1981

Growth Characteristics of Reef-Building Corals Within and External to a Naval Ordinance Range: Vieques, Puerto Rico

Richard E. Dodge
Nova Southeastern University, dodge@nova.edu

NSUWorks Citation

Dodge, Richard E., "Growth Characteristics of Reef-Building Corals Within and External to a Naval Ordinance Range: Vieques, Puerto Rico" (1981). *Marine & Environmental Sciences Faculty Proceedings, Presentations, Speeches, Lectures*. 7.
https://nsuworks.nova.edu/occ_facpresentations/7

Proceedings of the Fourth International Coral Reef Symposium, Manila, 1981, Vol. 2

GROWTH CHARACTERISTICS OF REEF-BUILDING CORALS WITHIN AND EXTERNAL TO A NAVAL ORDNANCE RANGE: VIEQUES, PUERTO RICO

Richard E. Dodge,
Nova University Ocean Sciences Center, 8000 N. Ocean Drive, Dania, Florida, U.S.A. 33004

ABSTRACT

The skeletal growth of reef-building corals is known to be sensitive to the environment. In particular, high levels of sedimentation and turbidity lead to decreased growth rate, suppressed growth variation, and, ultimately, coral death because of reduced illumination necessary to zooxanthellae and/or increased energy expenditure by the coral animal to remove impacted sediments.

To assess the effect of Naval Ordnance Range usage at Vieques, Puerto Rico, specimens of *Montastrea annularis* were collected from reefs adjacent to and removed from the range area. Growth was measured from annual increments revealed by X-radiography of medial slabs of the coral skeletons. Mean growth rates and growth variances were calculated for each station or station grouping over the common time period 1970-1977.

Statistical comparison of the growth data reveals a general similarity between range and control stations. This evidence coupled with quantitative coral abundance and diversity data of others indicate a lack of anomalous and adverse sedimentation/turbidity conditions affecting corals on reefs near the range area.

Chronologies of coral band widths compared to historical recorded environmental data indicate that a major natural parameter which controls coral growth in Vieques is annual water temperature variation.

INTRODUCTION

The island of Vieques, 33 km long and 7 km wide is located in the northern Caribbean sea 50 km off the eastern end of the larger island of Puerto Rico. Approximately 75% of the land area of the island is owned by the United States Navy and a portion of the eastern end is used primarily as a practice range for air-dropped bombs and ship's gunnery. Figure 1 shows the island and the area where range impact is concentrated.

Numerous coral reefs occur along the coast of Vieques as fringing, patch, and offshore bank barriers typical of this part of the Caribbean. In 1977 and 1978 litigation was brought against the U.S. Navy by the Commonwealth of Puerto Rico and others which claimed, among other things, that range usage was promoting excessive sedimentation and turbidity on nearby offshore coral reefs leading to their destruction and death.

It is well-known that while most corals can withstand a low sedimentation on their surface, very high sedimentation rates are lethal (Marshall and Orr 1931, Mayor 1918, Edmondson 1928). There are sublethal effects as well. On a Jamaican reef Dodge, Aller and Thomson (1974) and Aller and Dodge (1974) found both growth rate and growth variation of the hermatypic coral *Montastrea annularis* to be lower in areas of high resuspension of bottom sediments. Those results are supported by Loya (1976) who compared sizes of *M. annularis* on Puerto Rico reefs finding smaller colonies in more turbid, highly sedimented areas. In addition, Dodge and Vaisnys (1977) have found dredging for airport construction in Bermuda caused significant coral mortality which appeared to be preceded by a decreasing growth rate. Bak (1978) found dredging in Curacao caused death to coral species which were inefficient sediment rejectors and a suppression of calcification rate in other coral species. It was hypothesized, therefore, that anomalously high sedimentation and turbidity caused by range usage activities would be reflected, at minimum, in lowered coral growth rates and growth variation at affected reefs compared to more pristine sites.

