Effects of Suspended Sediment and Burial
Upon Survival and Growth of Eastern
Gulf of Mexico Corals

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SUMMARY

Effects of Suspended Sediment and Burial Upon Survival and Growth of Eastern Gulf of Mexico Corals

Laboratory experiments were undertaken to quantify the effects of high suspended sediment loads and total burial upon selected species of hard corals and sponges from the Gulf of Mexico. Suspended sediment studies lasted for 10 days each with survival and growth rates measured in control and experimental treatments. The coral species tested in these experiments included: Phyllangia americana, Scolymia lacera, Cladocora arbuscula, Manicina areolata, Isophyllia sinuosa, Solenastrea hyades, Stephanocoenia michelinii, and Siderastrea radians. The sponge species tested was Cinachyra apion. Coral growth rates were determined using the buoyant weight technique and were found to be significantly different between control and experimental treatments in one of four experiments, each at different suspended sediment loads. Natural sediments from the Gulf of Mexico were used in all experiments and the average suspended loads measured in the four laboratory suspended sediment experiments were 49mg/l, 101mg/l, 165mg/l, and 199mg/l. Sponge survival was not affected by exposure to the above suspended loads.

Burial experiments were undertaken with seven of the coral species and the sponge species. All corals tested displayed a relatively high tolerance to complete burial with LT_{50} values (burial time necessary to kill half of the specimens) ranging from 7 days to greater than 15 days. Sublethal stress, in the form of color loss and partial tissue death, was observed in most survivors of burial experiments. The sponge species tested experienced no mortality following 15 days burial.

Field measurements on two reef areas included suspended solids determinations for bottom water, coral vertical height measurements, and coral density estimates.

The data collected in these studies are analyzed and interpreted in light of previous published accounts of similar field and laboratory observations. The coral and sponge species tested in the present study appear to be among the most tolerant species tested within their respective groups.

Recommendations are made for further studies employing longer exposure periods and different environmental conditions. Additional field studies at reef sites near the disposal area are recommended.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

Coral distribution and ecology under natural conditions have been shown to depend upon numerous environmental factors. Vaughan (1916) determined that reef-forming corals were limited by: 1) the effect of sedimentation, 2) decreasing supply of plankton, 3) decreasing light intensity, and 4) lowering of the temperature. These and other factors have been examined subsequently and synthesized into a more complete understanding of Atlantic and Caribbean coral reef ecology (Edmondson, 1929; Goreau, 1959; Squires, 1958; Storr, 1964: Roos, 1971; Smith, 1971; Rylaarsdam, 1981 and references therein).

The specific limiting factor of interest in the present research is that of exposure to high levels of suspended sediment in the water. Since most vigorous coral reef development occurs in clear tropical waters, it has become axiomatic that clear water is essential for coral growth. A closer look at the problem has revealed that the tolerance of corals to turbid water varies considerably among species with some corals being quite resistant to sedimentation effects. Many of the principal reef-building corals in the Caribbean have a low tolerance to turbid water and as a result, reef development may be more successful in clearer water. In turbid water, reef development may be depressed and species composition may be shifted toward the more tolerant species (Roy and Smith, 1971).

Field observations have confirmed the relationship between suspended sediment levels and coral distributions in a variety of geographic locations including: Palao (Matoda, 1939), Australia (Mayer, 1918; Marshall and Orr, 1931); Hawaii (Edmondson, 1928), Fanning Island (Roy and Smith, 1971), Florida (Hubbard and Pocock, 1972), Jamaica (Dodge _et al._, 1974) and St. Croix (Rogers, 1983). In many cases, the same species or genera from different locations are found to inhabit the suboptimum turbid waters. These same corals appear to be dominant on the west central Florida patch reefs visited in the present study. For example, _Manicina_ _areolata_, _Isophyllia_ sinuosa, Cladocora arbuscula, and Siderastrea sp. were common inhabitants on the 26m reef off Tampa Bay, but are found in lagoon habitats and relatively turbid waters in more tropical Caribbean areas (Colin, 1978).

The coral species tested in the present investigation do not form "coral reefs" off west central Florida, but rather grow as individual colonies on the limestone substrata that form the basis of the patch reefs. The composition and geologic' origin of these limestone outcroppings is discussed in Smith (1976). Although these patch reefs are not typical coral reefs, as occur in the Florida Keys and elsewhere, they share some common features with the latter. For example, many vertebrate and invertebrate animals are found almost exclusively on patch reef habitats, and species diversity and abundance are often much higher on patch reefs than on surrounding soft substrata. Symbiotic relationships abound within patch reef communities attesting to the complexity of interrelationships among organisms. In addition, many plant and animal species attach permanently to the hard substratum.

Storms and strong currents periodically produce turbid water and stressful conditions for patch reef organisms. The observed long-term survival of many patch reef communities would suggest that the inhabitants are well adapted to handling periodic stress. Typical seasonal conditions in the Gulf of Mexico result in strong wave and current action with associated turbidity during the winter months, and relatively calm conditions and clear water throughout the summer (with an occasional hurricane). Most growth in patch reef corals probably occurs during the summer months when temperatures are high, plankton levels are high and clear water allows for good light penetration. High turbidity levels during summer would be expected to reduce light penetration and cause corals to expend more energy in cleaning activities. If the stress from turbid water were great enough, a reduction in coral growth rate might occur. The most extreme effect of turbid water, complete burial of organisms, might result in death of the corals.

The present investigation was undertaken to test the effects of high turbidity levels, produced by sediment resuspension, on the survival and growth rates of hard corals collected from Gulf of Mexico patch reefs off west central Florida. These tests were conducted under controlled laboratory conditions and were intended to simulate the levels of suspended sediment that might be expected to occur on the periphery of an ocean dredged material disposal site. Four different levels of suspended sediment were tested in ten-day survival and growth experiments. Results of these bioassays were used to test the hypothesis that increasing suspended sediment loads will result in decreased survival and growth rates. Additional laboratory experiments were employed to test the resistance of eight species to total burial under natural Gulf of Mexico sediment.

Field observations included identification of thirteen species of hard corals from patch reefs and measurements of vertical height for six species on two different reef areas. The results of these studies are presented in the following sections and interpreted in light of previous research on the same topic.

The two reef areas visited during this investigation were located ten nautical miles (nmi) and 18nmi offshore from Sarasota and Manatee Counties respectively (Figure 1). The dates of collecting trips and laboratory experiments are presented in the Chronology of Events (Table 1). The coordinates of the 10nmi reef were: 27°4.34' N latitude, 82°45.55 W longitude and the 18nmi reef: 27°27.16' N latitude, 83°06.25' W longitude.

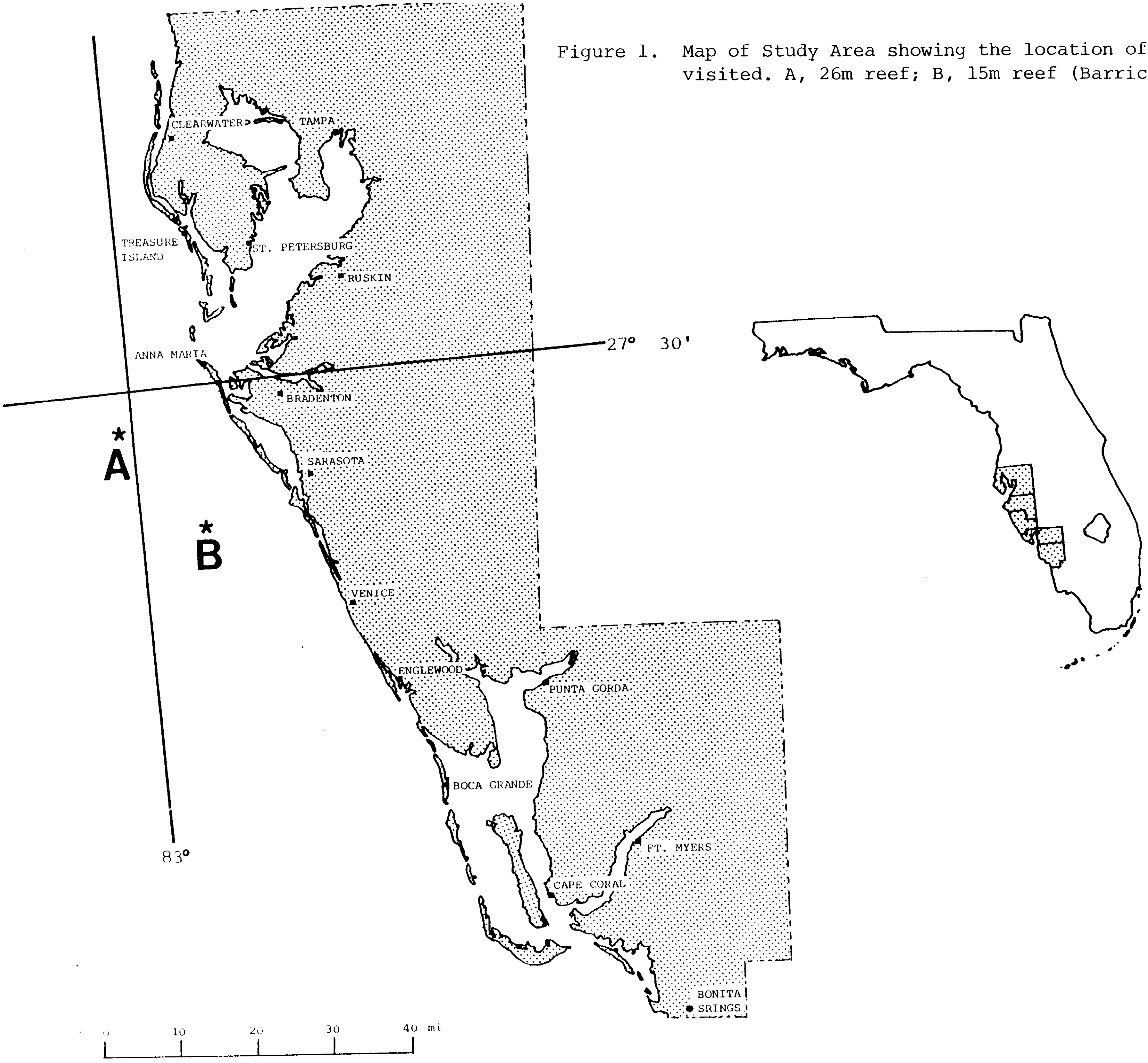


Figure 1. Map of Study Area showing the location of patch reefs visited. A, 26m reef; B, 15m reef (Barricuda Hole).

Table 1. Chronology of field and laboratory events.

Date (1984)	Event
4/20	Suspended solids samples obtained from Site 4
4/25	Suspended solids samples obtained from Gulf of Mexico
5/11	Suspended solids samples obtained from Gulf of Mexico
5/11	Coral and bottom sediment collection from Barricuda Hole
5/18-5/30	Coral suspended sediment experiment I, 49 mg/l
5/30-5/31	Coral burial experiment I, 24 hours
6/01-6/11	Coral suspended sediment experiment II, 101 mg/l
6/08	Suspended solids samples obtained from Gulf of Mexico
6/08	Coral and bottom sediment collection from 26 m reef
6/08	In situ coral height measurements taken at 26 m reef
6/05-6/13	Coral burial experiment II, 96 hours
6/22	Coral and sediment collection from Barricuda Hole
6/22	In situ coral height measurements taken at Barricuda Hole
6/15-6/25	Coral burial experiment III, 10 days
6/25-7/06	Coral suspended sediment experiment III, Phase I, 165 mg/l
7/10	Coral and sediment collection from Barricuda Hole
7/10	In situ coral height measurements taken at Barricuda Hole
7/05-7/11	Coral burial experiment V, 6 days
7/05-7/20	Coral burial experiment IV, 15 days
7/06-7/21	Coral suspended sediment experiment III, Phase II, 199 mg/l
7/24-7/31	Coral burial experiment VI, 8 days

II. METHODS

A. Collection and Handling

Special procedures were used for collection and transport of test organisms to maximize survival and minimize stress. All corals and sponges were hand-collected by SCUBA divers. Hard corals in the size range from 10 to 100g (estimated weight in air) were selected for collection. When a suitable specimen was encountered by a SCUBA diver, the diver would gently maneuver a knife blade or pry bar between the base of the coral and the substratum and dislodge the colony using steady pressure. Care was taken not to touch the fleshy portions of any corals during collection. With some specimens, it was necessary to remove sediment from around the base of the coral in order to locate an appropriate leverage point. Any specimens that were damaged during collection were not returned to the laboratory. *Manicina*, *Isophyllia*, *Cladocora*, and *Scolymia* were generally easy to collect while *Siderastrea*, *Solenostrea*, *Phyllangia*, and *Stephanocoenia* required more care to avoid damage. Once dislodged from the bottom, specimens were placed into nylon mesh bags and returned to the surface. Most hard corals have a low tolerance to exposure in air; therefore, collecting bags were rapidly transferred from the divers to tubs of clean seawater by an assistant on deck. Corals were then quickly sorted and placed into insulated containers for transport. The seawater in the containers was replaced with fresh seawater at least once per hour and the lids were kept in place to avoid stress from direct sunlight.

In the laboratory, field specimens were placed into aquaria with continuously flowing seawater and allowed to acclimate for seven days before being used in an experiment. Temperature, salinity, dissolved oxygen, and pH were monitored during the acclimation period. The photoperiod was set at 14:lO (light:dark) with a one-hour transition period on each end at approximately 75% of full illumination. Incident light in the photosynthetically active range (400-700 nm) was measured with a LiCor integrating photometer and found to be 2.0 and 2.5 uEs $^{-1}$m^{-2} for the control and experimental aquarium, respectively. This converts to approximately 0.3-0.4% of full noon solar irradiance at the same wavelength. Brine shrimp nauplii were added daily to each aquarium as food and screened cylinders placed over outflow ports to maximize brine shrimp retention. Food was added in the late afternoon, since most corals feed during darkness.

