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Coral Reefs

The Microcosm: A New Tool for Reef Research

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Summary. A microcosm has been developed at the Smithsonian Institution which closely simulates the functions of the shallow water Caribbean coral reef. Physical and chemical parameters, as well as the structure of the biological community, are briefly described and compared to a natural reef. The possibilities of the microcosm as a tool augmenting in situ research are briefly discussed.

Introduction

In recent decades there has been a growing interest in the possibility of using microcosms as tools to study marine systems (e.g., Dane 1979; Mann 1979). Oviatt et al. (1979) summed up this interest in stating:

> The natural system is too unwieldly for experimentation, and mathematical formulation(s) which permit self-design characteristics in simulation models are unknown... Microcosms are easily manipulated under controlled conditions yet retain much of the complexity of the real system which is not yet incorporated into computer simulation models. As such, microcosms become a powerful tool for investigation of the effects of perturbations, operating singly and in combination, of the ecosystems the microcosms miniaturize.

Microcosms or microecosystems have ranged in size from large plastic spheres blocking out discrete volumes of water in the open ocean to flasks in the laboratory (e.g., Abbott 1966; Antia et al. 1963; Ulanowicz et al. 1978; Perez et al. 1977). These may be open systems in which water is pumped constantly from the sea, or closed, in which the water is continuously recycled within the system containing representative samples of the environment for study and manipulation (Odum and Hoskin 1953).

Most scientists accept the statement that reefs are among the most complex of ecosystems; some would agree with Bradbury (1977) that "[c]oral reefs, perhaps together with rain forests, form a class of complex ecosystems which are neither qualitative or even quantitative extensions of simpler communities. They are systems of a higher order..." This complexity makes the study of reef biology both valuable and difficult, and until recently, its pursuit in the laboratory was severely circumscribed. Some very limited attempts have been made to develop conceptual models for reef systems (e.g., Lewis 1977; Sorokin 1974; Di Salvo 1972) but these have generally been considered inadequate, and, beyond the abortive efforts of the IDOE/CITRE group (Smith 1972), no serious effort has been made to develop a systems model for a reef. There has been only a single published attempt to develop a reef microcosm for research (Henderson et al. 1976) and that unit is intended to represent a reef flat under the simplest kind of reef conditions (Smith personal communication). Marine laboratory aquaria or wet tables usually support selected reef organisms. However, in no sense could these be called microcosms, for the purpose is to maintain specimens for research and practically none of the natural physical, chemical, or biological structure of the community is preserved.

In conjunction with an intensive field study, primarily on the Caribbean island of St. Croix, several microcosms have been constructed at the Smithsonian Institution that preserve to a large degree the complexity and function of a natural coral reef and its lagoon.

The Smithsonian Reef

This paper describes an 1800-gallon (seven kl) microcosm that has been in operation at the Smithsonian for about 5 years. This unit is the third of the prototype closed reef systems developed; it was followed by a somewhat larger model used for exhibit and research (Miller 1980; Walton 1980). The physical dimensions, arrangement and morphology are shown in Fig. 1. The shape and community structure have been scaled after a typical eastern Caribbean reef (Adey 1978; Adey and Steneck in Ms.), as have the light, wave energy and current conditions. The critical physical-chemical variables and their relationship to an actual reef on St. Croix, Virgin Islands are discussed below. The reef substructure contained within the Smithsonian microcosm has been built from dead carbonate material to simulate characteristic barrier reef configuration. This "reef" structure is deeper in the fore reef, crests near the

