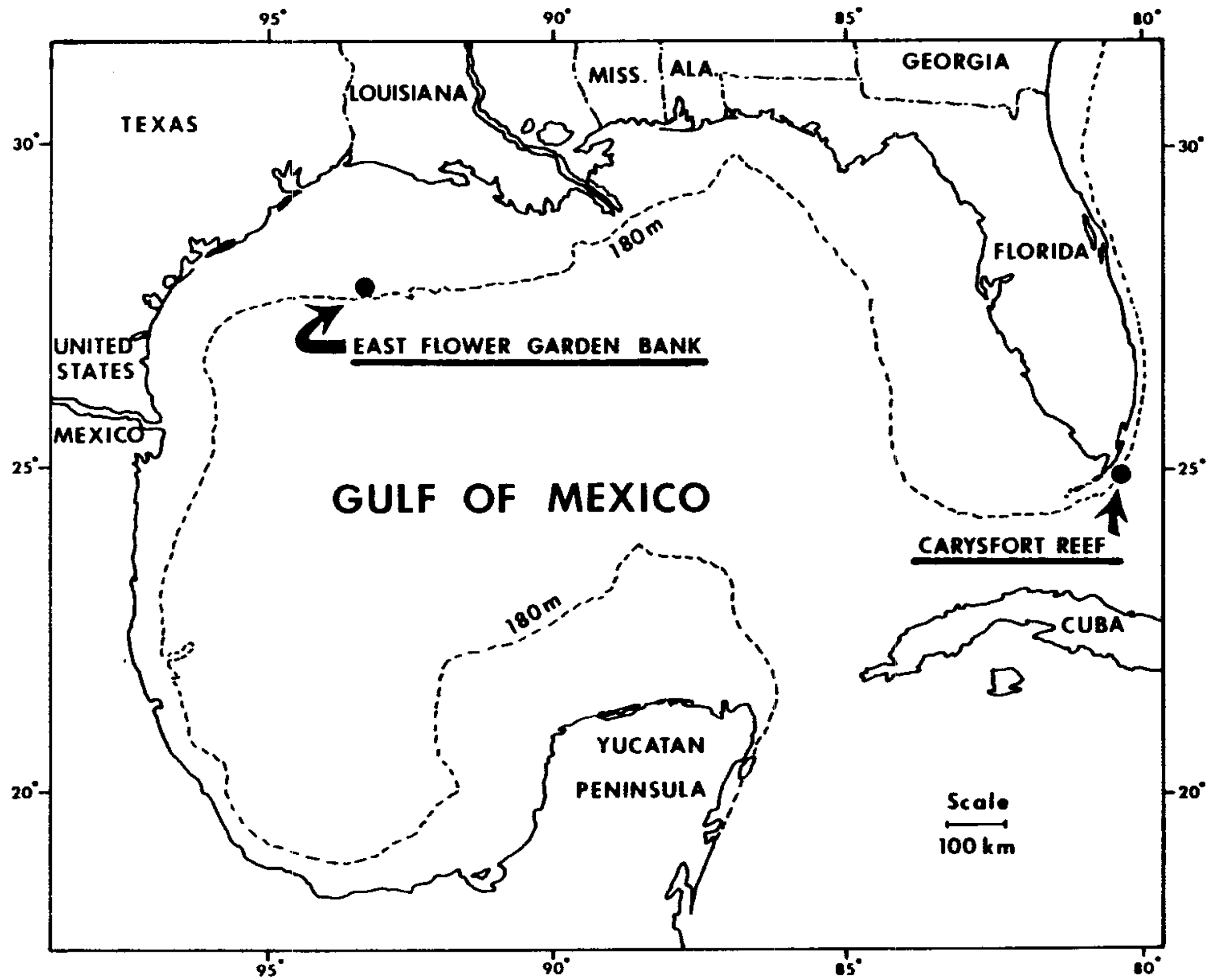
Year	Core 1	Core 2	Core 3	Core 4	Core 5	Core 6	Core 7	Core 8	Core 9	Core 10	Core 11	Core 12	Averag (All Cores
1978–79	9.4	6.4	7.0	7.8	8.3	6.2	8.3	10.1	4.8	6.4	5.3	10.2	7.5
78	10.9	6.6	9.6	10.4	7.0	6.6	7.6	10.6	5.7	4.5	8.5	8.5	8.0
77	9.3	6.5	7.2	8.2	6.9	7.0	8.7	9.6	5.5	5.2	8.1	8.6	7.6
76	8.9	5.5	8.5	9.4	6.1	9.4	9.0	7.8	6.2	5.9	6.3	9.5	7.7
1974–75	9.0	5.2	7.3	8.6	6.8	6.8	7.1	6.7	5.4	6.0	5.9	8.3	6.9
74	8.3	5.1	6.7	7.5	6.3	6.8	6.2	7.6	4.4	3.6	4.4	9.5	6.4
73	10.6	5.6	8.5	9.0	6.2	6.8	7.3	7.7	4.3	5.0	5.7	7.8	7.0
72	*11.0*	*6.1*	*5.3*	*12.0*	*6.7*	*7.7*	*10.0*	*8.8*	*6.3*	*6.1*	*6.9*	*11.6*	*8.2*
71	8.9	6.1	5.6	9.2	7.0	8.0	8.6	9.3	4.6	5.4	6.2	8.6	7.3
1969–70	8.2	6.4	6.9	8.0	6.9	6.0	6.4	8.0	5.0	4.0	5.0	9.7	6.7
69	8.4	5.5	5.0	8.8	5.6	6.0	5.4	9.3	4.1	4.6	4.6	8.2	6.3
68	8.9	7.2	6.6	8.4	6.5	8.4	9.9	9.3	5.6	4.8	5.8	8.8	7.5
67	9.6	8.3	8.5	9.7	6.8	8.7	8.4	10.9	5.6	6.4	5.5	9.2	8.1
66	8.7	5.7	7.0	10.9	5.0	7.8	8.1	8.3	5.2	5.0	5.6	8.6	7.2
1964–65	7.9	7.1	7.8	9.3	5.3	7.5	8.1	10.2	5.5	4.4	4.9	9.1	7.3
64	9.0	6.4	7.1	11.0	6.1	7.9	8.5	8.7	6.8	6.5	6.2	7.6	7.7