No deaths occurred in any coral species due to transport from the field nor acclimation conditions when the above procedures were followed.

B. Experimental Exposure System

All suspended sediment and burial experiments were carried out in a climate-controlled laboratory. Two parallel recirculating seawater systems were used in suspended sediment tests. These systems each consisted of a 200 liter polyethylene reservoir from which seawater was pumped to a 55 liter head tank provided with two magnetic stirrers. Water flowed by siphon from the head tank to a 60 liter exposure tank where the experimental and control animals were housed. Flow rates from the head tank into the exposure tank provided approximately 44 volume changes per 24 hours. Overflow water from the exposure tanks flowed back to the reservoir. Total water volume in each system was 115 liters. The seawater used in all experiments was obtained from the laboratory-wide system (114,000 liter) which is supplied from Gulf of Mexico water pumped from New Pass, Sarasota, Florida.

During initial acclimation periods for corals collected offshore, the exposure tanks were connected to flow-through seawater from the laboratory-wide system. At least two days prior to beginning an experiment, water flow through the exposure tanks was switched to the 115 liter recirculating system. Seawater in the two parallel recirculating systems was replaced with seawater from the laboratory-wide system after each ten-day experiment. Temperature, salinity, dissolved oxygen, and pH measurements during each experiment indicated that water quality remained constant for the ten-day experimental period.

Coral burial experiments were carried out in 20 liter all glass aquaria supplied with flowing seawater from the laboratory system. A subgravel filter was placed in each aquarium and covered with 3.5cm of crushed coral gravel. Experimental animals were arranged on top of this gravel and a map constructed showing the location of each organism. Sediment from the Gulf of Mexico was sieved through a 0.5mm screen and added to the aquarium until all specimens were covered. The subgravel filter provided sufficient water flow down through the sediment to prevent anoxic conditions from occurring. At the end of each experiment, specimens were removed from the sediment and placed into recovery aquaria provided with flowing seawater. The health and general condition of each experimental animal was recorded immediately following removal from burial. Some organisms survived burial, but appeared to be heavily stressed. For this reason, each organism was checked again at 24 hours and seven days with the final survival rate based upon the data collected at seven days after removal from the sediment.

C. Coral Growth Rates

During each of the four suspended sediment bioassays, the beginning and final weight of each coral colony or individual was measured using the buoyant weight technique described by Dodge et al. (1984). A basket was suspended beneath an American Scientific Products DTL 2500 top-loading electronic balance and positioned over a 38 liter aquarium so that the basket and coral would be completely submerged during weighing. Each coral was weighed to the nearest 0.019 and the temperature and salinity of the water in the weighing aquarium measured after every fifth weighing. The buoyant weights were converted to equivalent weights in air using the formula:

$$W_a = \frac{W_w}{(1 - \frac{Dw}{Dm})}$$

W_a is weight in air

W_w is buoyant weight

D_w is the density of water

D_m is the density of the coral

D_m was assumed to be 2.94 (the density of pure aragonite) and D_w was calculated from the temperature and salinity of the seawater in the weighing aquarium using Table 2.1 in Riley and Chester (1971). The resulting weights in air (W_a) were then used to compute growth rates. The change in weight of a specimen over the course of the experiment was divided by the initial weight of the coral to obtain a normalized value expressed as mg growth/g body weight/l0 days, Some problems were encountered with this technique and are explained in the Discussion.

D. Determination of Survival

Survival rates were determined for each species of experimental animal during both suspended sediment experiments and burial experiments. Some of the organisms, such as *Scolymia* and *Phyllangia* represented single individuals and could be easily classified as alive or dead. Most species tested form colonies consisting of numerous corallites or "individuals", and for these species, intermediate conditions occur. In either case, a corallite was considered alive if its soft tissues appeared normal, or if its tentacles were extended in feeding posture during the recovery period. Sponges used in suspended sediment and burial experiments were considered alive if still firm to the touch, and dead if mushy or covered with fungus.

Sublethal responses were recorded for corals exposed to suspended sediment or used in burial experiments. Loss of color associated with expulsion of zooxanthellae was a common response in *Manicina*, *Scolymia*, *Isophyllia*, and *Solenastrea*. Shrinkage of soft tissue and exposure of underlying skeletal features was observed in *Manicina*, *Scolymia*, and *Isophyllia*. Most hard corals produce mucus on their soft tissues, and this feature was used to assess relative health. In cases where it was difficult to determine if a coral was alive, the presence of mucus was taken as a sign of life. The absence of surface mucus was a common feature on all corals considered to be dead.

E. Experimental Animals

Eight species of hard corals and one sponge species were used in suspended sediment tests and burial experiments. Each specimen was carefully selected in the field and collected, transported, and acclimated according to the procedures above, prior to use in bioassays.

The hard corals observed in the field included:

Phylum Cnidaria
Class Hydrozoa
  Order Milleporina
    Family Milleporidae
      Millepora alcicornis Linnaeus
          (not used in experiments)

Class Anthozoa
  Order Scleractinia
    Family Astrocoeniidae
      Stephanocoenia michelinii Milne Edwards and Haime

    Family Siderastreidae
      Siderastrea radians (Pallas)
      Siderastrea siderea (Ellis and Solander)
          (not used in experiments)

    Family Poritidae
      Porites porites (Pallas)
          (not used in experiments)

    Family Rhizangiidae
      Phyllangia americana Milne Edwards and Haime

    Family Mussidae
      Scolymia lacera (Pallas)
      Isophyllia sinuosa (Ellis and Solander)

    Family Faviidae
      Manicina areolata (Linnaeus)
      Cladocora arbuscula (Lesueur)
      Solenastrea hyades Milne Edwards and Haime

Family Oculinidae
  Oculina diffusa Lamarck
    (not used in experiments)

Family Meandrinidae
  Dichocoenia sp. (observed but not collected)

Phylum Porifera

Family Craniellidae
  Cinachyra apion Uliczka

Twelve species of scleractinian hard corals and one species of hydrocoral were collected from patch reefs off Sarasota and Manatee Counties. Eight of these species were used in laboratory experiments, and six species were measured in the field for vertical height above the substratum. The species listed above that were not used in laboratory experiments include:

Millepora alcicornis
Siderastrea siderea
Porites porites
Oculina diffusa
Dichocoenia sp.

These species were not used because insufficient numbers of specimens were encountered at the reefs visited. Some of these species are quite common on other patch reefs in the general vicinity. For example Millepora alcicornis and Porites porites are quite common on a large reef area west of the previously designated dredged material disposal site (Site A) in about 20m depth. Oculina diffusa and Dichocoenia sp. have never been observed to be abundant on any local patch reef examined by the author.

F. Total Suspended Solids

Seawater samples were collected from several locations in the Gulf of Mexico during March, April, May and June, 1984 for determination of total suspended solid loads in near bottom water. Samples were collected from most stations with a Niskin bottle within lm of the bottom and transferred to precleaned polypropylene containers for transport to the laboratory. Samples from Site 4, the Barricuda Hole, and the 26m reef were collected by divers using precleaned collapsible polyethylene bottles.

Water samples were collected periodically from the experimental and control exposure aquaria during the course of each suspended sediment bioassay. All suspended solid samples were stored at 4°C until analyzed, and all samples were analyzed in duplicate.

Polycarbonate filters with a pore size of 0.45µm were vacuum rinsed with distilled-deionized water, dried at 100°C for two hours and weighed. A premeasured volume of well-mixed sample was then filtered, followed by a second distilled-deionized water rinse to remove any salt. Filters were dried at 100 °C for two hours and reweighed.

III. RESULTS AND DISCUSSION

The results of the present investigations are discussed below under the main headings, Laboratory Studies and Field Studies. The Laboratory Studies included coral survival and growth experiments under suspended sediment loads of 49-199mg/l, and coral and sponge burial experiments. Field Studies included suspended solids measurements in the Gulf of Mexico, coral vertical height measurements, and coral density estimates at two reef areas in the Gulf.

A. Laboratory Studies

1. Suspended Sediment Experiments

Four suspended sediment experiments were completed using hard corals and sponges exposed to natural sediment from the Gulf of Mexico. Each experiment lasted for ten days with survival and growth rates measured for each coral specimen and survival rate determined for sponges. A different suite of experimental animals was used in each experiment except for the final two suspended sediment tests in which the same animals were exposed for a total of twenty days and checked for survival and growth at ten-day intervals [Suspended Sediment Experiment III (SSE III), Phases I and II]. The results of these experiments are presented as average growth rates for experimental and control groups in Tables 3-6, and graphically for each species in Figures 2-10. Figures 2-6 summarize the growth responses for each species tested at a given suspended solids load. Figures 7-10 represent the change in growth response for each species with increasing suspended solids load.

a) Survival

In general, coral and sponge survival was not affected by exposure to the levels of suspended solids tested during the time course of these experiments. No sponge deaths were recorded and only one species of coral, *Siderastrea radians*, had colonies die during suspended sediment tests. These coral deaths occurred in SSE III, Phase II with colonies from both experimental and control treatments being affected. Four of five control colonies died while two of five experimental colonies died, suggesting that these deaths were unrelated to the suspended sediment load.

At the end of the first and second ten-day periods of SSE III, each coral was examined for general health and appearance. Experimental treatment specimens were cleaned of any accumulated sediment prior to examination. At the flow rates used in these experiments, it was unavoidable that some sediment accumulated &-the numbered dishes used to hold the experimental animals. Some corals were partially buried as a result of this and suffered some polyp death or polyp bleaching. Bleaching of polyps or entire colonies was assumed to be a result of zooxanthellae expulsion.

At the end of SSE III, Phase I, the following species in the experimental treatment displayed partial polyp death or polyp bleaching in some individuals: Scolymia lacera, Stephanocoenia michelinii, Siderastrea radians, and Solenastrea hyades. Control specimens were similarly affected in S. hyades. At the end of Phase II (second ten days), color loss was noted in the experimental treatment for S. lacera, Manicina areolata, S. hyades, S. radians, Isophyllia sinuosa, Cladocora arbuscula, and S. michelinii. Similar color loss was observed in control treatment individuals of M. areolata, S. hyades and S. radians. It is difficult to quantify bleaching on coral specimens since only a portion of the animal was affected in most cases. On the basis of number of individual specimens affected, regardless of the extent of bleaching, fourteen experimental treatment corals and ten control treatment corals experienced some color loss. Some hermatypic corals are known to expel their zooxanthellae if kept in the dark for extended periods of time (Edmondson, 1928). Reduced light levels in the experimental treatment aquarium may have contributed to zooxanthellae loss in the present case, but was not a factor in the control aquarium.

Sponges exposed to suspended sediments tended to become coated with up to 1mm of clay-like material by the end of ten days. Cross-sections of these experimental treatment sponges revealed dark streaks leading into the interior of the specimens suggesting that some sediment may have accumulated within the circulatory channels. These dark streaks were absent in cross-sections of control sponges. All sponges in all four suspended sediment experiments survived the exposure.

b) Growth Rate

Growth rates were variable between different species of corals and variable within species between different experiments. The average growth rates for seven species that were exposed to control conditions in laboratory experiments are presented in Table 2. One species, *Phyllangia americana,* was used in suspended sediment experiments I and II but is not included in Table 2 due to the unexpectedly high variability of the data. This species was commonly collected with relatively large amounts of non-coral substratum attached and this may have affected the growth rate measurement.

Isophyllia sinuosa had the lowest control growth rate of the corals tested and *Cladocora arbuscula* had the highest (Table 2). Growth rates for control and experimental treatments for each of four suspended sediment experiments are presented in Figures 2-5 and Tables 3-6. The data are summarized at the bottom of each table as the average growth rate for all species tested including the significance (t-test) of any difference between control and experimental treatments. In all experiments except SSE III, Phase I (Table 5), there was no significant difference in average growth rate between control and experimental treatments. In SSE III, Phase I, the average control growth rate was significantly higher ($P<0.05$) than that of the experimental group. The same group of specimens exposed for the second ten days of the experiment (SSE III, Phase II, Table 6) displayed no significant difference between treatments. The growth rates for the entire twenty-day period (SSE III, Phases I and II) were not significantly different between control and experimental treatments when analyzed collectively (Figure 6). Average growth rates of corals were higher in the second phase of SSE III than the first phase for both treatments (Tables 5 and 6). This may indicate that the corals were still adapting to the specific laboratory conditions during the first phase. The specimens used in this

Table 2. Average growth rate (mg/g/10 days) of corals from control treatments of four suspended sediment experiments.

	Average Growth rate as mg/g/10 days	
Species	Control	Number Tested
Scolymia lacera	1.55	10
Manicina areolata	2.15	20
Solenastrea hyades	4.95	20
Siderastrea radians	1.63	15
Isophyllia sinuosa	0.35	10
Cladocora arbuscula	7.18	20
Stephanocoenia michelinii	3.30	10
Average for all species:	3.45	105

Figure 2. Average growth rates (n=5) for five species of corals exposed to control and experimental conditions (49 mg/l suspended solids) for 10 days. Suspended Solids Experiment I.