To test this hypothesis a study of the growth characteristics of the coral species *Montastrea annularis* at various reef locations within and external to the Vieques range area was undertaken. *M. annularis* was chosen as the species of interest because it has been termed the major reef-forming coral of the Caribbean (Goreau 1959) and it is abundant on Vieques reefs. In addition, the skeleton of *M. annularis* contains a record of its annual growth in the form of alternating density bands which are visible X-radiographically (Dodge and Thomson 1974, Dodge, Aller and Thomson 1974, Macintyre and Smith 1974, Hudson et al. 1976). It is therefore possible to measure the annual growth of specimens of this species for many years.

METHODS AND MATERIALS

Figure 1 shows sampling locations on the reefs of

Vieques. At each station specimens of *Montastrea annularis*, 10-40 cm in height, were collected in 3-5 m water depth. A total of 91 corals were obtained at 15 sites during the period May-July, 1978. Specimens were suitable for collection if they were "normal" in form, position, and appearance, that is, not overturned, diseased, or overshadowed by neighboring corals. Individual heads collected were of the columnar growth form. An effort was made to collect only from the fore-reef slope of reef stations and to select only those specimens most representative of the entire suite of corals in the area. Two areas were chosen as being clear of obvious range activities and possible consequent effects: in the North, stations N8, N9, and N10 (all from Mosquito Reef) and in the South, station S2 on the major reef of Ensenada Honda. By necessity, due to the different locations of these stations from the more eastern range stations, wind-waves and water flow patterns may differ slightly. Range stations were concentrated on the North and South sides of Vieques on reefs close to the principal land impact area (See Fig. 1).

After collection specimens were sectioned with a masonry rock saw and parallel-sided slabs were obtained to include the point of origin of the colony and the surface of maximum growth of the living surface. All slabs were transported to the laboratory and individually X-rayed for eventual production of X-radiograph positives. Further details of this procedure may be found in Dodge and Vaisnys (1980) and Dodge (1980).

On each X-radiograph positive annual density bands were examined and assigned years of formation from the known date of collection and the position of the bands near the coral surface. Annual band widths (yearly growth increments) were measured on the X-radiograph by drawing a line transect from points of maximum height of the coral surface to the colony origin. A mark was made along the transect at the upper edge of the high density band part of each annual band. Band widths were measured by caliper for each year. Six specimens were rejected from the analysis due to errors in cutting sections, extensive bioerosion obscuring growth features, and/or lack of well-developed banding. This fraction was less than 7% of the total number collected.