63	9.9	6.3	7.0	12.0	6.4	7.5	8.3	8.5	5.6	5.0	7.7	8.8	7.8
62	8.8	6.5	5.6	8.4	4.5	7.1	8.6	6.2	6.8	5.7	5.2	7.9	6.8
61	8.0	7.8	5.3	7.7	6.4	7.2	7.0	7.7	5.3	4.2	4.9	7.1	6.6
1959–60	7.5	6.0	5.5	8.9	5.0	6.1	6.7	7.0	5.9	4.7	4.9	5.8	6.2
59	9.9	7.6	5.5	8.9	4.9	7.1	8.0	9.8	6.4	6.1	6.1	6.5	7.2
58	8.4	6.1	5.5	8.6	5.4	7.0	6.7	10.3	5.6	4.6	6.1	6.5	6.7
57	11.3	7.8	9.2	11.6	6.9	9.4	11.8	10.9	6.9	4.2	7.2	9.3	8.9
56	12.5	7.4	7.4	12.2	8.9	7.0	12.0	11.8	7.0	5.1	9.7	8.3	9.1
1954–55	8.9	8.3	8.8	11.2	8.2	10.5	10.7	11.3	7.4	5.8	9.7	7.7	9.0
54	11.8	8.3	7.3	13.9	8.6	7.9	5.6	11.7	7.2	7.7	8.3	8.7	8.9
53	8.8	8.7	7.9	7.4	7.0	8.5	11.6	11.5	7.5	7.3	8.3	7.8	8.5
52	10.4	7.3	7.9	10.8	7.7	8.7	9.5	13.3	7.0	8.9	7.9	9.5	9.1
51	10.5	6.3	8.4	10.5	7.9	6.6	8.9	13.1	5.8	7.9	8.9	8.3	8.6
1949–50	11.5	6.3	7.0	13.0	9.2	10.3	12.6	9.4	6.9	9.3	8.7	7.8	9.
49	7.6	6.7	8.6	10.6	7.4	7.6	9.7	13.0	10.1	8.0	10.8	8.7	9.1
48	10.7	8.1	6.1	10.2	7.7	9.4	9.5	13.9	6.2	9.4	8.0	8.2	9.0
47	9.2	5.6	7.1	9.5	7.2	6.5	9.8	9.2	7.9	8.4	8.3	7.5	8.0
46	10.9	9.1	8.2	10.3	6.5	11.5	9.7	6.8	8.5	8.7	8.5	8.2	8.9
1944–45	10.9	7.4	8.8	12.3	8.0	7.6	10.0		8.6	9.4	8.6	8.8	9.