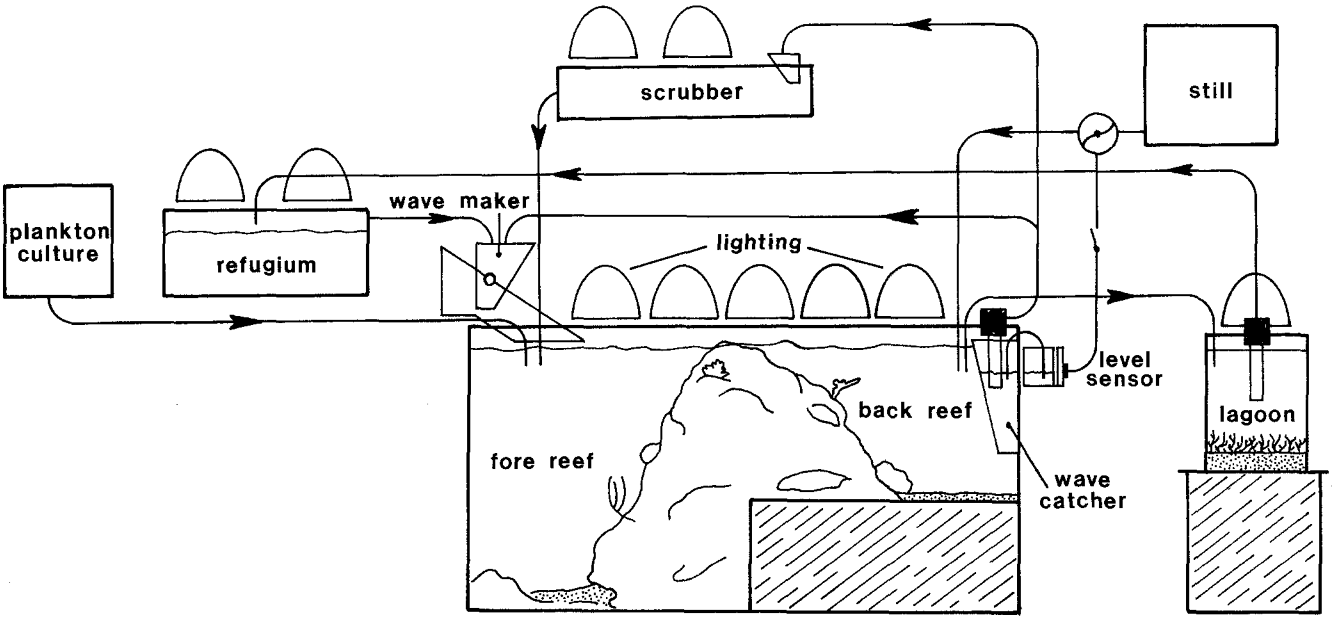

Fig. 1. Schematic diagram of the Smithsonian coral reef microcosm and its lagoon. The main reef tank is 3.7 in. long, 18 m high, and 1.2 m wide

water surface, and drops to a shallow sandy lagoon behind. The sandy back reef area develops the overgrazed and reworked aspect known as a reef halo (Ogden and Zieman 1977). The lagoon, physically isolated as a separate unit to simulate distance from the reef, allows controlled grazing and successful development of a lagoon community.

Living material for transplantation to this microcosm was collected in the field and returned to the laboratory by air in insulated containers containing aeration equipment, an operation that averages 6–10 h from ocean to tank. The water contained within the tank microcosm was initially prepared with artificial sea salts, but is gradually being mixed with natural sea water at a rate of about 4 l per day. The sea water used for exchange is obtained on the outer coast of Virginia; it is coarse-filtered, but otherwise untreated.

The wave action and current flow necessary for reef development is induced by centrifugal pumps that remove water from one end of the tank and deliver it to a "wave generator" at the other. The latter overturns every 25 s, spilling the contents into the tank. This flow, combined with that of several additional pumps which do not cycle through the wave generator, produce a mean current across the reef flat of from 2–4 cm/s. This is low compared to the mean flow rate of 10 cm/s found on the windward reef flats of St. Croix, but it is within the range of the more protected sections of that reef.

Wave reflection at the downstream end of the tank is prevented by a box-like "wave catcher", a separate reservoir containing the intakes for the pumps supplying the wave maker. As the water is pumped from this enclosure, the level drops, to be filled again as the wave rolls across the tank and spills into the open top. This mechanism is also a critical element in salinity control, since water level in the catcher is amplified in proportion to tank levels. The wide level of fluctuation in the catcher is smoothed by a small siphon/reservoir device as shown in Fig. 1, and the level monitored by an electronic capacitance sensor that activates a pump delivering distilled water to the tank. Approximately 80 l/day is evaporated from the system and since such large volumes of replacement water are required, high quality, de-ionized water is necessary. Detection and replacement of as little as 50–100 ml of evaporated water at one time is possible, maintaining salinity over a very narrow range on an hour-to-hour basis. Generally, it has been maintained at 35.0–36.0‰ to match eastern Caribbean reef water, although on occasion it has been allowed to fall as low as 34.5‰ or as high as 36.5‰ for several weeks.