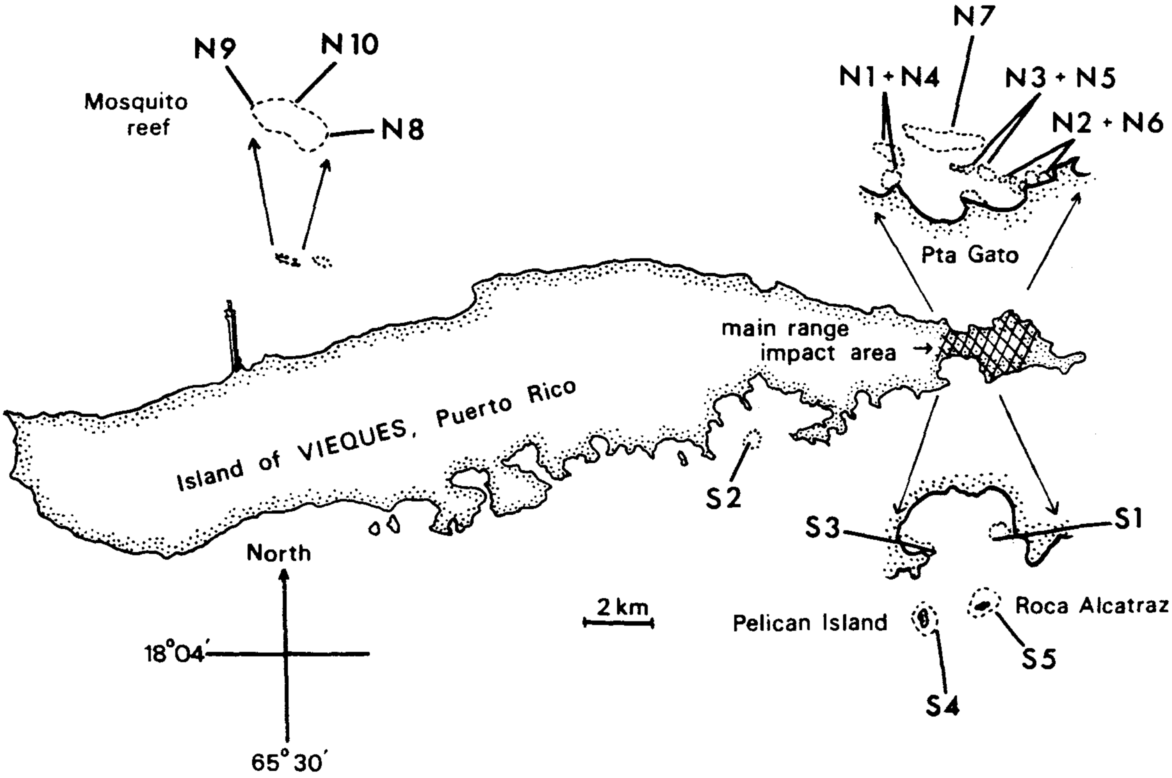

Figure 1. Sketch map of the island of Vieques, Puerto Rico showing station locations and area of main range impact.

DATA ANALYSIS

The raw data available after band width measurements were in the form of annual linear growth increments over a period of years for each appropriate coral. Because it was desired to compare coral growth spatially between reef areas, it was necessary to determine a time span which would include as many specimens as possible and yet retain an adequate sample size. The period 1970-1977 was chosen because of its recent eight-year time span (over which range usage was known to be active) and because for nearly all specimens measured, the number of years in each encompassed the span.

For this time period the mean growth rate in cm/yr, standard deviation and index variance was calculated for each station or station grouping. Table 1 presents these data. Stations were group if they were similar in terms of distance and general reef setting or if a particular station had too few corals for reasonable statistical confidence.

Table 1. Calculations on coral growth over the 1970-1977 period for each station. $\bar{X}$ mean growth rate in cm/yr: s.d. = standard deviation of that mean; N = number of measurements: Index variance = variance of the suite of measurements when converted to Index values as discussed in text.

STATION	(# Corals)	$\bar{X}$	s.d.	N	Index Variance
N2+6	(6)	.790	.129	48	.0201
N3+5	(14)	.910	.131	112	.0134
N7	(6)	.889	.168	47	.0239
N4+1	(10)	.861	.199	80	.0211
N8	(8)	1.034	.155	64	.0161
N9	(4)	.912	.105	30	.0161
N10	(5)	.990	.295	40	.0357
S1	(8)	.905	.153	62	.0155
S2	(6)	1.056	.280	48	.0286
S3	(8)	1.007	.237	62	.0350
S4	(5)	.924	.184	40	.0253
S5	(5)	1.002	.169	40	.0150

The variance index was computed by converting the entire band width sequence of each coral into index values (i.e., each band width as a % of the mean growth rate of the entire coral) and then using these values (over the 1970-1977 period) to calculate variance in the normal fashion. This was done to normalize corals to their respective means and to obtain information on growth variation independent of possible differences in individual coral growth rates.

In order to quantitatively compare station mean growth rates, the data were subjected to an ANOVA and SNK test (Zar 1974) and results of the SNK test are presented in Table 2. Differences between station index variances were assessed by F test (Zar 1974) and the results are presented in Table 3.

For assessment of trends in the growth of corals over time, chronologies of each station or station groupings were constructed by sequentially averaging by year the index series of each coral in the grouping desired (see Fig. 2).