44	11.9	6.7	8.0	11.0	8.1	7.5	9.6		8.5	10.2	7.7	10.8	9.
43	10.4	6.7	6.9	10.2	8.5	10.4	10.0		7.4	7.9	8.8	9.5	8.8
42	8.3	7.0	6.9	10.9	7.0	9.2	9.2		7.7	7.2	6.7	8.3	8.0
41	6.6	8.1	6.9	10.4	8.1	8.6	8.8		8.0	7.6	8.4	8.6	8.
1939–40	8.9	5.9	8.1	12.8	6.6	9.2	10.5		8.1	6.4	9.3	7.3	8.5
39	11.3	7.8	7.6	13.2	8.3	8.0	10.0		7.7	8.1	8.8	8.3	9.0
38	9.4	6.8	8.9	12.4	7.5	8.2	9.0		7.9	8.9	8.0	8.0	8.6
37	*11.1*	*7.1*	*8.1*	*11.6*	*8.0*	*7.5*	*9.3*		*8.5*	*9.5*	*8.7*	*7.7*	*8.8*
36	10.0	6.0	7.8	10.9	7.8	8.1	7.7		8.1	8.5	8.8	7.2	8.
1934–35	10.2	7.2	7.2	11.7	9.5	8.8	8.0		7.0	8.1	8.6	7.9	8.6
34	12.7	8.3	8.0	12.7	8.6	9.7	9.8		8.5	8.5	7.0	9.3	9.
33	11.2	6.9	9.1	12.2	9.8	11.3	7.5		7.5	7.5	10.3	8.8	9.
32	10.2	8.2	6.0	11.6	8.1	9.0	7.5		10.1	8.2	9.6	10.7	9.0