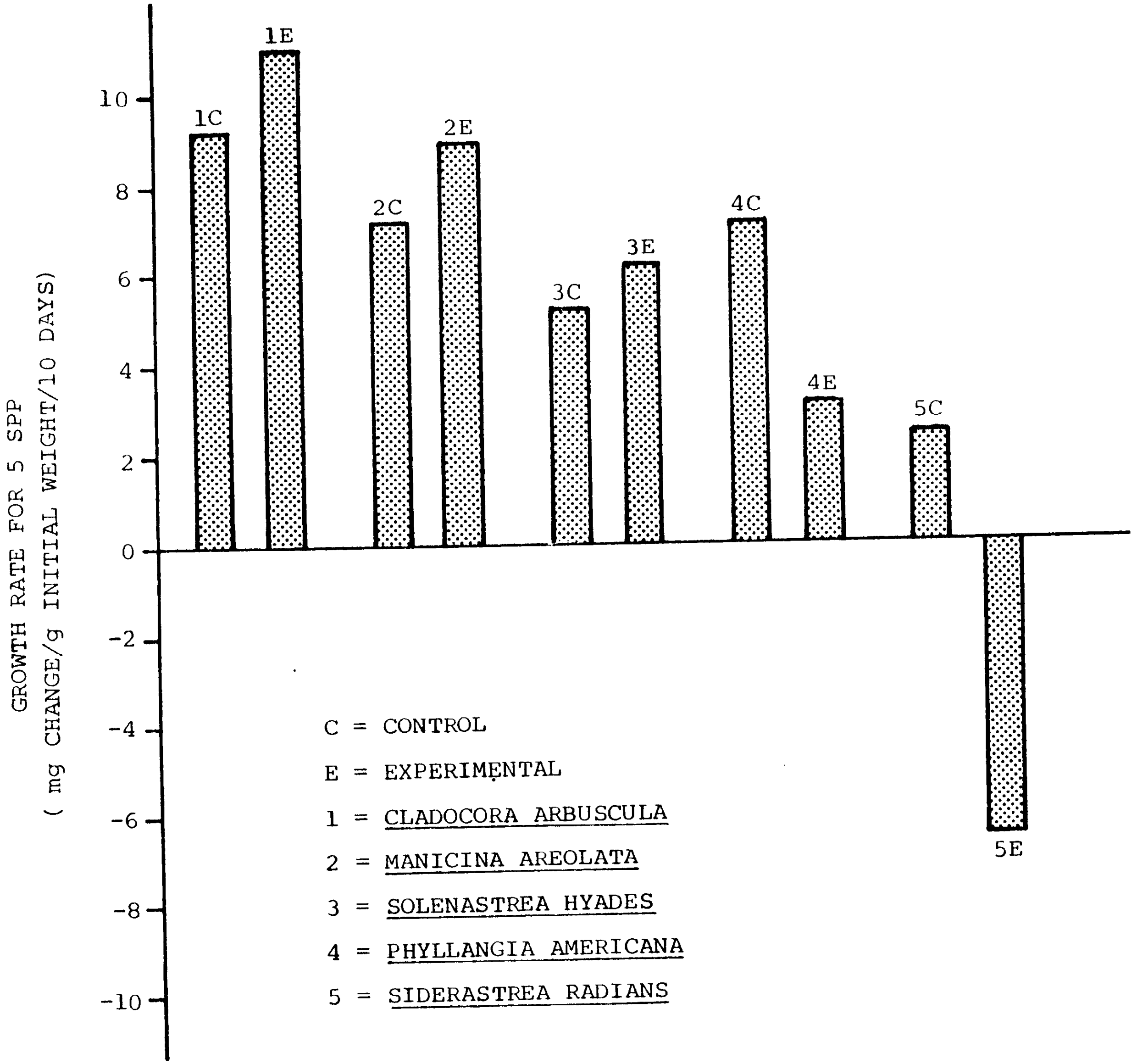


Table 3. Average growth rates for five species of hard corals exposed to an average of 49 mg/l suspended solids for 10 days in the laboratory. Suspended Sediment Experiment I.

	Averaqe Growth rate (n=S) as mg/g/10 days	
Species	Control	Experimental
Cladocora arbuscula	9.2	11.0
Manicina areolata	7.2	8.8
Solenastrea hyades	5.3	6.1
Phyllangia americana	7.1	3.1
Siderastrea radians	2.6	-6.4
Average for all species:	6.28	4.52
Standard deviation :	5.20	13.67
Number tested :	25	25
Significance :	$t_s = 0.602$ (Not Significant)	

Figure 3. Average growth rates (n=5) for seven species of corals exposed to control and experimental conditions (101 mg/l suspended solids) for 10 days. Suspended Solids Experiment II.

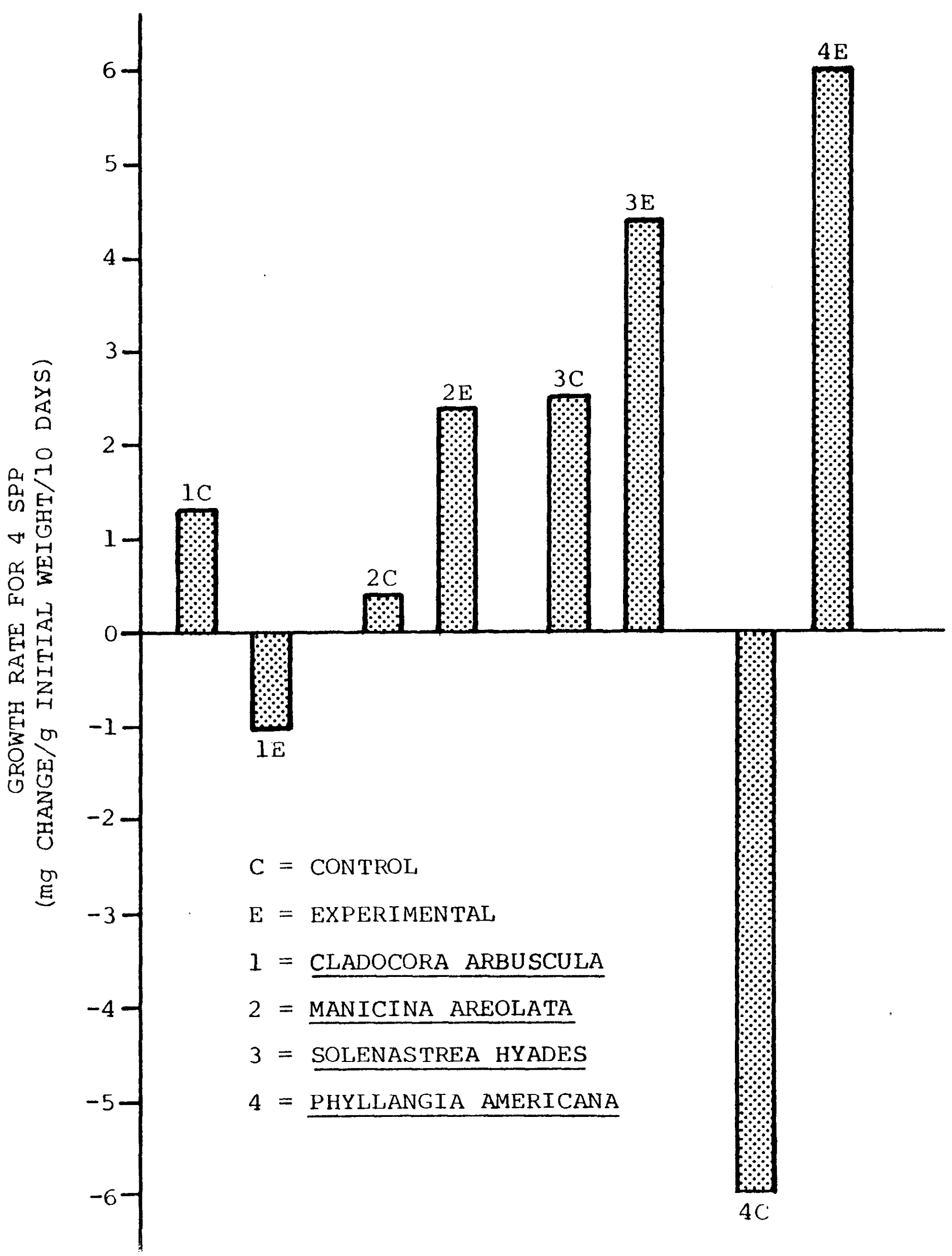


Table 4. Average growth rates for four species of hard corals exposed to an average of 101 mg/l suspended solids for 10 days in the laboratory. Suspended Sediment Experiment II.

Species	Average Growth rate (n=5) as mg/g/10 days Control	Experimental
Cladocora arbuscula	1.3	-1.0
Manicina areolata	0.4	2.4
Solenastrea hyades	2.5	4.4
Phyllangia americana	-9.8	34.8
Average for all species :	-1.40	10.15
Standard deviation :	16.7	34.6
Number tested :	20	20
Significance :	t_s = 1.344 (Not Significant)	
Average without *Phyllangia*:	1.4	1.9
Standard deviation :	3.8	9.8
Number tested :	15	15
Significance :	t_s = 0.184 (Not Significant)	

Figure 4. Average growth rates (n=5) for seven species of corals exposed to control and experimental conditions (165 mg/l suspended solids) for 10 days. Suspended Sediment Experiment III, Phase I.

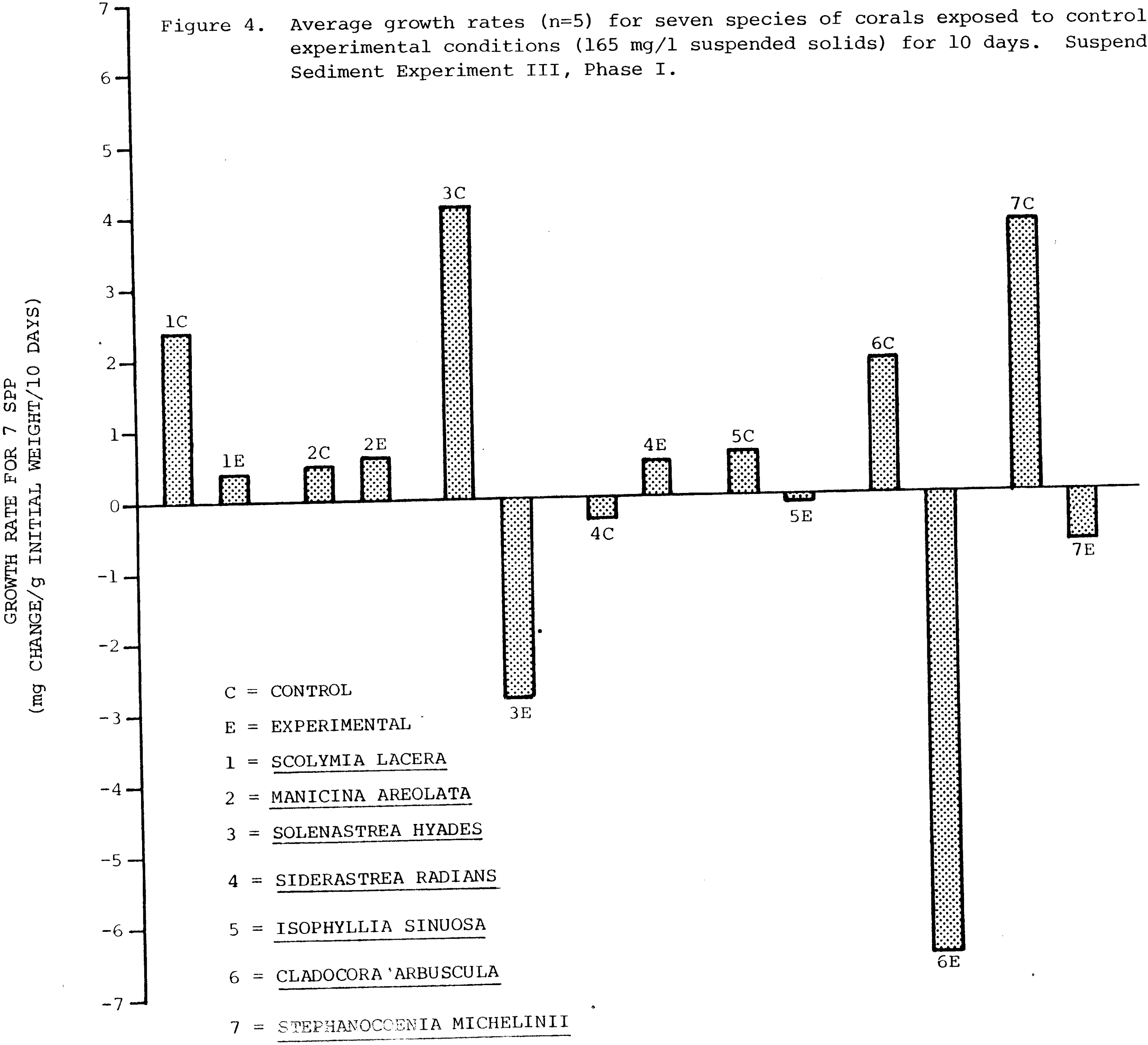


Table 5. Average growth rates for seven species of hard corals exposed to an average of 165 mg/l suspended solids for 10 days (first 10 days) in the laboratory. Suspended Sediment Experiment III, Phase I.

Species	Average Growth rate (n=5) as mg/g/10 days Control	 Experimental
Scolymia lacera	2.4	0.4
Manicina areolata	0.5	0.6
Solenastrea hyades	4.1	-2.8
Siderastrea radians	-0.3	0.5
Isophyllia sinuosa	0.6	-0.1
Cladocora arbuscula	1.9	-6.5
Stephanocoenia michelinii	3.8	-0.7

Average for all species:	1.85	-1.22
Standard deviation :	4.89	5.05
Number tested :	35	35
Significance :	$P < 0.05$ (t-test)	

$t_s = 2.584$

Figure 5 Average growth rates (n=5) for seven species of corals exposed to control and experimental conditions (199 mg/l suspended solids) for 10 days. Suspended Solids Experiment III, Phase II.