RESULTS AND DISCUSSION

The SNK test of Table 2 indicates the following for between station comparisons of mean growth rate (at the $p < .01$ level). In the North control station N8 has significantly higher mean growth rate than one control (N9) and all range stations (N2+6, N3+5, N7, and N4+1). Range station N2+6 is not statistically different from one range (N4+1) and one control (N9) but is lower than the other North stations (N8, N10, N3+5, and N7). Control N10 is greater than range station N4+1 but not different from other range and control stations. In the South: control station S2 has significantly higher mean growth than range stations S1 and S4. All other South comparisons indicate no statistical difference.

The F test of Table 3 for differences in growth variation (variance index) indicates (at the $p < .01$ level) in the North that all range and control sta-

Table 2. SNK Test (Zar 1974). Results of the differences between station mean growth rates over the period 1970-1977. NS indicates no significant difference and *indicates significant difference at least at the p < .01 level. C above is station name indicates a non-range site.

NORTH	N2+6	N3+5	N7	N4+1	C N8	C N9	C N10
N2+6	—						
N3+5	*	—					
N7	*	NS	—				
N4+1	NS	NS	NS	—			
C N8	*	*	*	*	—		
C N9	NS	NS	NS	NS	*	—	
C N10	*	NS	NS	*	NS	NS	—

SOUTH	S1	C S2	S3	S4	S5
S1	—				
C S2	*	—			
S3	NS	NS	—		
S4	NS	*	NS	—	
S5	NS	NS	NS	NS	—

Table 3. F test (Zar 1974). Results for differences between station Index Variances over the period 1970-1977. NS indicates no significant difference and *indicates significant difference at least at the p < .01 level (probability level is correct and has been adjusted for the multi-sample hypothesis). C above a station name indicates a non-range site.

NORTH	N2+6	N3+5	N7	C N4+1	C N8	C N9	N10
N2+6	—						
N3+5	NS	—					
N7	NS	NS	—				
N4+1	NS	NS	NS	—			
C N8	NS	NS	NS	NS	—		
C N9	NS	NS	NS	NS	NS	—	
C N10	NS	*	NS	NS	NS	NS	—