31	8.7	7.1	7.3	11.4	7.9	8.2	9.2		8.3	8.4	8.7	8.2	8.
1929–30	10.0	7.8	10.0	10.8	6.6	10.2	8.7		8.5	7.2	10.0	9.1	9.0
29	10.6	10.1	10.5	10.2	6.7	10.5	9.1		9.9	7.4	10.3	10.8	9.
28	11.3	7.1	8.6	12.9	6.7	9.9	10.4		9.7	7.7	8.8	9.2	9.
27	10.3	7.9	8.7	11.4	8.5	10.9	9.6		7.5	7.2	10.0	8.8	9.
26	9.1	7.9	6.6	12.2	6.2	10.3	9.1		7.7	7.9	9.9	7.7	8.
1924–25	10.6	9.0	7.8	12.8	8.5	8.5	9.8		8.3	7.5	7.5	10.0	9.

* Measurements in mm.

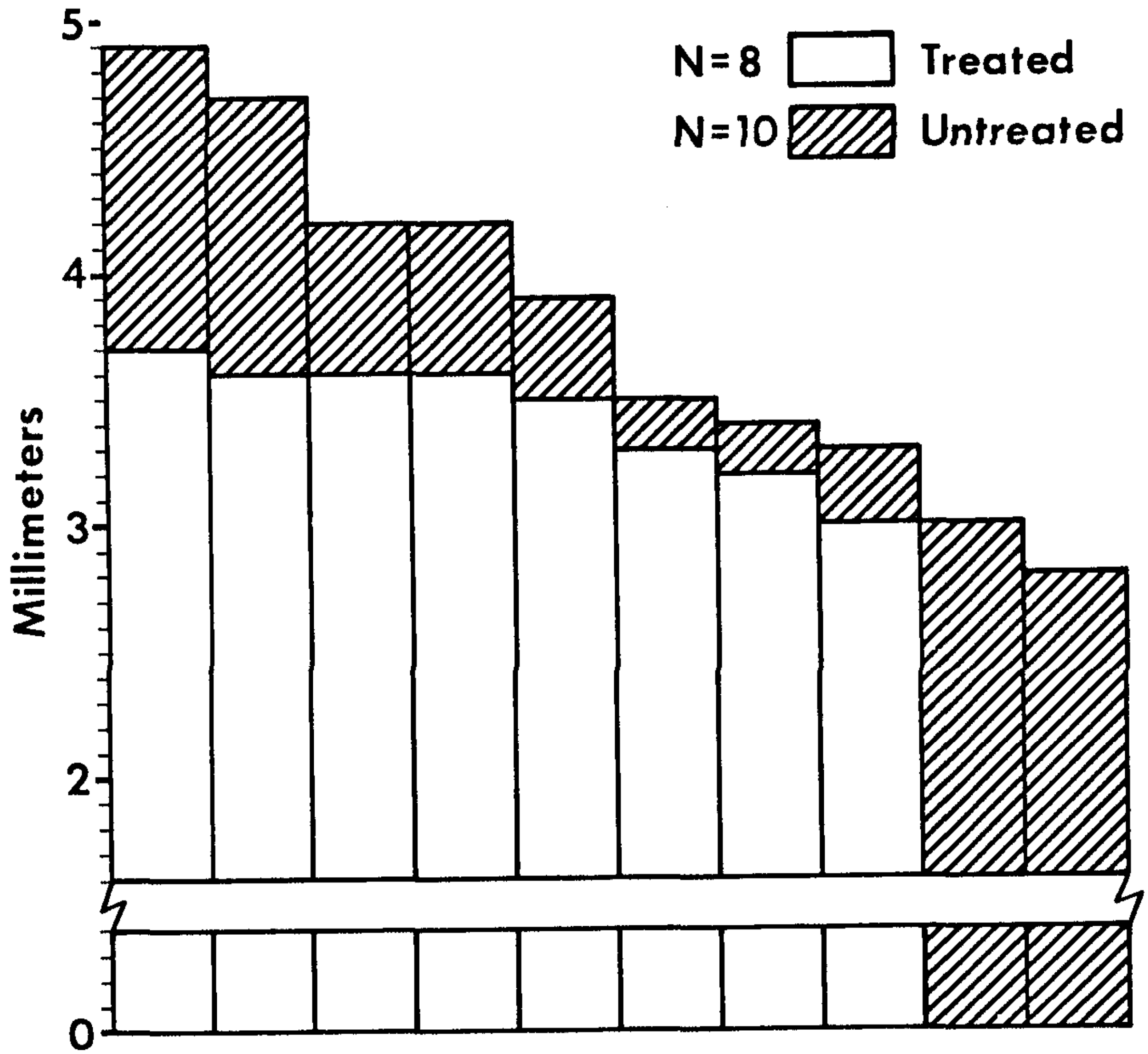
Table 3 (continued)*

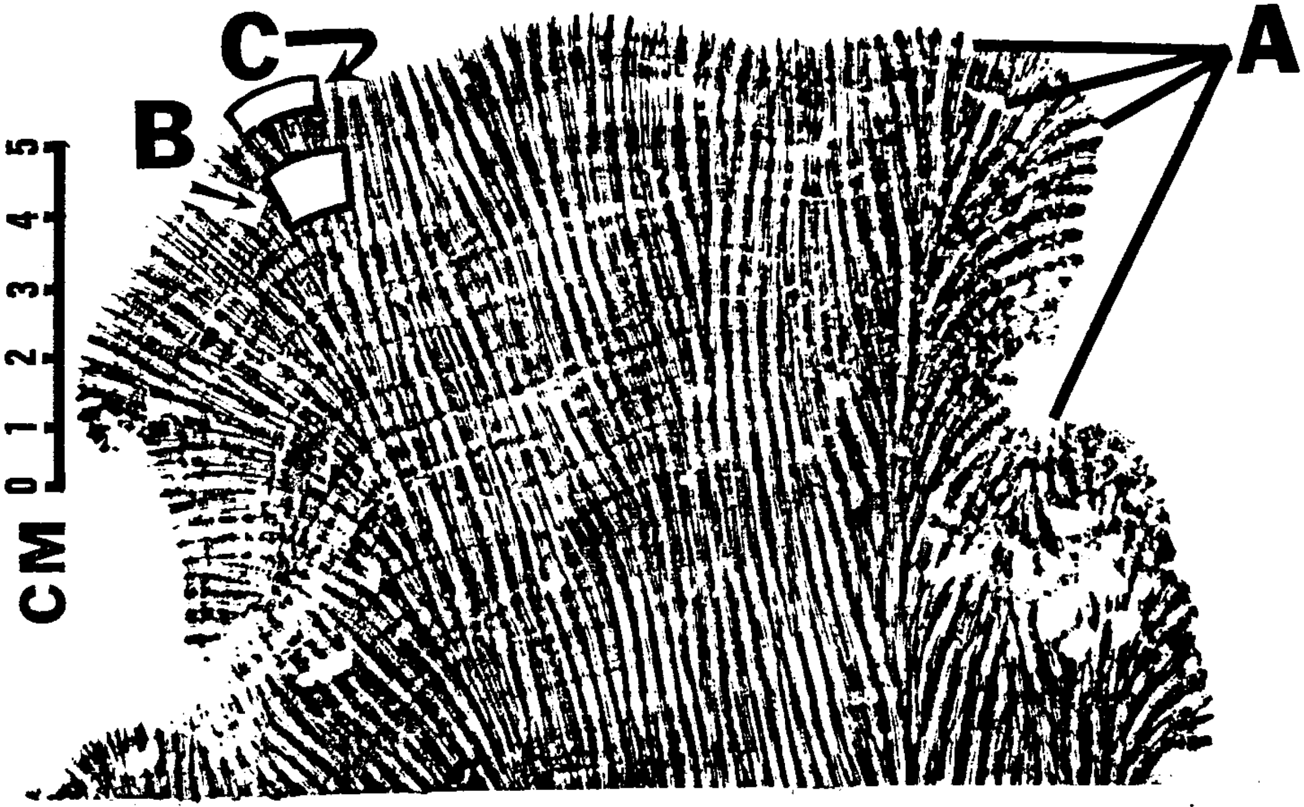
Year	Core 1	Core 2	Core 3	Core 4	Core 5	Core 6	Core 7	Core 8	Core 9	Core 10	Core 11	Core 12	Averag (All Cores
1923-24	10.1	8.4	9.7	10.4	7.2	10.0	8.4		6.1	10.1	10.1	9.5	9.1