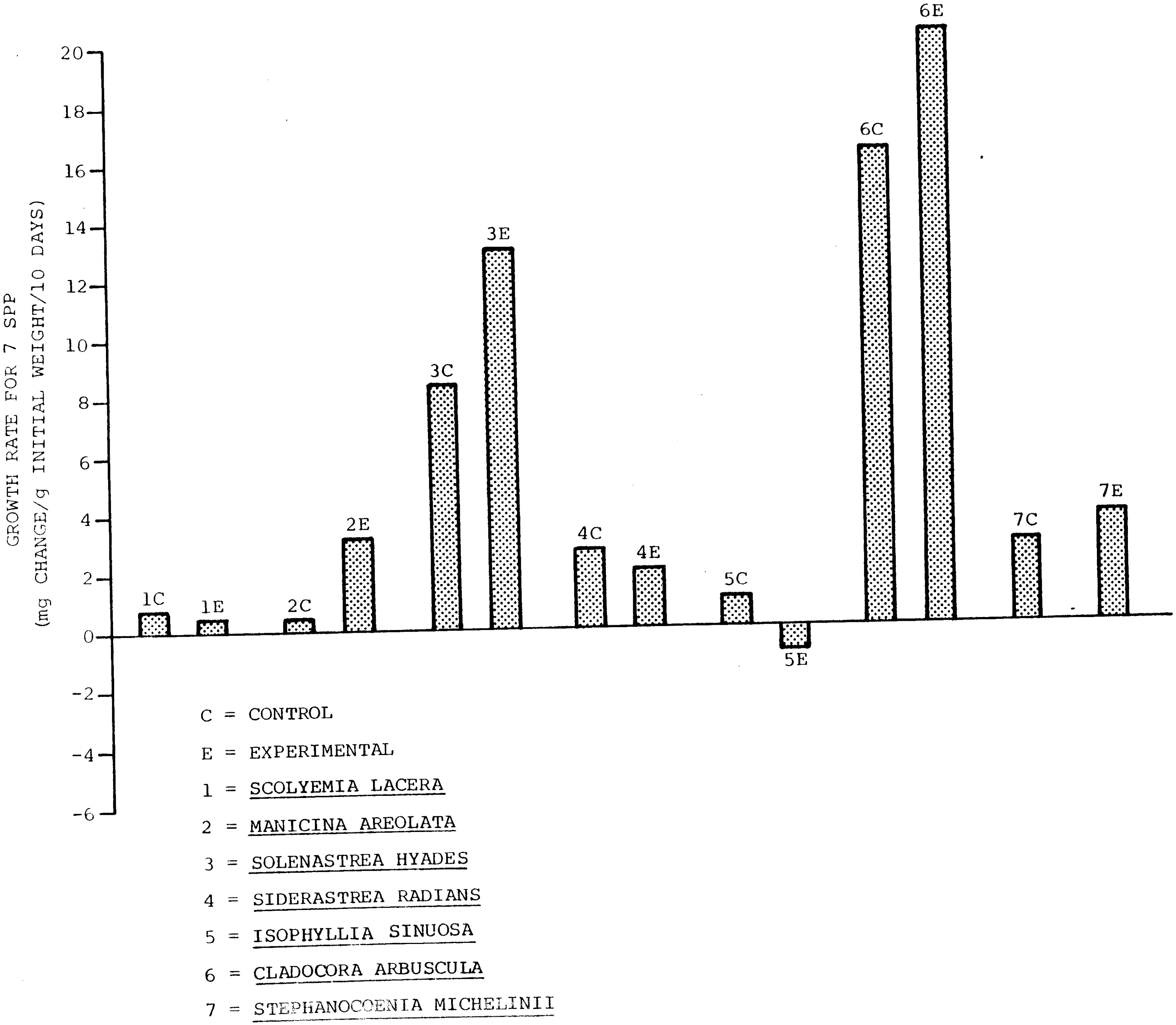
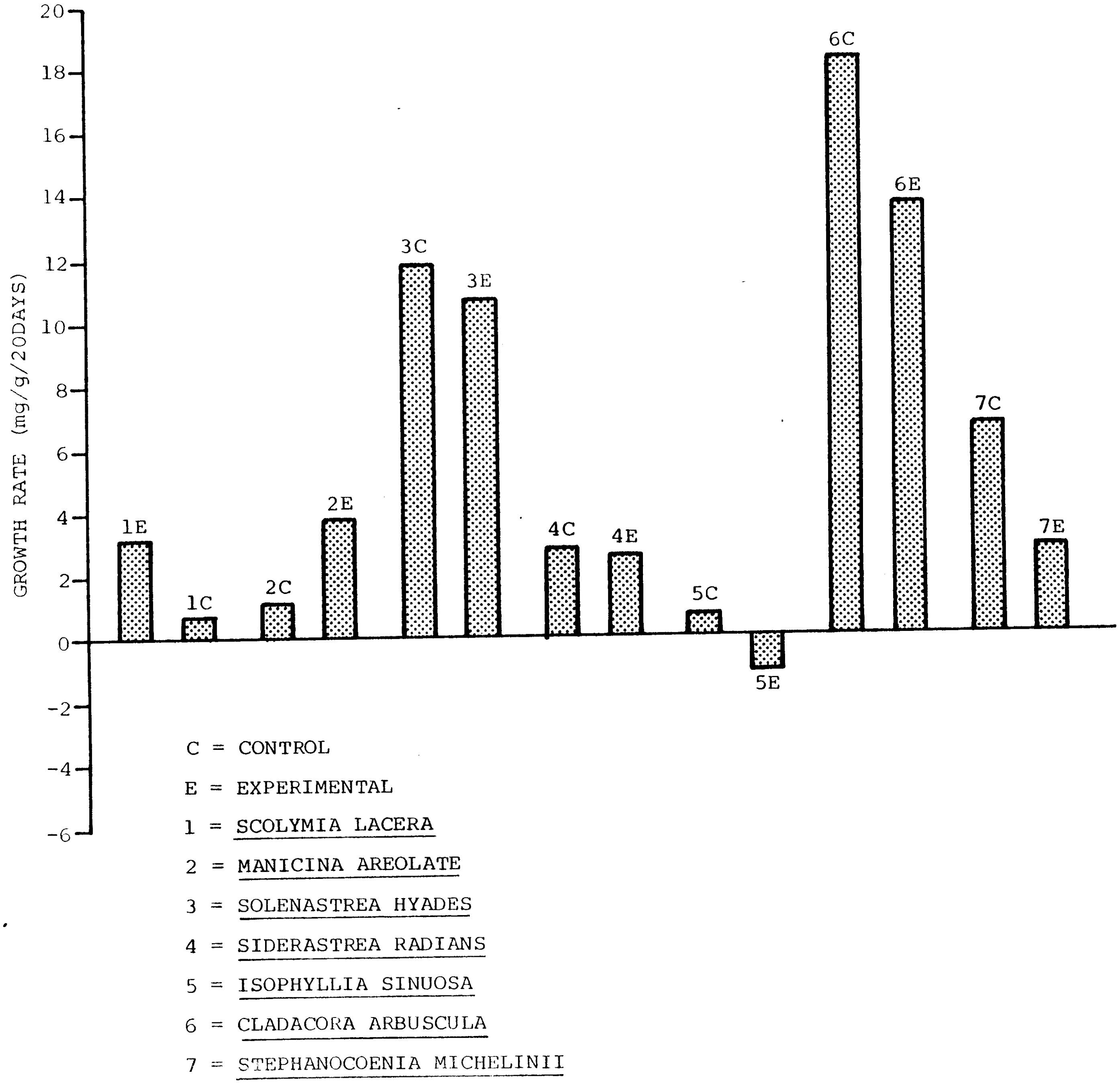


Table 6. Average growth rates for seven species of hard corals exposed to an average of 199 mg/l suspended solids for 10 days (second 10 days) in the laboratory. Suspended Sediment Experiment III, Phase II.

	Average Growth rate (n=5) as mg/g/10 days	
Species	Control	Experimental
Scolymia lacera	0.7	0.5
Manicina areolata	0.5	3.3
Solenastrea hyades	7.9	13.6
Siderastrea radians	2.6	2.0
Isophyllia sinuosa	0.1	-0.9
Cladocora arbuscula	16.3	20.3
Stephanocoenia michelinii	2.0	3.6
Average for all species:	4.42	6.05
Standard deviation :	6.80	8.17
Number tested :	35	35

Significance : $t_s = 0.907$ (Not Significant)
$t_{[0.05,68]} = 1.997$

Figure 6. Average growth rates (n=5) for seven species of corals exposed to control and experimental treatments for 20 days. Suspended Sediment Experiment III, Phase I and II combined.



experiment were acclimated to laboratory conditions for seventeen days prior to the beginning of Phase I, and both phases of SSE III were conducted under virtually identical physical and chemical conditions (Table 7).

The response of individual coral species to the various suspended solids loads tested is presented in Figures 7-10. Some species (*Manicina areolata*) had consistently higher (although not significant) growth rates in experimental treatments than in control treatments. Other species displayed more variable responses but no clearcut trend was evident indicating a significant decrease in growth rate with increasing suspended solids load. Species that grew more in experimental treatments than in controls may have been obtaining additional nutrients from the suspended sediment, which contributed to growth or facilitated calcification. A possible solution to the problem of variable growth rates within species would be to chart individual growth rates of corals for several weeks prior to beginning an experiment. This would provide a baseline for comparison with subsequent experimental treatments and would help to establish adequate acclimation times for growth studies.

Field research on tropical corals has indicated an inverse relationship between coral growth and suspended sediment levels (Dodge, *et al.,* 1974). The hypothesis that increasing suspended solids loads will result in decreased growth rates of corals is based upon the assumption that every specimen has a given energy budget to work within. Anabolic processes depend upon heterotrophic feeding efficiency and autotrophic synthesis (in hermatypic forms). Catabolic processes include respiration, cleaning maintenance and self-defense. The balance between anabolic and catabolic processes is positive if food energy intake and autosynthesis are higher than energy expenditures. A positive energy balance results in growth of the coral and development of reproductive organs. As the balance approaches zero, less energy is available for growth and reproduction. An increase in suspended sediment levels will result in an increase in cleaning activity of a coral and may interfere with normal feeding mechanisms. If the energy expended in cleaning becomes sufficiently

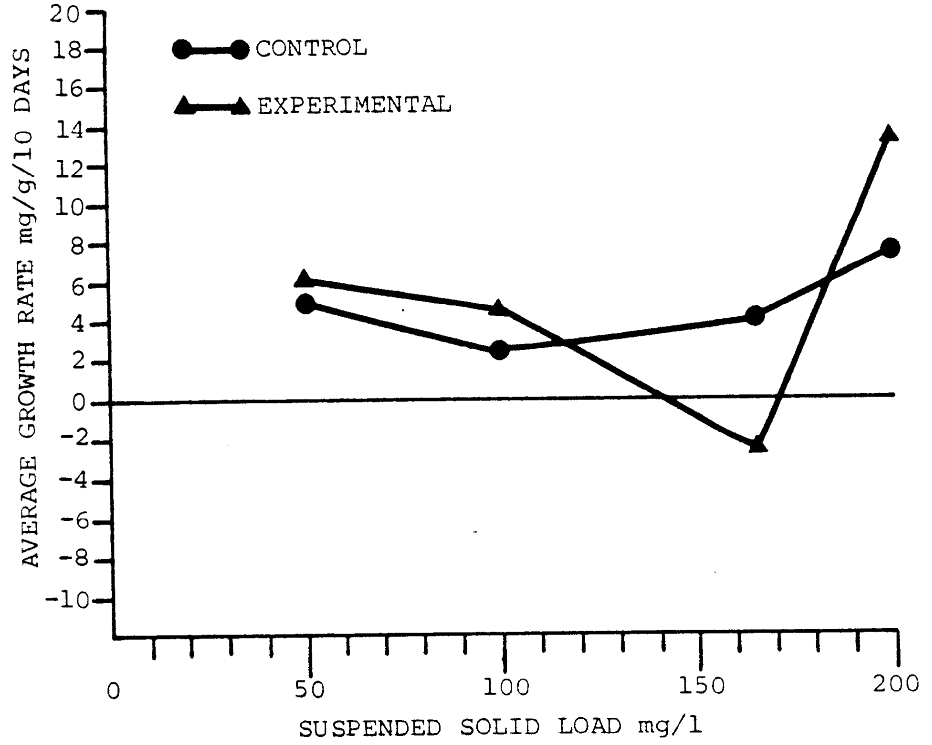
Table 7. Physical and Chemical parameters of seawater during Suspended Sediment Experiment III.

1984	Temperature °C		Salinity o/oo		pH		Dissolved Oxygen mg/ℓ	
Date	Control	Exper.	Control	Exper.	Control	Exper.	Control	Exper.
Phase I								
6/25	24	24	34.0	34.5	7.86	7.84	6.0	6.1
6/27	24	24	34.0	34.5	7.91	7.88	4.3	4.8
6/28	24	24	34.5	34.5	7.92	7.90	4.3	5.2
6/29	24	24	34.5	34.5	7.93	7.87	5.8	5.8
7/01	24	24	34.5	34.5	7.94	7.93	--	--
7/02	24	24	34.5	35.0	7.88	7.88	--	--
7/03	24	24	34.5	35.0	7.94	7.97	--	--
7/05	24	24	35.0	35.0	7.91	7.93	5.4	5.5
Phase II								
7/11	25	26	34.5	34.5	7.99	8.06	--	--
7/12	24	24	34.5	34.5	7.90	7.94	--	--
7/13	24	24	34.5	35.0	7.83	7.91	6.2	6.2
7/16	24	25	35.0	35.5	7.94	8.01	--	--
7/17	25	25	35.0	35.5	7.90	7.97	--	--
7/18	25	25	35.0	35.5	7.89	8.01	6.1	6.2
7/19	25	25	35.0	35.5	7.86	7.95	--	--
7/20	25	25	35.0	35.5	7.88	7.91	--	--

Figure 7. Average growth rates (n=5 per data point), for *Solenastrea hyades* (A) and *Siderastrea radians* (B) exposed to increasing suspended solids.