SOUTH	S1	C S2	S3	S4	S5
S1	—				
C S2	NS	—			
S3	NS	NS	—		
S4	NS	NS	NS	—	
S5	NS	NS	NS	NS	—

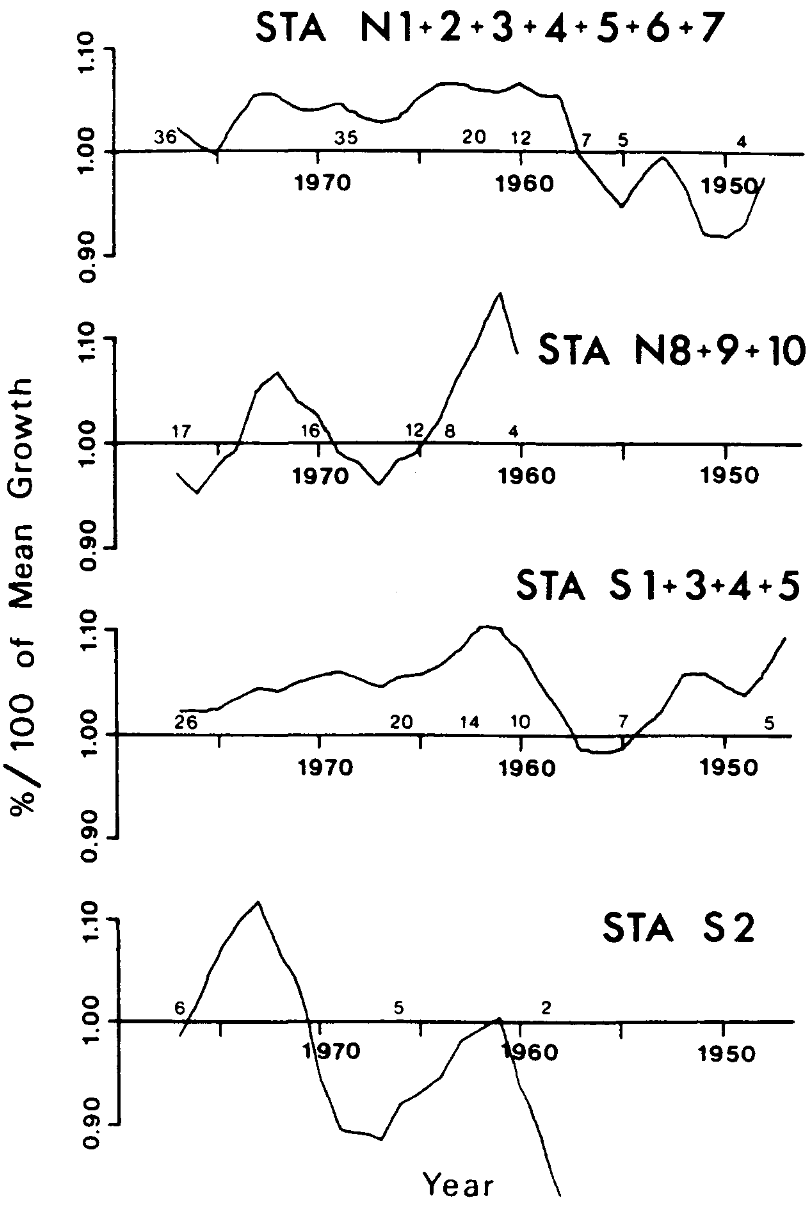

Figure 2. Index growth chronologies of all corals at the indicated stations or station groupings. The horizontal axis is year of annual growth and the vertical axis expresses growth as a percentage of the mean growth rate of all corals in the grouping. The small numbers above the horizontal axis indicate the number of corals included in the chronology at that point. For the first 3 plots the chronologies are not plotted beyond where there are less than 4-5 corals available for averaging. A 3-year moving average has been applied to each chronology in order to smooth out high frequency variation.

tions are not different with the exception that control N10 is greater than range N3+5. In the South no differences were found between range and control stations.

This study was initiated to test the hypothesis that corals on reefs in close proximity to the ordnance range showed growth characteristics consistent with harmful effects of increased sedimentation and turbidity. If range activities had significantly disturbed the functioning of living corals on the nearby reefs by promoting excess sedimentation and turbidity, a number of occurrences would be expected. The most obvious effect would be massive coral mortality in heaviest sedimented areas followed in less severe areas by selective coral mortality according to the coral species, sediment rejection capability discussed by Hubbard and Pocock (1974) and Bak and Elgershuizen (1976). Moderate increases in sedimentation and turbidity would be expected to decrease both coral mean growth rate and growth variance (Dodge, Aller and Thomson 1974, Dodge and Vaisnys 1977, Bak 1978). This is because turbidity reduces necessary light to the included zooxanthellae of coral tissues, thereby causing consequent decreases in photosynthetic ability. In addition, increased sedimentation on corals may increase the amount of time necessary for self-cleaning. This energy expenditure could otherwise be used for activities such as capturing zooplankton for food, reproduction, and growth.

The hypothesis is not so far confirmed by the data. Differences in growth characteristics do exist between stations but are not generally consistent with major anomalies between range and control sites. Furthermore, mean growth rate and growth variance differences are not coupled. For example, in the North, range station N2+6 shows lowered growth rate in relation to two range stations and two control stations but no difference between the remaining range and control stations. Similarly in the South, two range stations (S1 and S4) are lower than the control while two others (S3 and S5) are not. If adverse sedimentation effects were present, it might be expected that at least both S1 and S3 should be lower due to their closer proximity to land. For differences between station growth variation there are none between range and controls in the South, and in the North only two stations show significant differences.