23	11.0	6.7	9.7	13.0	7.3	8.2	9.8		7.1	7.0	7.3	9.7	8.8
22	10.9	7.8	9.8		10.4	8.6	11.7		6.2	9.0	9.3	9.4	9.3
21	10.3	6.5	11.1		10.0	9.4	11.7		6.1	8.8	9.0	9.7	9.3
1919-20	10.4	7.2	8.8		8.9	8.9			6.9	8.3	9.5	7.6	8.5
19	10.3	8.4	9.6		8.5	8.0			6.8	7.7	11.3	9.5	8.9
18	9.4	6.6	8.7		6.9	9.9			6.3	7.7	9.3	9.4	8.2
17	10.6	7.7	11.7		8.0				7.5	7.9	10.1	10.3	9.2
16	12.4	9.4	8.1		8.0				6.6	8.1	8.9	11.1	9.1
1914-15	11.2	6.5	9.2		7.6				7.2	8.7	9.5	8.7	8.6
14	11.3	9.0	9.0		11.0				7.5	7.8	7.5	9.1	9.0
13		7.5	9.8		7.7				7.7	8.0	9.0	9.3	8.4
12		7.4	12.6		8.1				5.6	7.5	11.2	9.0	8.8
11		9.1			7.7				7.9	8.3	8.4	10.3	8.6
1909-10		7.6			7.5				8.7	9.1	10.5	8.5	8.7
09		8.0			9.4				8.3	8.7	10.8	8.8	9.0
08		7.7			9.8				7.3	8.9	10.7	8.1	8.8