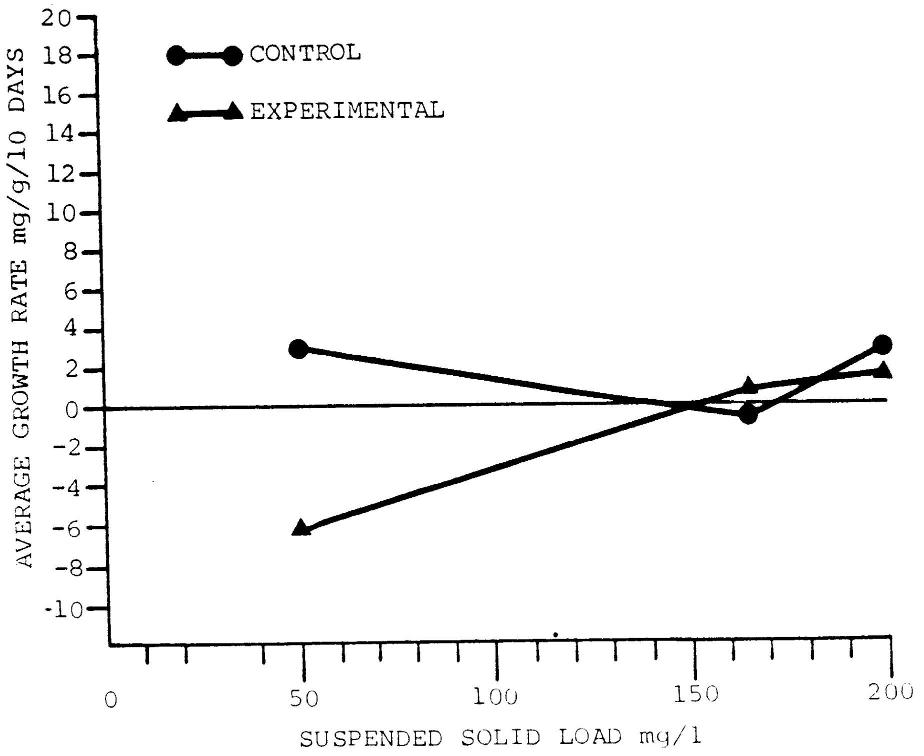
A.

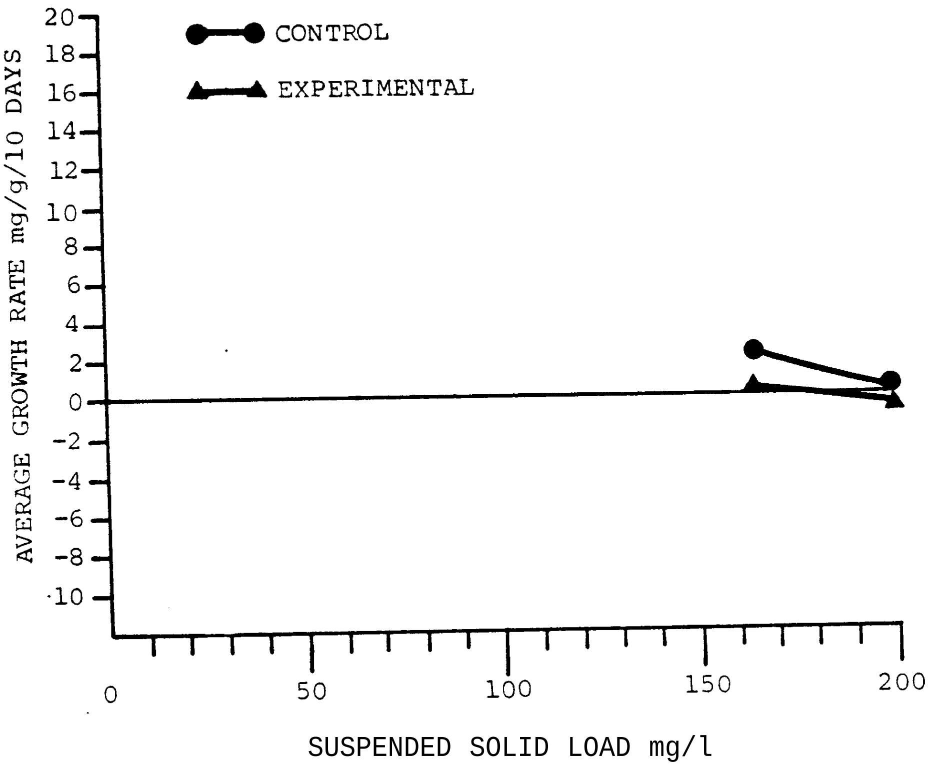
SOLENASTREA HYADES



B.

SIDERASTREA RADIANS





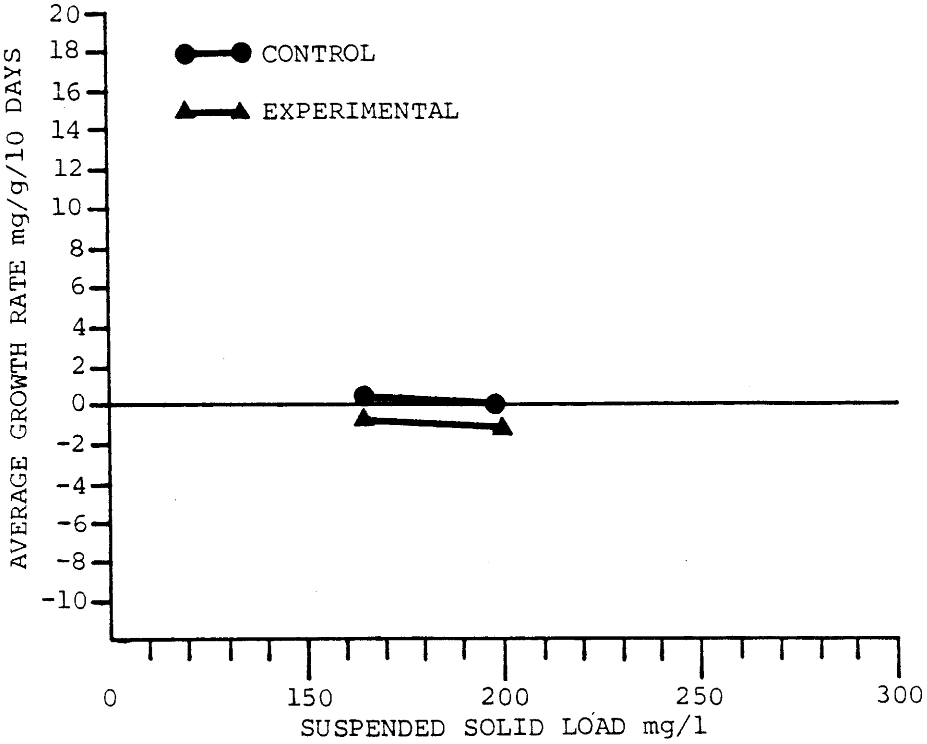
SCOLYMIA LACERA

Figure 8. Average growth rates (n=5 per data point) for _Scolymia lacera_ exposed to increasing suspended loads.

Figure 9. Average growth rates (n=5 per data point) for _Isophyllia sinuosa_ (A) and _Stephanocoenia michelinii_ (B) exposed to increasing suspended loads.

ISOPHYLLIA SINUOSA

A.



B.

STEPHANOCOENIA MICHELINII

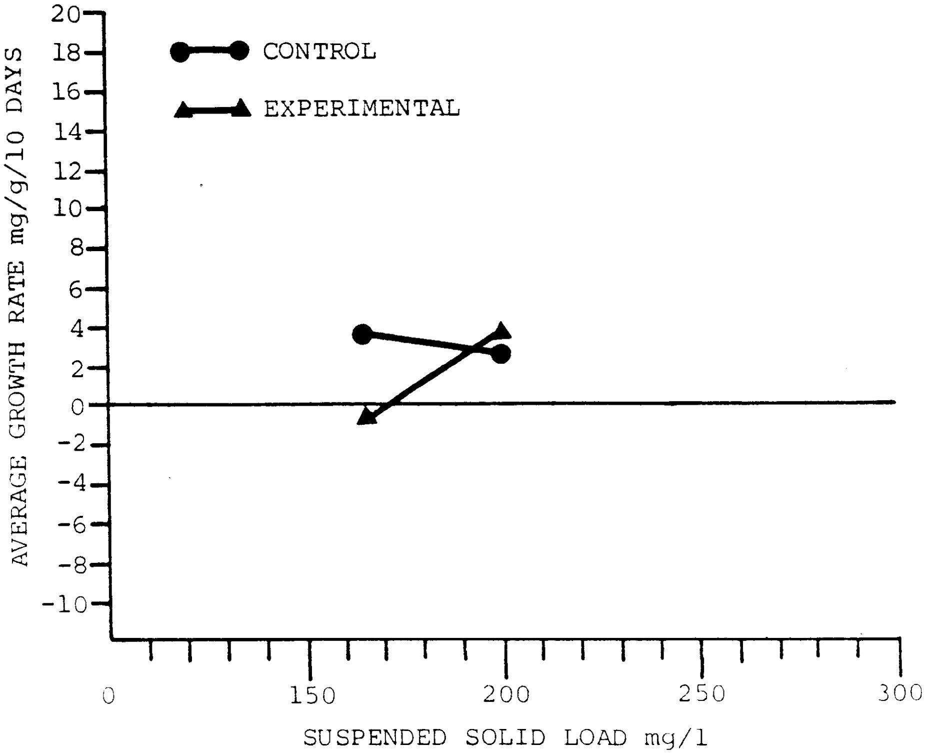
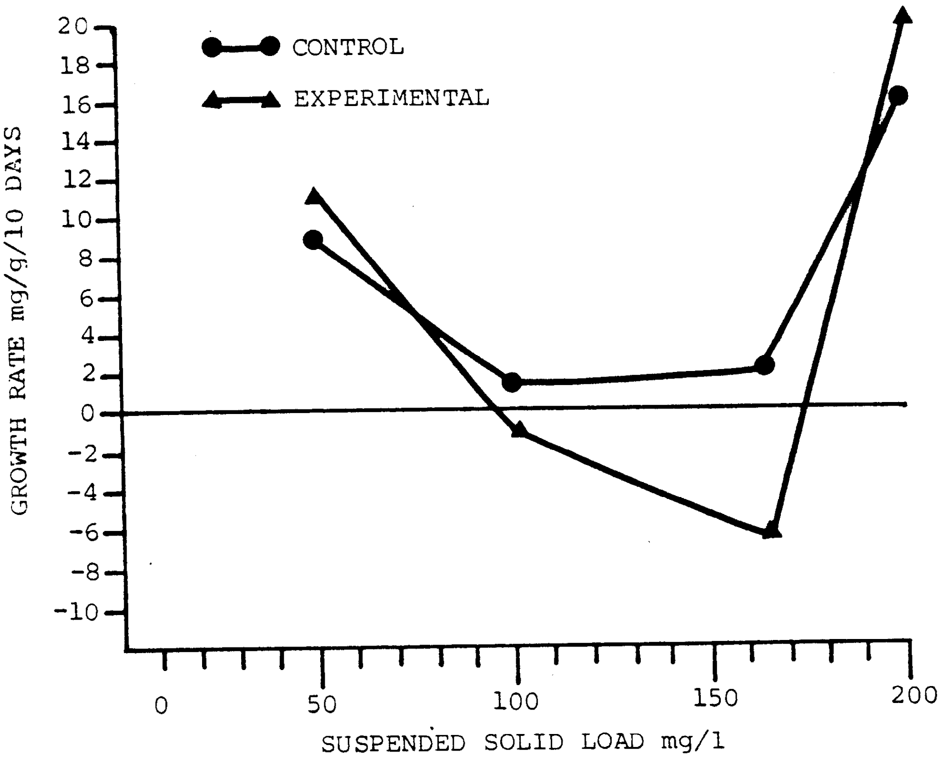
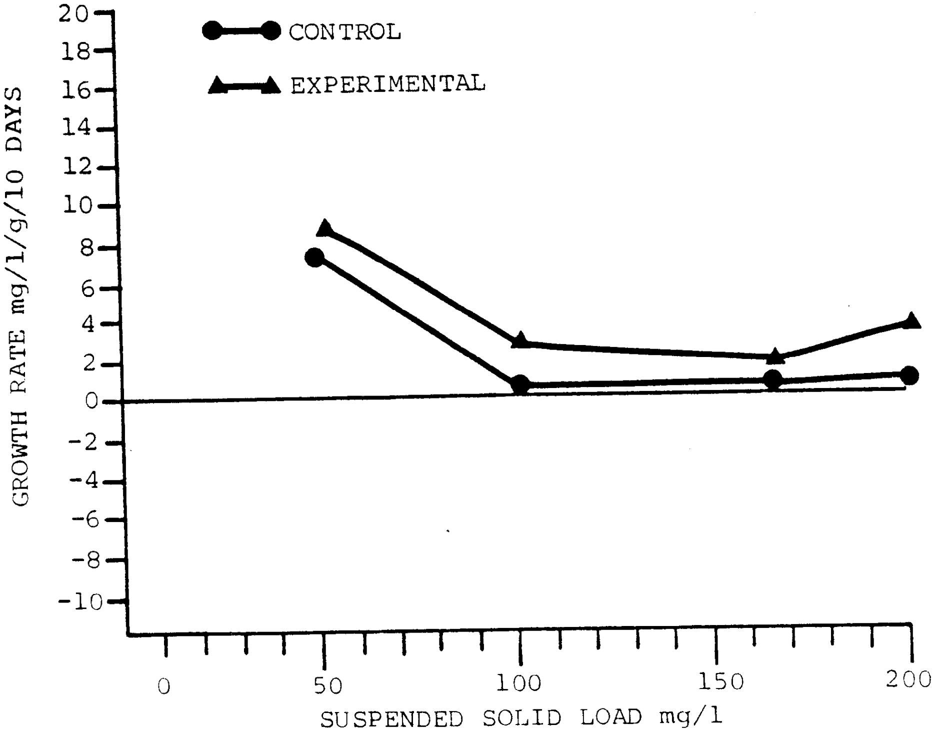


Figure 10. Average growth rates (n=5 per data point) for _Cladocora arbuscula_ (A) and _Manicina areolata_ (B) exposed to increasing suspended loads.