Additional qualitative and quantitative data are available which suggest a minor effect of range usage on surrounding coral reefs. Qualitative observations during collection trips indicated examples of high and/or non-natural sedimentation/turbidity were rare. Moreover, Antonius and Weiner (1978) and Antonius (1981) have used line transects to determine quantitative abundance and coverage of coral species on Vieques range reefs and similarly situated reefs of St. Croix, U.S. Virgin Islands (an equivalently sized and shaped island located some 200 km to the southeast of Vieques). Only minor differences were apparent and none to suggest changes in distributional patterns by sedimentation. Ordnance impact on the reefs was shown to have caused instances of coral breakage and shattering. This was, however, low in terms of percentage and appeared within the normal range of coral breakage from natural waves and storms.

There are certain environmental parameters which do appear to limit the growth of Vieques corals. Averaging the growth of many corals by year at selected sites acts to filter out individual growth variations caused by microhabitat and perhaps genetic differences and to expose the variation which is common to the group as a whole (Dodge and Vaisnys 1975, 1977, see also Fritts 1972). Station and grouped station chronologies were prepared for the Vieques corals and these are shown in Figure 2. Table 4 presents the correlation coefficients between these chronologies over the period 1960-1977 (18 years).

An obvious and statistically significant correlation is evident between the chronologies of the North range stations, the North control stations, and the South range stations. The lack of agreement between the South control (S2) is explained by the small number of individual corals available for the chronology construction. The agreement between the bulk of the stations indicates that a common pattern of growth is present, probably related to an environmental feature common to all corals.

The most obvious choices for comparison to the coral chronologies are long time series of environmental parameters known to affect corals. Historical data for either solar radiation or nutrients were not available; however, Miller (1978) provides annual means of sea surface temperatures in Marsden Square 043 (latitude 10°N-20°N by

Table 4. Correlation Matrix. Correlation coefficients calculated between coral Index Chronologies of Figure 2 over the period 1960-1977 (n= 18 years). An asterisk (*) indicates those correlation coefficients significantly different from zero at the $p < .01$ level.

STATION	C N1+2+3+4+5+6+7	C N8+N9+N10	S2	S1+2+3+4+5
N1+2+3+4+5+6+7	—			
C N8+9+10	.734*	—		
C S2	-.143	-.255	—	
S1+3+4+5	.763*	.788*	-.291	—

longitude 70°W-60°W). These data are plotted in comparison to the South range coral chronology in Fig. 3. An obvious relationship is evident. When the coral band width chronology, C(t), is regressed against the annual sea surface temperature time series T(t), over the period 1946-1970 (25 years) the result is:

$$T(t)°C = 2.105 \pm .141\ C(t)\ mm/yr + 25.550$$

(significantly by F test at $p < .05$ level). The ± figure is the standard error of estimate for the regression coefficient. The correlation coefficient is $r = +.445$ (significantly different from zero at the $p < .05$ level). This regression gives the result that coral growth varies positively with increasing temperature within a small island area. It supports, and the significance and intensity of the relationship is comparable to, the results of Weber and White (1977)