07		7.1			10.5				7.4	10.7	8.6		8.9
06		7.2			8.9				6.2	9.7	8.8		8.2
1904-05		7.5			7.8				7.5	7.6	10.3		8.1
04		7.7			7.9				7.3	10.0	10.6		8.7
03		9.3							6.6	8.6	9.0		8.4
02		8.0							7.3				7.7
01		7.7							7.0				7.4
1899-00		8.9							7.4				8.2
99		7.1							6.5				6.8
98		6.5							7.3				6.9
97		7.3							8.7				8.0
96		6.6							8.1				7.4
1894-95		5.5							8.7				7.1
94		6.9							9.3				8.[illegible]
93		6.9							7.5				7.[illegible]
92		6.7							8.3				7.5
91									8.6				8.6
1889-90									8.9				8.9
89									7.3				7.[illegible]
88									7.1				7.[illegible]
1886-87									9.4				9.[illegible]

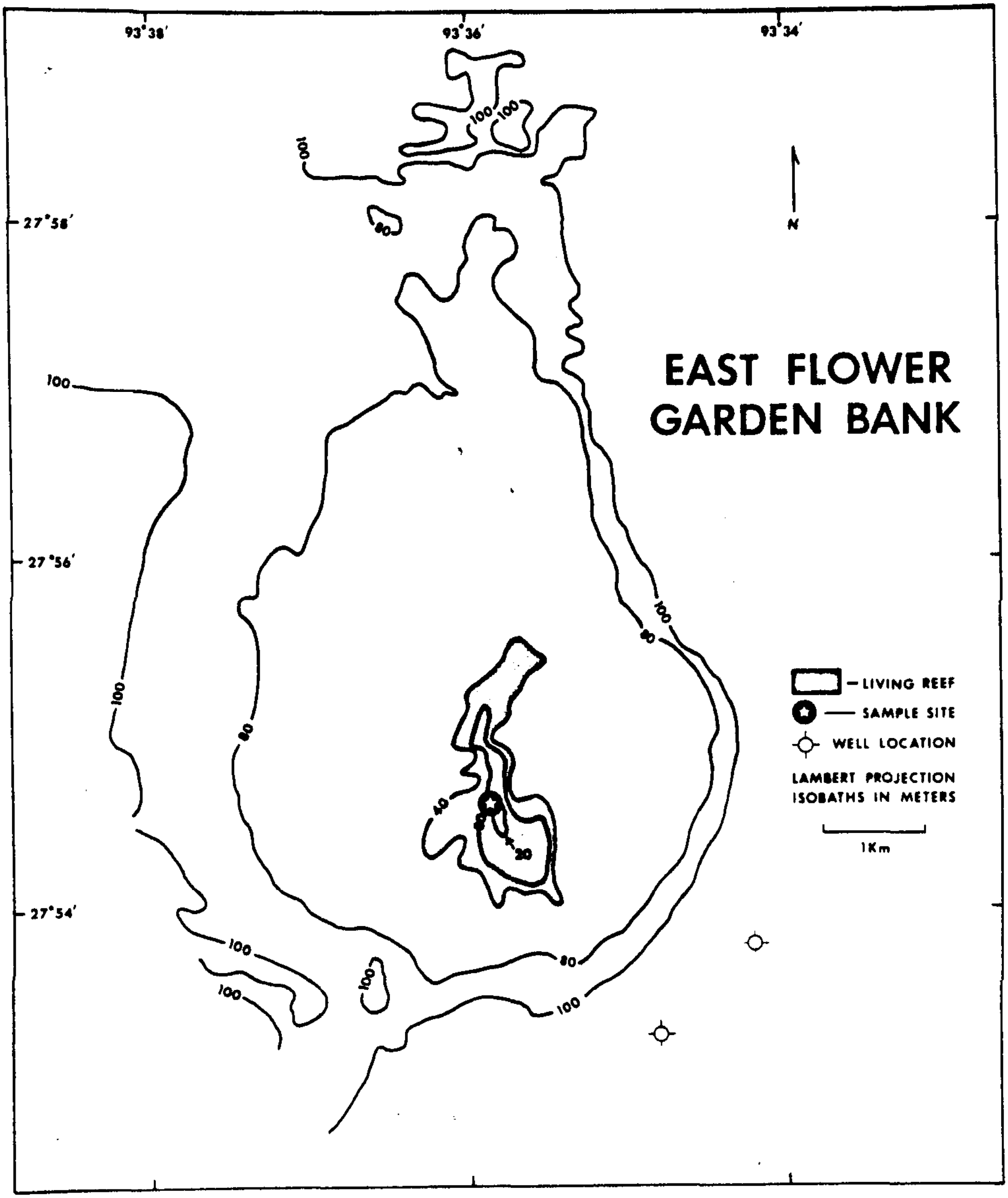
* Measurements in mm.


TEXAS
LOUISIANA
MISS.
ALA.