The fluorescent illumination commonly used for culture work on both terrestrial and aquatic organisms, even the more sophisticated "full spectrum" lamps, cannot practically generate the intensity of natural solar radiation normally incident to shallow, tropical reef areas. Clear, metal-halide vapor lamps (General Electric and Sylvania) have proven satisfactory because of intensity and spectral quality. Eight 400-watt and two 1,000-watt lamps provide an irradiance over the 4.5 m^2 area of the reef tank, close to that measured in the field: in the back reef section of the microcoms light energy measures 500–900 $uE/m^2/s$, compared to 1,100 $uE/m^2/s$ recorded in the late spring at a depth of 1 m on the reef flat at St. Croix. To compensate for the slightly lower instantaneous energy, the light period has been extended to bring total light energy input to comparable levels in the microcosm (Table 1).

Lamps lighting the main reef tanks are controlled by five separate circuits and illumination periods vary for each. Activation of circuits is sequential, operating over a 2½-h period, simulating in step-like fashion the changing

Table 1. Comparisons between microcosm and St. Croix natural reef – yearly mean or range

	Microcosm	St. Croix Reef
O_2 concentration	5.5–6.2 mg/l 7.5–8.3 mg/l	(min.) 5.2–6.6 (max.) 7.4–9.3
GPP	32.5 g O_2/m^2/day (13 g C/m^2/day)	20–80 g O_2 (back) 18–20 g O_2 (fore)
Respiration	0.9 g O_2/m^2/day	2.6 g O_2 (back) 0.7 g O_2 (fore)
pH	8.2–8.3	No data
Nutrients (mg-at/l) (typical lower values)	NO_2^- 0.3 NO_3^2 0.9 PO_4 0.2 Ammonia 0.2	$NO_2^- = 0.1$ $NO_3^2 = 0.0$ $PO_4^2 = 0.09$ outflowing water – –
Light, reef flat (µE/m^2/day)	35.3 10^6 (14 h)	39.6 10^6

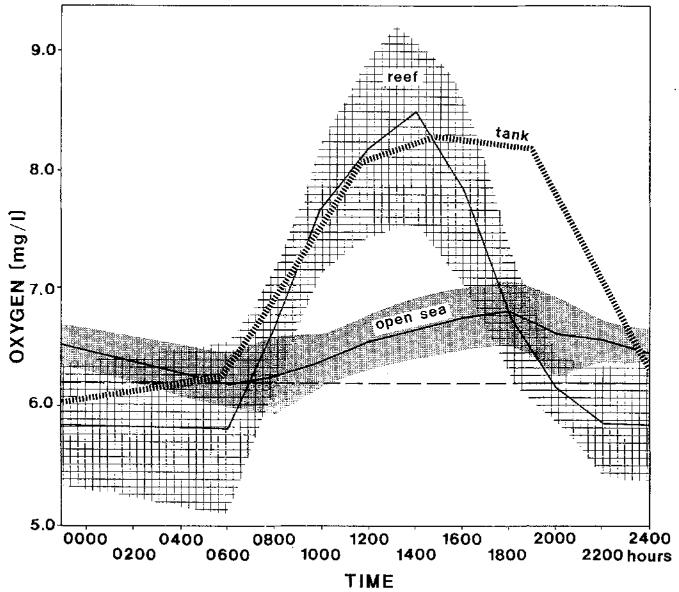

Fig. 2. Comparison of typical diurnal dissolved oxygen cycle in reef microcosm with that of water incoming and leaving a St. Croix reef (Adey and Steneck 1982). The *solid lines* for reef and open sea indicate mean values for three reef sites over four seasons. The *shaded area* shows the range for the two natural sites. The tank line is a typical diel plot of dissolved oxygen in the tank for a 10/4/10 light/transition/dark cycle. There is little day to day variation if flow rate and light number and cycle is kept constant

intensity of dawn and dusk. The crest area experiences the longest light period (14 h) and the deepest areas, the shortest (9.5 h), effectively increasing the depth scaling factor.