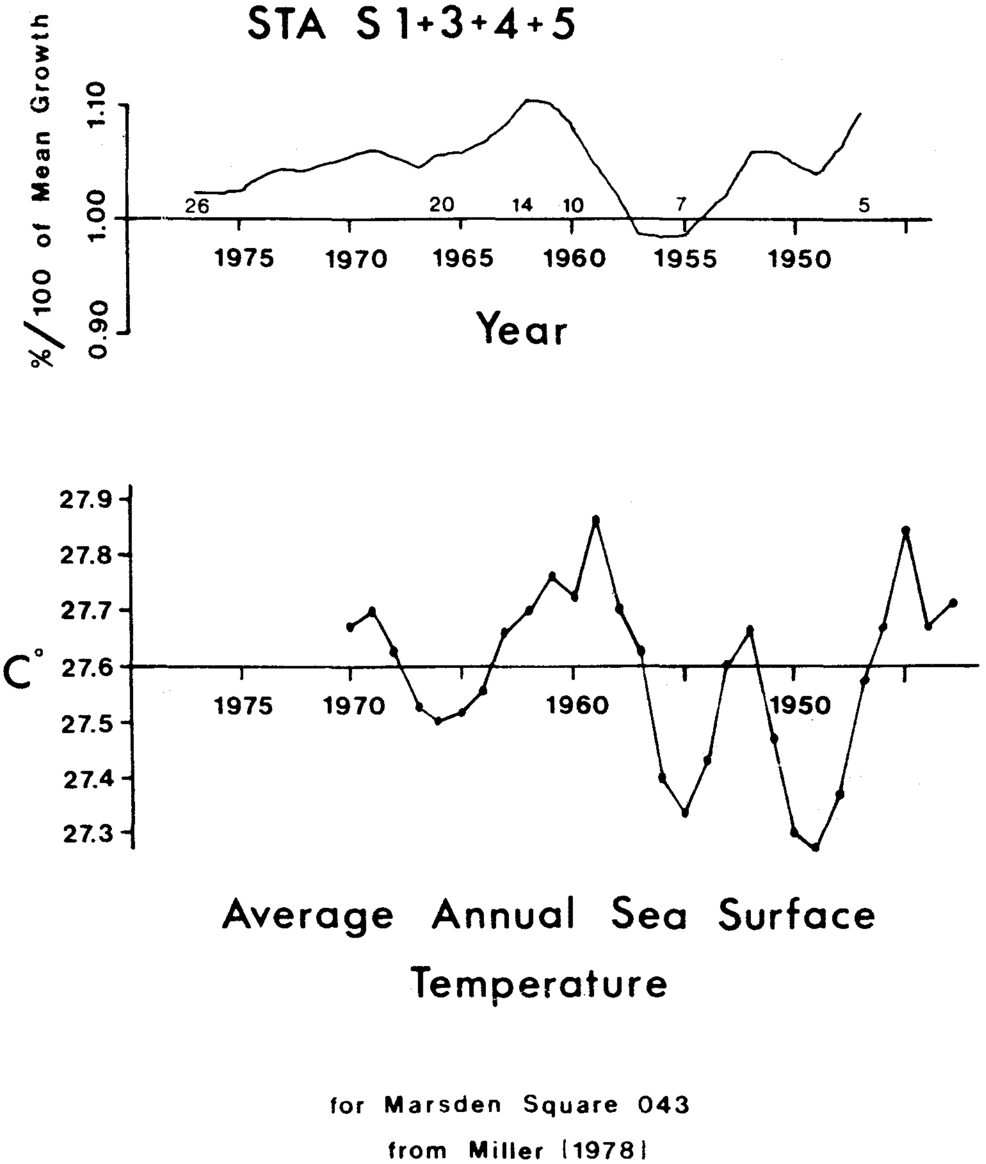

Figure 3. The upper graph is the South range index chronology as described in caption of Fig. 2. The lower graph is a plot of average annual sea surface temperature in Marsden Square 043. The data were taken from Miller (1978) and have been smoothed by a 3-year moving average. The regression equation described in the text uses the coral chronology converted to band with values.

who compared mean coral growth rate of *M. annularis* with average water temperature for widely separated reefs in the Caribbean. With both a longer temperature time series and a more complete chronology of coral bands (which contains an equal number of corals for each year represented) it seems probable that an even better statistical relationship could be educed.

The relationship of the Vieques coral growth chronologies with themselves and with the temperature time series indicates a major control on Vieques coral growth is annual water temperature variation and further supports the conclusion that Vieques coral growth is not obviously disturbed from range use activites. In addition, the regression equation with further refinement and longer lived corals may have value for reconstructing annual sea surface water temperatures in the distant past where no historical water data exist. Finally, the regression indicates that years of cooler temperature are years of lowered growth for corals in this region. Because this is a stress situation, it should alert marine managers and those planning potential impacts or insults to the marine environment to curtail possible synergistic and detrimental effects which might influence living corals and coral reefs of the area at those times.

ACKNOWLEDGEMENTS

Ms. Mary Margaret Goodwin, the U.S. Navy, the U.S. Dept. of Justice, and the U.S. Environmental Protection Agency (Gulf Breeze Laboratory, Grant #CR807314010) are gratefully acknowledged for their support of this project.