GEORGIA
FLORIDA
UNITED STATES
MEXICO
EAST FLOWER GARDEN BANK
180m
GULF OF MEXICO
CARYSFORT REEF
CUBA
180m
YUCATAN PENINSULA
Scale
100 km
95°
90°
85°
80°
30°
25°
20°

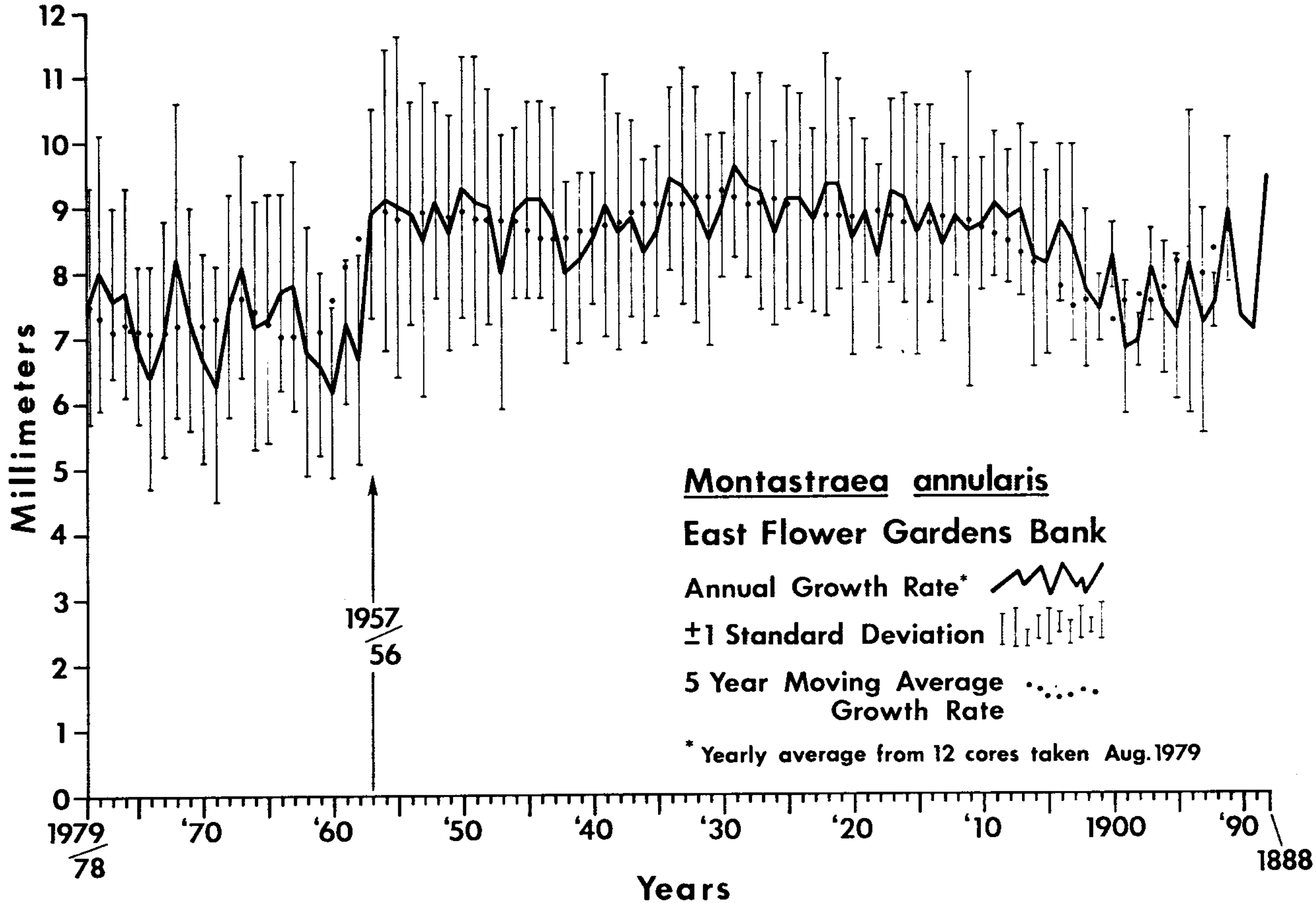

B
A
N


N=8 Treated
N=10 Untreated
Millimeters
5
4
3
2
0


A
B
C
CM
0
1
2
3
4
5



93°38′
93°36′
93°34′
27°58′
27°56′
27°54′
N
EAST FLOWER GARDEN BANK
100
80
40
20
LIVING REEF
SAMPLE SITE
WELL LOCATION
LAMBERT PROJECTION
ISOBATHS IN METERS
1Km


Millimeters
12
11
10
9
8
7
6
5
4
3
2
1
0
1979
78
'70
'60
1957
56
'50
'40
'30
'20
'10
1900
'90
1888
Years
Montastraea annularis
East Flower Gardens Bank
Annual Growth Rate*
±1 Standard Deviation
5 Year Moving Average Growth Rate
* Yearly average from 12 cores taken Aug. 1979