CLADOCORA ARBUSCULA



MANICINA AREOLATA

high, a decrease in growth rate may occur. At the extreme, if sediment continues to settle on a coral faster than it can be removed, the coral will be buried and may ultimately die. Suspended solids may also reduce light penetration, resulting in decreased photosynthesis by zooxanthellae and subsequently decreased growth in the coral.

Results of the present suspended sediment experiments do not support the hypothesis that increased suspended sediment loads cause decreased growth rates in the species tested under laboratory conditions.

Some coral specimens experienced a weight loss during one or more of the experiments. This happened in both control and experimental treatments but was more common in the latter. An assumption of the buoyant weight technique is that the weight of a coral in seawater is due entirely to the aragonite skeleton, with all soft tissues having the same density as the seawater. Therefore, weight loss should only occur with loss of skeleton. Special care was taken in handling specimens to prevent chipping of the base or damage to the living portion of the coral. Skeletal loss may have occurred in some specimens through the activity of boring organisms such as polychaetes, bivalves, and sponges. Dodge et al. (1984) recommends collecting the residue produced by borers and weighing it along with the corals. This was not possible in the present situation, due to the accumulation of sediment around corals in the experimental treatment. Another possible mechanism of weight loss may be related to the sediment accumulation around the base of corals in the experimental treatment. This sediment accumulated to depths of 12mm around the base of some corals and became anaerobic (based upon black color) below 2-3mm from the surface. The chemical conditions within this anaerobic sediment may have caused dissolution of a portion of the coral base. A third possible contributor to weight loss may have been cryptic non-boring invertebrates associated with the corals. Animals such as shrimp, echinoderms, and amphipods were discovered on some corals (especially Cladocora arbuscula), and may have left the host or switched hosts during experiments. Attempts were made to limit these associated animals as much as possible; further, the mass of the animals that escaped detection was unlikely to be large enough to account for observed weight losses. In any event, there is no reason to suspect that boring organisms or associated fauna were more abundant on experimental corals than on control corals, since test animals were selected at random and assigned to treatments.

Some anomalous growth rates, such as those reported for Phyllangia americana (Table 4), were likely due to the small size of specimens used. This species was difficult to collect in large monospecific colonies and as a result some small individuals (less than 2g) were used in the first two experiments. Small corals tend to exaggerate the experimental error incurred in weighing when the data are normalized.

The experimental error associated with the buoyant weight method was determined in two ways. First, the same specimen was weighed three times and variations were noted. This was performed with five different specimens: the largest variation observed was 0.6mg/g. The second method of determining experimental error involved weighing the same specimens three days apart, and subtracting the expected amount of (determined from separate weighings of control corals) growth from any observed change in weight. The remainder represents experimental error. Forty-five specimens from SSE III, Phase II were weighed and then reweighed three days later with an average weight change of 0.218mg/g/day. The expected growth was determined from the average growth rates of all control treatment corals (105 measurements on seven species), and was determined to be 0.345mg/g/day (Table 2). The difference between these two, ± O.l27mg/g/day, represents the estimated experimental error in weighing.

2. Burial Experiments

Six burial experiments were undertaken in which coral and sponge specimens were completely covered with natural Gulf sediment and left for various lengths of time. Not all species of corals were used in each experiment. The survival rates for individual species of corals are presented in Figures 11-14. A standard time-response curve was constructed for each species that exhibited any mortality during burial tests and the LT_{50} was calculated from this curve. The LT_{50} represents the burial time necessary to kill half of the experimental organisms and is presented for each species tested in Table 8. Scolymia lacera and Isophyllia sinuosa had the lowest tolerance to burial with 50% mortality at about seven days. Solenastrea hyades and the sponge Cinachyra apion were most resistant to burial with 100% survival after 15 days burial (the longest burial period).

Many coral specimens tested in burial experiments suffered sublethal damage that was expressed as color loss, soft tissue damage, invasion by algae, or reduced feeding activity in recovery aquaria. Each specimen was examined seven days after being disinterred and if still alive, considered to have survived the experiment. Holding these specimens in recovery aquaria for longer periods of time would likely have resulted in additional mortality therefore, the LT_{50} values reported in Table 8 should be considered as preliminary estimates.

B. Field Studies

1. Distribution and Ecological Observations

No quantitative measurements were attempted of coral abundance at either of the reef areas visited. The following accounts are therefore based upon qualitative diver observations and field notes recorded after each dive. Based upon assessment of typical conditions, coral and sponge species were classified as abundant (five or more specimens per square meter), common (one to four specimens per square meter) or rare (less than one specimen per square meter). Coral sizes are based upon random field measurements.

a) Scleractinian Corals

Stephanocoenia michelinii.

This species was encountered on both the 15m and 26m reefs. Its abundance was characterized as common on both reefs. The largest specimen extended 7cm above the substratum and several colonies were estimated to be 10-20cm in diameter. This species grew in flattened hemispherical colonies at both depths and was encountered throughout the reef plateau. Stephanocoenia has been previously reported from Sarasota (Smith, 1976), West Indies, Bahamas, Florida, and Bermuda

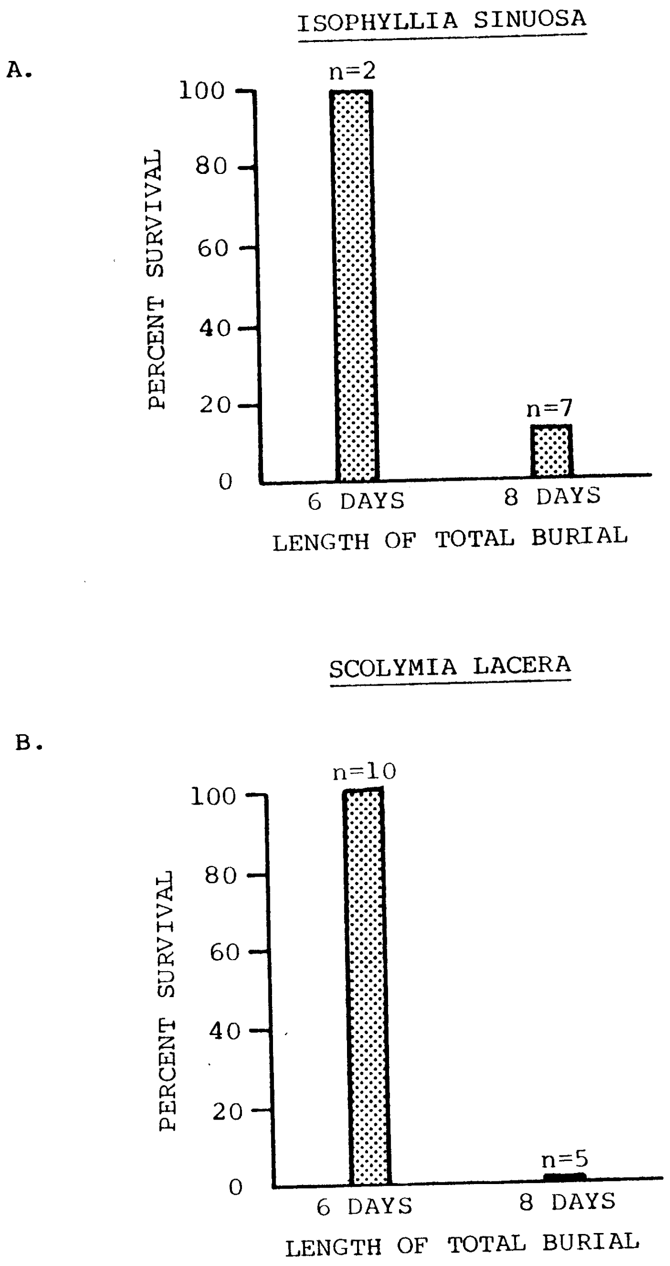


Figure 11. Survival rates following complete burial for increasing periods of time for *Isophyllia sinuosa* (A) and *Scolymia lacera* (B)

Figure 12. Survival rates following complete burial for increasing periods of time for *Manicina areolata*.

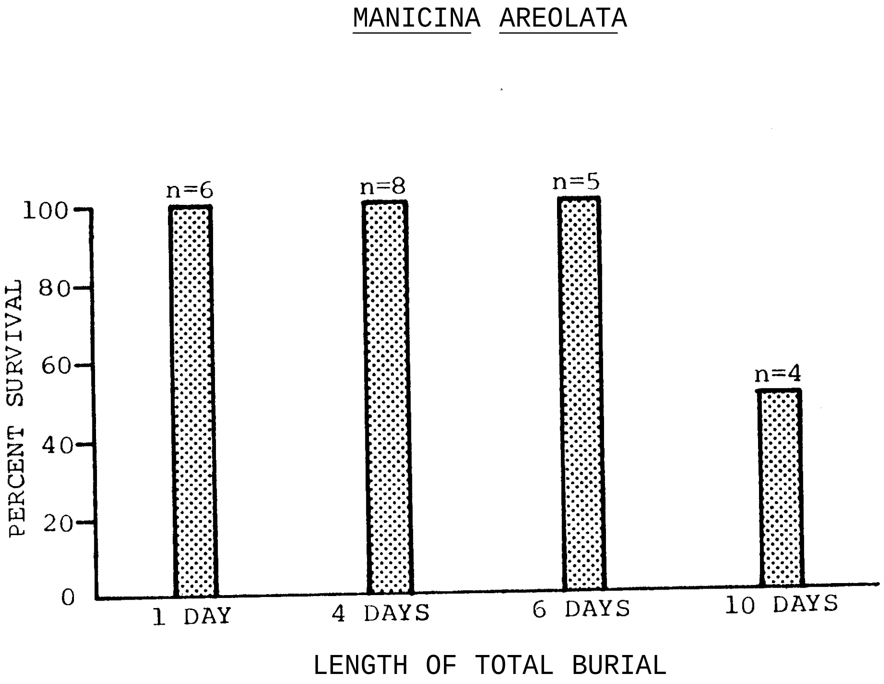


Figure 13. Survival rates following complete burial for increasing periods of **time** for _Siderastrea radians_ (A) and _Stephanocoenia michelinii_ (B).

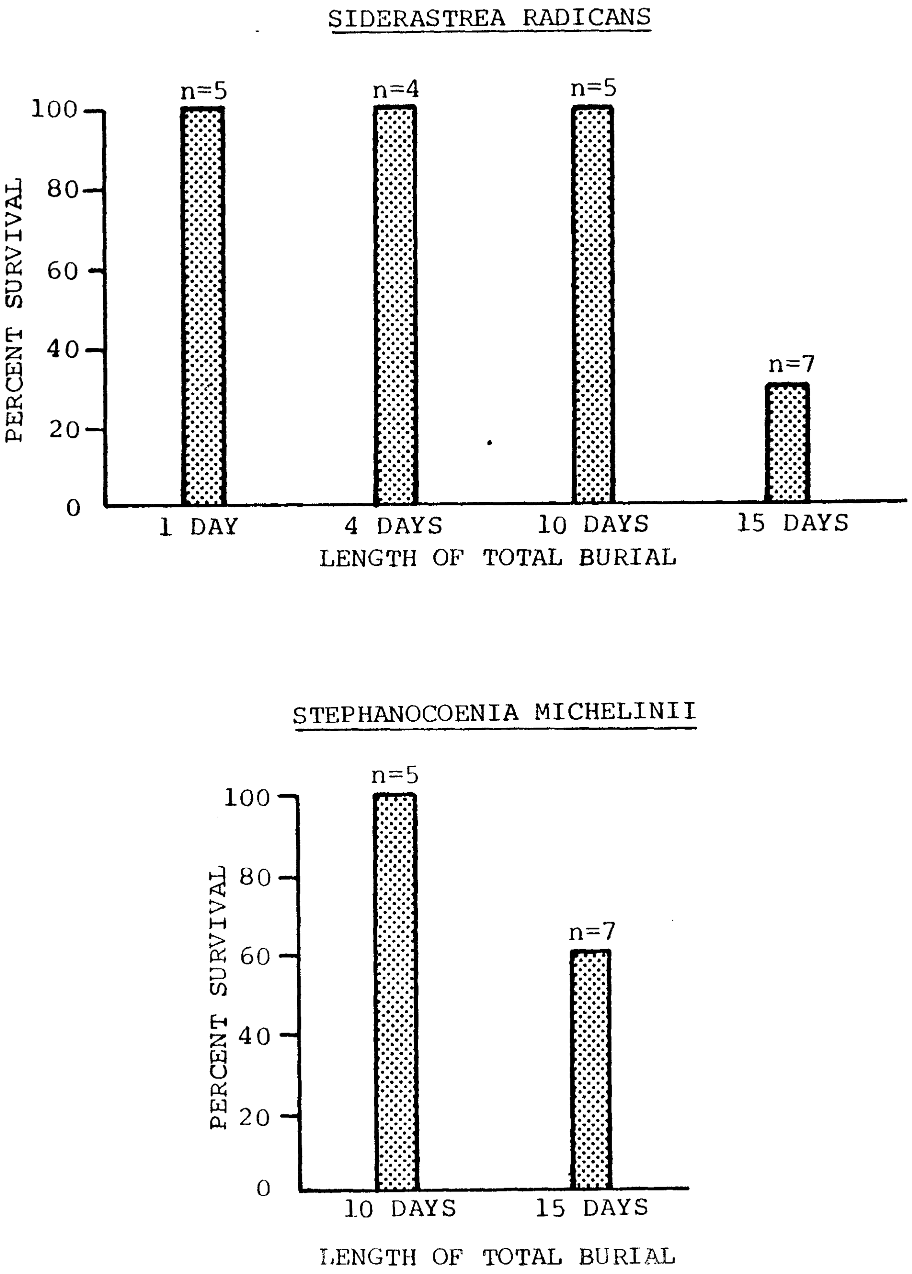


Figure 14. Survival rates following complete burial for increasing periods of time for Solenastrea hyades (A) and Cladocora arbuscula (B).