REFERENCES

Aller, R.C. and R.E. Dodge. 1974. Animal-sediment relations in a tropical lagoon — Discovery Bay, Jamaica. J. Mar. Res. 32:209-232.

Antonius, A. 1981. Coral reefs under fire. Proc. 4th Int. Coral Reef Symp. Vol. 1.

Antonius, A. and A. Weiner. 1978. A quantitative biological and health assessment of selected coral reefs in Vieques (Puerto Rico) and the U.S. Virgin Islands. Report submitted to EG&G/U.S. Navy/U.S. Dept. of Justice.

Bak, R.P.M. 1978. Lethal and sublethal effects of dredging on reef corals. Mar. Poll. Bull. 9:14-16.

Bak, R.P.M. and J.H.B.W. Elgershuizen. 1976. Patterns of oil-sediment rejection in corals. Mar. Biol. 37:105-113.

Dodge, R.E. 1980. Preparation of coral skeletons for growth studies. *In* D.C. Rhoads and R.A. Lutz (eds.). Skeletal Growth of Aquatic Organisms. Vol. 1, Appendix 1, Part B. Topics in Geobiology. Pp. 615-618. New York and London: Plenum Press.

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

Dodge, R.E. and J. Thomson. 1974. The natural radiochemical and growth records in contemporary hermatypic corals from the Atlantic and Caribbean. Earth and Planet. Sci. Lett. 23:313-322.

Dodge, R.E. and J.R. Vaisnys. 1975. Hermatypic coral growth banding as environmental recorder. Nature 258:706-708.

____________. 1977. Coral populations and growth patterns: responses to sedimentation and turbidity associated with dredging. J. Mar. Res. 35:715-730.

____________. 1980. Skeletal growth chronologies of recent and fossil corals. *In* D.C. Rhoads and R.A. Lutz (eds.). Skeletal Growth of Aquatic Organisms. Vol. 1, Chap. 14. Topics in Geobiology. Pp. 493-517. New York and London: Plenum Press.

Edmondson, C.H. 1928. The ecology of a Hawaii coral reef. Bernice P. Bishop Mus. Bull. 45:1-64.

Fritts, H.C. 1972. Tree-rings and climate. Sci. Am. 226:93-100.

Goreau, T.F. 1959. The ecology of Jamaican coral reefs, 1. species composition and zonation. Ecology 10:67-90.

Hubbard, J.A.E.B. and Y.P. Pocock. 1972. Sediment rejection by recent scleractinian corals: a key to paleo-environmental reconstruction. Geol. Runds. 61:598-626.

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

Loya, Y. 1976. Effects of water turbidity and sedimentation on the community structure of Puerto Rico corals. Bull. Mar. Sci. 26:450-466.

Macintyre, I.G. and S.V. Smith. 1974. X-radiograph studies of skeletal development in coral colonies. Proc. 2nd Int. Coral Reef Symp. 2:277-287.

Marshall, S.M. and A.P. Orr. 1931. Sedimentation on Low Isles reef and its relation to coral growth. Brit. Mus. (N.H.) Great Barrier Reef Exped. Scientific Reports 1:93-133.

Mayor, A.G. 1918. Ecology of the Murray Island coral reef. Carnegie Inst. Wash. Pub, 213. 9:3-48.

Miller, A.R. 1978. A preliminary comparative study of historical sea surface temperatures at potential OTEC Sites. Proc. 5th Annual Conference on OTEC. Miami, Florida: 214-230.

Weber, J.N. and E. White. 1977. Caribbean reef corals *Montastrea annularis* and *Montastrea cavernosa* — long-term growth data as determined by skeletal X-radiography. *In* S.H. Frost, M.P. Weiss and T.B. Saunder (eds.). Reefs and Related Carbonates — Ecology and Sedimentation. A.A.P.G. Stud. Geol. 4:171-179.

Zar, J.H. 1974. Biostatistical analysis, Englewood Cliffs, N.J.: Prentice-Hall, Inc., 620 p.