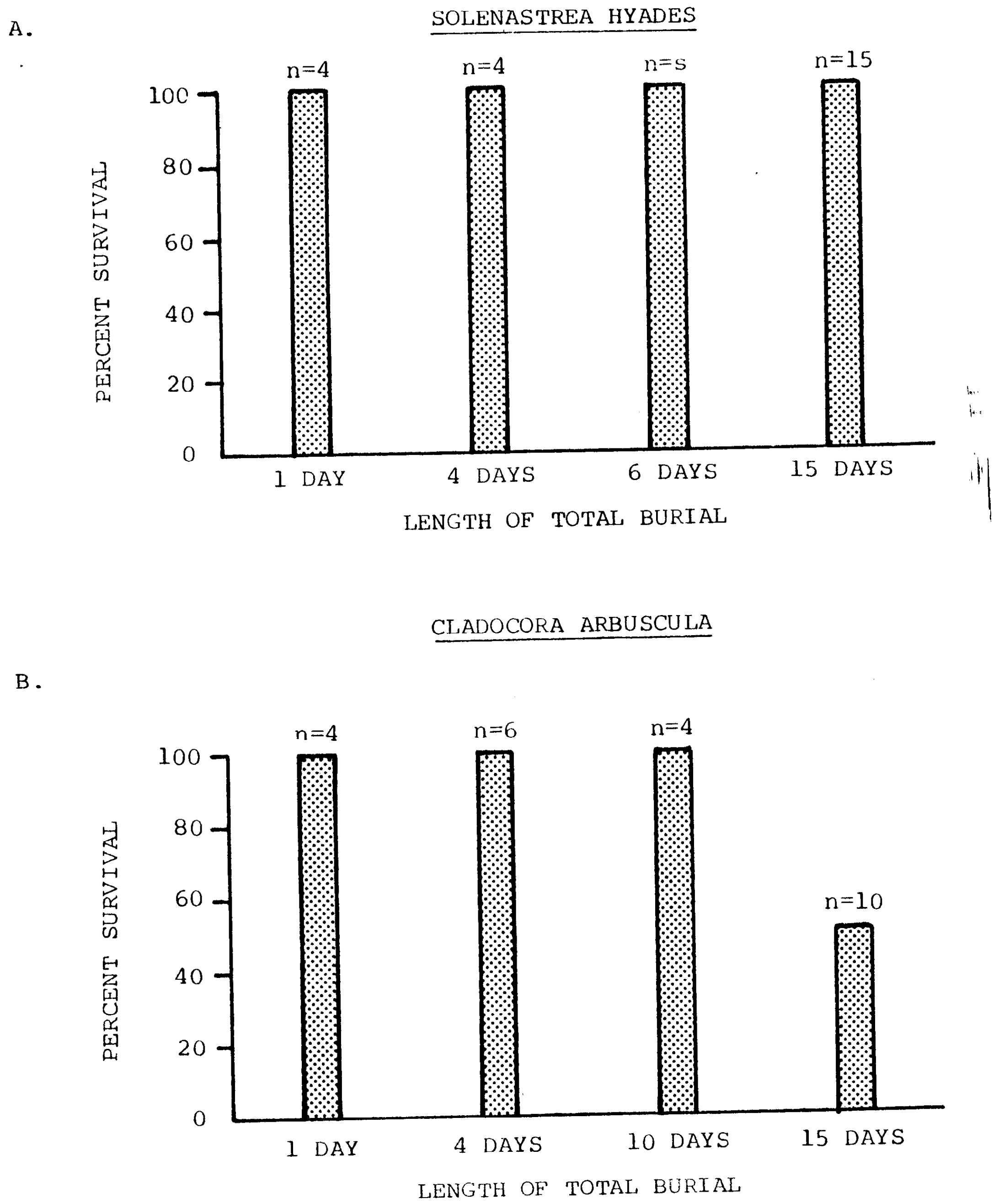


Table 8. Coral and sponge burial results expressed as estimated LT_{50} (burial time necessary to kill half of the experimental animals).

Species	LT_{50}
Scolymia lacera	7 days
Isophyllia sinuosa	7.2 days
Manicina areolata	10 days
Siderastrea radians	13.6 days
Cladocora arbuscula	15 days
Stephanocoenia michelinii	16.2 days
Solenastrea hyades	>15 days
Cinachyra apion	>15 days

(Smith, 1971), and Belize (Cairns, 1982). This species is similar to *Siderastrea* radians in appearance, and easily confused with the latter in the field.

Siderastrea radians and *Siderastrea siderea*.

These two closely related species were encountered on both reef areas and were virtually impossible to tell apart in the field. Based upon the specimens collected and subsequently identified in the laboratory, S. radians was more abundant than *S. siderea.* Taken collectively, *Siderastrea* spp. were characterized as abundant on the 15m reef and common on the 26m reef. The largest colony measured was 6cm high and hemispherical in shape. The average size of colonies (*S. radians* and *S. siderea*) on the 15m reef was 2.4cm in height (Table 9). Colonies were distributed throughout the reef plateau at both study sites. Previous records include: *S. radians:* Bermuda, Florida, Bahamas, West Indies, South America (Smith, 1971); Bahamas (Storr, 1964, Squires, 1958): Belize (Cairns, 1982); tropical western Atlantic and eastern Atlantic (Colin, 1978). *S. siderea*: Sarasota (Smith, 1976); Florida, West Indies, Bahamas, Bermuda (Smith, 1971); Bahamas (Squires, 1958); Caribbean, Bahamas, northern Gulf of Mexico, southern Florida, Bermuda (Colin, 1978); Bahamas (Storr, 1964).

Phyllanqia americana.

This ahermatypic species was collected from both the 15m and 26m reef areas, and was most abundant near the edge of the reef along the upper portions of undercut ledges. In these specific areas, the density of *Phyllanqia* was characterized as abundant, with far fewer specimens encountered on the reef plateau. Most individuals and colonies were small encrusting forms that were difficult to detach from the substratum. This species has been reported from Puerto Rico (Almy and Carrion-Torres, 1963); eastern Gulf of Mexico (Cairns, 1977); southern Florida to the southern Caribbean (Colin, 1978); eastern Gulf of Mexico (Collard and D'Asaro, 1973); Belize (Cairns, 1982); Curacao and Bonaire (Roos, 1971).

Scolymia lacera.

This hermatypic species was encountered on both the 15m and 26m reefs and occurred as solitary individuals. Densities were considered to be common on the 26m reef and rare on the 15m reef, with most individuals observed on the reef plateau. Coloration was variable from light brown to dark green, and a wide range of sizes were observed on the 26m reef. The average vertical height of individuals was 2.6cm although only a small number were measured in the field (Table 9). *Scolymia* was the most aggressive hard coral collected and was observed to attack nearby colonies of *Solenastrea hyades* in the laboratory by extension of mesenterial filaments. *Scolymia* was never observed in the field to be growing in close proximity to other coral species. This species has been reported from Sarasota (Smith, 1976); Curacao, Bonaire, Cuba, Hispanola, Puerto Rico, Los Roques (Netherlands Antilles), West Indies (Roos, 1971); Florida Middlegrounds (Hopkins et al., 1977); Belize (Cairns, 1982); Atlantic Ocean and Caribbean (Smith, 1982); Caribbean, Bahamas, southern Florida and Bermuda (Colin, 1978).

Isophyllia sinuosa.

This hermatypic species was observed on both the 15m and 26m reefs. Its distribution and abundance were similar to *Scolymia lacera*, with more specimens encountered on the 26m reef than on the 15m reef. Densities were considered to be rare on both reefs, with most colonies encountered on the reef plateau. Coloration was brilliant on most specimens and varied from light green to dark green. Several specimens had commensal polychaetes (*Polydora* spp.) protruding through the top of the colonies. Vertical heights of colonies were not measured in the field but specimens collected for laboratory tests ranged in weight (in air) from about 14g to over 100g. Previous records of this species include: Curacao, Bonaire, St.Martin, Bermuda, Florida, Puerto Rico, West Indies (Roos, 1971); Puerto Rico (Almy and Carrion-Torres, 1963); Sarasota (Smith, 1976); Bimini (Squires, 1958); Florida (Smith, 1948); Belize (Cairns, 1982); Caribbean, Bermuda, Bahamas, southern Florida (Colin, 1978).

Manicina areolata.

This hermatypic species was encountered on both the 15m and 26m reefs, with more specimens observed on the deeper reef. Densities were considered to be generally rare, with most specimens present on the reef plateau. Vertical size of colonies was measured on both reefs, with average heights of 3.1cm and 3.8cm on the shallow and deep reef, respectively. Vertical height ranged from 1 to 10cm for this species, with some specimens estimated to exceed 30cm in diameter on the 26m reef. Colin (1978) reported that this species may occur as an unattached colony in sandy lagoon habitats; however, all specimens encountered in the present study were firmly attached to the substratum. Coloration varied from light brown to dark brown to light green. Some Manicina colonies had commensal boring polychaetes (Polydora websteri) within the colony. Previous records of this species include: tropical western Atlantic, except Bermuda (Colin, 1978); Aruba, Curacao, Bonaire, St. Martin, Bermuda, Florida, Hispaniola, Puerto Rico, Barbuda, Martinique, Los Roques, Antilles (Roos, 1971); Puerto Rico (Almy and Carrion-Torres, 1963); Florida Middlegrounds (Hopkins et al., 1977); Bahamas (Storr, 1964); Sarasota (Smith, 1976); Bimini (Squires, 1958); Florida, Bahamas, West Indies (Smith, 1948): Belize (Cairns, 1982).

Cladocora arbuscula.

This hermatypic species is one of the most common hard corals encountered on west central Florida reefs. It was present on both reefs visited in the present study, with densities considered to be abundant on the 26m reef and common on the 15m reef. The author has encountered this species on patch reefs and artificial reefs in depths from 5m to 45m. The vertical height of colonies was measured on both reefs, with average heights recorded as 2.8cm on the 15m reef and 7.6cm on the 26m reef (Table 9). Cladocora colonies harbored numerous associated fauna, including amphipods, snapping shrimp, sponges, polychaetes, and brittle stars. Colonies were present on both reef areas throughout the reef plateaus and on the extreme edges of the reefs. Densities were highest near the edge of the reefs. Previous records of this species include: Florida Middlegrounds (Hopkins et al., 1977); Puerto Rico (Almy and Carrion-Torres, 1963); St. Martin, Florida, St. Kitts (Roos, 1971); Sarasota (Smith, 1976); Florida, Bahamas, West Indies (Smith, 1948); Caribbean, Bahamas, southern Florida (Colin, 1978); Belize (Cairns, 1982): Jamaica (Wells, 1973).

Solenastrea hyades.

This hermatypic species is one of the most common hard corals, along with Cladocora, encountered in the study area. It was collected from both the 15m and 26m reefs, and was considered to be abundant on both reefs. This species forms the most massive colonies of any species used in the present experiments. Average vertical height of colonies was determined to be 6.0cm on the 15m reef, and 4.9cm on the 26m reef. The largest colony measured was 20cm high, and was located on the 15m reef. Solenastrea colonies were most common on the reef plateau. Previous records of this species include: Sarasota (Smith, 1976); Florida, Bahamas, West Indies (Smith, 1948); Jamaica (Rylaarsdam, 1981; Wells, 1973).

b) Sponges

Numerous species of sponges are known from the eastern Gulf of Mexico, although the present state of completed systematic studies is somewhat primitive (Hopkins et al., 1977). Many species observed at the present study sites appear to be restricted to hard substrata while a small number of species are found on soft as well as hard substrata. The species selected for laboratory testing in the present study was chosen because of its relatively high abundance on both reefs and because it is a perennial species. Samples of this species were sent to Dr. Klaus Ruetzler of the Smithsonian Institution, Washington, D.C. for identification and have been tentatively identified as Cinachyra apion. This genus of sponges is presently being revised by Dr. Ruetzler and his colleagues.

Cinachyra apion.

This "orange softball" sponge was encountered on both reefs and was common to abundant in both areas. The shape and growth pattern of this species made collection easy, since a knife blade could be inserted beneath the sponge and the animal sliced free of the substratum with little effort. The abundance and ease of collection

Table 9. Vertical height above the substratum of Gulf of Mexico hard corals from two different reefs.

Species	Reef Area (depth in m)	Average Height (cm)	Range (cm)	Number Measured	Standard Deviation
Manicina areolata	15	3.1	1-7	16	1.5
	26	3.8	2-10	14	2.0
Cladocora arbuscula	15	2.8	1-6	16	1.5
	26	7.6	4-11	20	2.4
Solenastrea hyades	15	6.0	2-20	17	4.5
	26	4.9	4-7	8	1.2
Scolymia lacera	26	2.6	2.5-3	4	0.3
Siderastrea spp.	15	2.4	1-5	14	1.2
	26	4.5	3-6	2	2.1
Stephanocoenia michelinii	15	4.6	3-7	4	1.8

of this species were responsible for its selection for study. Cinachyra is closely related to the genus Craniella, and the two are difficult to distinguish. Samples of our specimens have been sent to sponge experts for confirmation of identification. Specimens used in laboratory experiments were 2-4cm in diameter, however, individuals up to 15cm diameter have been encountered in the field. Previous records of this species include: Florida Middlegrounds (Hopkins et al., 1977); Virgin Islands (Wiedenmayer, 1977); Florida Keys, Caribbean (Vicente, 1982).

2. Coral Height Measurements In Situ

A program of coral measurements was initiated in order to document the average vertical height above the substratum of dominant species on the two reefs sampled. Six species were measured at random and averaged separately for the two reef areas. The results of these measurements are presented in Table 9. The tallest coral colony measured was one of Solenastrea hyades that extended 20cm above the substratum. The largest average height (7.6cm) was that of Cladocora arbuscula at the deeper reef and the smallest average height (2.4cm) was that of Siderastrea spp. at the shallow reef. It would be desirable to obtain measurements of additional coral specimens on a larger variety of reefs before any general trends become evident and before any predictions can be made regarding the effects of dredged material disposal. With an adequate sample size of coral heights and a quantitative estimate of sediment dispersal and accumulation, predictions may be possible concerning the extent of effects and the most likely species to be affected by disposal operations.

3. Suspended Solids Measurements

Nineteen water samples were collected from the Gulf of Mexico between March and July 1984 for analyses of suspended solids loads. Sampling stations ranged from 1 to 17nmi offshore, and results of analyses are presented in Table 10. The highest suspended solids load measured was 37.6mg/l at a station 1nmi offshore. Samples from the vicinity of Site 4 contained 22.8mg/l and 7.4mg/l total suspended solids. All of the values reported in Table 10 represent relatively calm water loads, and all represent predisposal conditions. A more'

Table 10. Total suspended solids in water samples collected from the Gulf of Mexico.

Date Collected	Sample Site	Water Depth (m)	Total Suspended Solids (mg/l)
3/13/84	1 nmi off Sarasota	7	37.6
	4 nmi off Sarasota	11	34.6
	7 nmi off Sarasota	12	36.6
	10 nmi off Sarasota	13	34.2
4/11/84	1 nmi off Sarasota	7	34.2
	4 nmi off Sarasota	11	16.2
	7 nmi off Sarasota	12	8.2
	10 nmi off Sarasota	13	11.4
4/20/84	Site 4 (Station 4-28)	24	22.8
4/25/84	1 nmi off Sarasota	7	19.8
	4 nmi off Sarasota	11	12.0
	7 nmi off Sarasota	12	15.0
	10 nmi off Sarasota	13	9.2
5/11/84	1 nmi off Sarasota	7	12.0
	4 nmi off Sarasota	11	9.6
	7 nmi off Sarasota	12	8.9
	10 nmi off Sarasota	13	10.4
5/11/84	Barricuda Hole	15	26.2
6/08/84	5 nmi S of Site 4	26	7.37

extensive series of measurements is desirable in order to ascertain the maximum and annual average loads that corals and sponges might be exposed to under natural conditions. This information would also be important for interpretation of the experimental results from the present suspended sediment bioassays.

C. Discussion

Results of field studies on coral distributions have indicated a negative correlation between suspended sediment loads and hard coral abundance. Mayer (1918) found that hard corals on Murray Island reefs were distributed in accordance with certain environmental factors; only corals that were tolerant to higher temperatures and turbid water were found near shore. He found *Siderastrea* radians to be among the most resistant corals tested, and able to survive total burial for more than 73 hours. Edmondson (1928) tested the resistance of Hawaiian corals to siltation and burial in the laboratory, and found that tolerance ranged from 12 hours to 10 days between species. He did not test any of the species or genera used in the present studies. Marshall and Orr (1931) conducted field and laboratory studies on the effects of siltation and burial upon Australian corals, and concluded that branching colonies or those with large polyps were best able to clean themselves. They also observed in field tests that water currents helped to facilitate sediment removal from living corals. In general, Marshall and Orr (1931) found the genera *Favia* and *Fungia* to be most capable of sediment removal, while *Porites* was the least efficient in sediment removal among the species they tested.

Detailed studies by Hubbard and Pocock (1972) on coral morphology and behavior revealed clues to environmental distribution patterns relative to sediment removal abilities in 26 coral species. They described four means of sediment removal by corals, including: 1) distension by water uptake, 2) tentacular activity, 3) ciliary activity, and 4) mucus entanglement. Their observations indicated that coral species vary considerably in their efficiency of sediment removal, and that many species are size-specific sediment rejectors. Several species tested in the present studies were also tested by Hubbard and Pocock (1972, pg. 604). These authors found *Solenastrea* hyades to be a poor sediment rejector, while the following species are listed in order of increasing sediment rejection efficiency: Cladocora arbuscula, Siderastrea siderea, Manicina areolata, and Isophyllia sinuosa. The efficiency of sediment rejection (rate of sediment removal) measured by Hubbard and Pocock (1972) should not be equated with tolerance of a species to sediment loads, since the present studies indicate that Cladocora arbuscula was among the most tolerant species, based upon burial and suspended sediment studies, while Isophyllia sinuosa was the least tolerant to these conditions.

Roy and Smith (1971) compared two habitats on Fanning Island in the Pacific Ocean that differed in water clarity and suspended sediment loads. They measured suspended loads in open ocean (0.03mg/l), clear lagoon water (1.0mg/l) and turbid lagoon water (3.5mg/l). Their results on coral distribution showed that only four coral species recorded in clear lagoon settings were absent from turbid lagoon reefs, and that the same coral species often displayed different growth forms between the two habitats. In addition, they found that live corals covered 62% of the bottom in clear water lagoon areas and 31% in turbid lagoon habitats.

Dodge et al. (1974) tested the hypothesis that constant energy expenditure for sediment removal might decrease coral growth rates. They measured growth of Montastrea annularis colonies from two habitats in Jamaica that differed in the degree of natural sediment resuspension. Analysis of results revealed a definite negative correlation between resuspended sediment loads and coral growth.

The emerging trends from the above field and laboratory studies indicate that many coral species can tolerate natural sediment suspended loads and burial for relatively short periods of time (i.e., the duration of most laboratory tests) but that long-term exposure to suspended sediment can cause reduced coral growth and reduced reef development (as implied from field distribution studies and measured in quantitative field growth studies).

The effects of sediment resuspension on coral reefs as a result of anthropogenic activities have been well documented. Reviews of dredging, filling, dredged material disposal and mining effects upon coral reefs are presented by Levin (1970) and Endean (1976). Bak (1978) and Courtenay et al. (1974) have provided additional studies on the effects of dredging turbidity upon coral reef communities. Widespread destruction of reefs due to these activities has been recorded in Bermuda; Johnston Island; St. Thomas, V.I.; Okinawa; and Magnetic Island, Queensland. The addition of complicating factors such as toxic pollutants in sediments can significantly aggravate effects on corals. Endean (1976) reviewed many of these situations, including the effects of land clearance, nuclear weapons testing, sewage pollution, thermal pollution, desalination effluents, Oil pollution, and chemical pollution on coral reef habitats.

One of the most widely studied complex effluents has been used drilling muds from petroleum exploration and production rigs. Experiments using corals exposed to various concentrations of drilling muds in the field and laboratory has revealed significant effects upon survival (Thompson and Bright, 1980; Hudson, Shinn and Robbin, 1982; Rogers, 1983), behavior (Thompson and Bright, 1980), growth (Hudson and Robbin, 1980; Hudson, Shinn and Robbin, 1982; Dodge, 1982: Kendall et al., 1983) and physiology (Krone and Biggs, 1980; Kendall et al., 1983; Szmant-Froelich, 1983).

In the present studies, only natural uncontaminated sediments were employed in laboratory tests. The species of hard corals inhabiting reefs off the west central portion of Florida appear to be among the most tolerant species tested with regard to suspended sediment and burial effects. Species that can withstand continuous exposure to 150-200mg/l of suspended sediment for 20 days with no mortality and no significant reduction in growth rate must be adapted to living in turbid waters. No literature reports were found that suggested that any coral specimen could survive total burial for more than 10 days, and most species previously tested could not tolerate much more than two days of burial. For the corals tested in the present studies, the shortest burial LT_{50} was seven days, with three species greater than or equal to fifteen days.

The natural distribution of corals can give a good indication of general tolerance of a species to environmental factors. Many of the corals inhabiting patch reef communities off west central Florida have been found to occupy the least favorable habitats in more tropical settings such as lagoons and near-shore reefs (Colin, 1978; Griffin, 1974). Some species have even been recorded to occur as unattached colonies in lagoon habitats: and Hubbard and Pocock (1972) reported that *Manicina areolata* and *Isophyllia sinuosa* had the ability to right themselves if turned upside down in the sediment.

Compared to more tropical habitats, the patch reefs off west central Florida are exposed to more severe environmental conditions, such as low winter water temperatures, turbid water, and shallower light penetration. It is not suprising that the most tolerant species inhabit these areas, but alternatively, it may be that these species are living near their physiological tolerance limits of environmental conditions and may be more sensitive to additional prolonged adverse conditions *(i.e.* chronic siltation stress) than their tropical congeners. Laboratory tests conducted during the present study were intended to simulate environmentally advantageous conditions for coral survival and growth with regard to temperature, salinity, food availability, and light levels. Additional testing at lower temperatures or lower light levels may result in more stressful conditions for the corals.

IV. CONCLUSIONS

Thirteen species of hard corals were identified from patch reefs off west central Florida. Of these, eight species were exposed to high levels of suspended sediment in the laboratory and seven species were exposed to prolonged burial. The results of these experiments indicate that the species tested are among the most resistant corals in the Caribbean region to the effects of suspended sediment and physical burial. These findings are consistent with the fact that west central Florida patch reefs are exposed to more severe environmental conditions, such as cold water, high turbidity, and low light penetration during winter months, than more tropical reefs to the south. The species composition of patch reef corals is likely governed by the tolerance of individual species to the local environmental conditions.

Laboratory experiments conducted during the present study were carried out under controlled conditions intended to simulate favorable environmental levels of light penetration, food availability, salinity, and temperature. The response of these same corals might be different at temperature, light, and food levels characteristic of winter conditions. In addition, the maximum duration of laboratory suspended sediment experiments (20 days) may not have been long enough to demonstrate chronic effects.

The parameters quantitatively measured in laboratory experiments (survival and growth rates) were adequate for assessing potential acute and chronic effects under the exposure conditions tested.

In general, the conclusions that can be drawn from the present laboratory experiments include:

1. Survival rates of the coral and sponge species tested were not affected by continuous exposure to an average suspended sediment load of 49, 101, 165, and 199mg/l for 10 days.

2. Growth rates of the coral species tested were not significantly different between control and experimental treatments after exposure to 49, 101, and 199mg/l for 10 days.

3. The average coral growth rate for seven species exposed to 165mg/l suspended sediment load for 10 days was significantly different in control and experimental treatments.

4. The average coral growth rate under laboratory conditions was determined to be 0.35mg/g body weight/day based upon control treatments for seven species (n=105).

5. Total burial of corals under natural sediment was lethal to most species. The estimated LT_{50} values (burial time necessary to kill half the specimens) ranged from 7 days to greater than 15 days. One coral and one sponge species experienced no mortality after 15 days burial.

6. One species of coral, *Siderastrea radians*, did not survive well in the laboratory even under controlled conditions. Two species, *Cladocora arbuscula* and *Solenastrea hyades*, adapted very well to laboratory conditions and produced the highest growth rates of the species tested.

7. Sublethal effects, expressed as loss of color and partial tissue death, were observed in survivors of burial experiments and in some specimens exposed to suspended sediment.

The present studies have produced some important information concerning the potential effects of suspended solids and burial on patch reef hard corals and sponges. This report also provides detailed procedures for collection, handling, and experimental design that can be useful for future studies. This project was not intended to provide a definitive predictive scheme for determining the short or long-term effects of suspended sediment or burial upon patch reef communities. These predictive capabilities can only come from a combination of additional laboratory studies and coordinated field activities.

V. RECOMMENDATIONS

The following recommendations are offered as a means for improving upon the laboratory procedures described herein and for designing future studies aimed at obtaining the goal of predictive ability.

1. Longer term laboratory survival and growth rate studies under constant and fluctuating suspended sediment loads should be attempted. The growth studies should include at least two weeks of pretreatment growth measurements on each coral, followed by weekly measurements on control and experimental treatments for at least 60 days.
2. Coral growth studies, as described above, should be undertaken at temperature and light levels characteristic of both summer and winter.
3. Coral species that were not tested or only partially tested in the present studies, as well as additional sponge species, should be included in future survival and growth experiments. Additional coral species suggested for testing include *Porites porites* and *Phyllangia americana*.
4. The most reliable and representative coral species from the present studies that are recommended for further testing are: *Cladocora arbuscula*, *Solenastrea hyades*, *Stephanocoenia michelinii*, *Manicina areolata*, and *Scolymia lacera*.
5. Additional burial experiments should be undertaken using additional coral and sponge species, and at least two different temperature regimes.
6. Laboratory suspended sediment and burial experiments should be undertaken using dredged material recovered from Site 4.
7. Suspended sediment loads in near-bottom water should be determined at Site 4 during actual disposal operations. An average suspended sediment load for several stations at various distances from the disposal point, and a maximum value from the disposal plume, would be useful for interpretation of laboratory exposure levels.

8. Sublethal measures of stress should be tested and incorporated into future studies. Possible parameters might include quantification of polyp bleaching, and measurements of coral oxygen consumption.
9. Additional assessments for establishing background data on patch reef populations near the disposal site should be undertaken, including coral density measurements, and coral height measurements for each species.
10. Field tests should be attempted to assess the impact of burial under natural conditions upon selected portions of existing reefs. These studies should employ natural sediment as well as dredged material.

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Appendix - Plates

Information available upon request from Mote Marine Laboratory Library.