A summer-winter temperature cycle approximating that on St. Croix reefs is followed by adjusting the level of air conditioning in the tank room. Summer temperatures in the tank lie between 27–29 °C, and usually follow a daily range of less than 1–1.5 °C. Winter temperatures are generally kept between 25–27 °C, also with minimum daily range of less than 1.5 °C.

No bacterial ("biological") filtration, air bubbling or chemical conditioning is incorporated into this system, as is standard practice in other closed-system aquaria. During the daylight hours no such conditioning is needed as extensive photosynthesis on the reef surface renders ammonia unmeasurable by standard techniques and maintains oxygen at supersaturated levels. A device patented by the Smithsonian Institution, called an "algal turf scrubber" (see below), maintains water quality during the dark hours.

Chemical Factors

Dissolved oxygen concentrations, as measured on a Martek water quality analyzer, range from a minimum of about 5.5–6.2 mg/l to a maximum of 7.5–8.3 mg/l, a diurnal pattern close to that measured on a St. Croix reef flat (Adey and Steneck, in preparation) with moderate wave action (Fig. 2). Since this microcosm is a closed system and the reef is physically very short, use of the upstream-downstream method to monitor productivity is impracticable. The rate of change of oxygen concentration at saturation is measured to determine utilization at night and production during full illumination. This approach avoids the complex problem of oxygen exchange with the atmosphere and indicates a gross primary productivity of 32.5 g O_2/m^2/day (13 g C/m^2/day). This compares to 20–80 g O_2/m^2/day for back reefs and 18–20 g O_2/m^2/day for fore reefs as measured in St. Croix. Community respiration for the entire system is 0.9 g O_2/m^2/day. This compares to an average rate of 2.6 g O_2/m^2/day for St. Croix back reef zones, and 0.7 g O_2/m^2/h for the fore reef. These measurements were accomplished without the algal turf scrubber (described below) attached.

pH is monitored primarily as a measure of the state of the carbonate system, particularly the concentration of CO_2 in the tank water. The relationship between pH, photosynthesis and calcification, which in some degree affects all calcifying reef organisms, is critical in the microcosm. Detailed data on pH in a shallow water Caribbean reef environment are lacking. A normal range of 8.2 to 8.3 is indicated (Smith 1973), which is duplicated in the microcosm in accordance with a daily cycle that peaks about 1900 hours from a minimum at 0800 hours.

Nutrient levels in the tank vary considerably according to the import-export regime in effect, discussed in more detail below. The primary variables measured on a continuous flow analyzer are ammonia, nitrite, nitrate, and phosphate, which all show marked diurnal cycles when levels are relatively high. At low concentrations, only NO_3 shows a clear diurnal cycle, correlated with primary production. Average nutrient levels are recorded in Table 1; except for nitrate, these are above the average found at St. Croix, although within the upper limit there. Ammonia has a mean concentration in the tank of about 0.2 µg-at/l; however, comparable data are not available for the field.

During a period when import/export ratio was maintained at a figure greater than one (see below), NO_3 concentration remained at a constant 5 to 8 µg-at/l, increasing the export rate eventually drove this measurement to less than 1.0 µg-at/l (other measured nutrients being proportional). At this point when this decreasing concentration reached 2 µg-at/l, heterocysted blue-green algae, absent at higher levels, become important constituents in the algal turf community. Acetylene reduction analysis of this community shows a high rate of nitrogen fixation, presumably by the blue-greens. Nitrogen fixation cannot be detected in the turfs of the tank when nitrate concentrations reach 4 µg-at/l, although fixation has been recorded in refugium tank sediments up to a level of 5 µg-at/l (Brawley and Adey 1979).

Nutrient Cycle Manipulation

In the process of microcosm development, a system has been devised to regulate nutrients, pH, and oxygen. Primary productivity and biochemical parameters are controlled by a patented "algal turf scrubber", incorporated into the system as shown in Fig. 1. This is an instrument for the propagation of turf algae, exploiting their photosynthetic processes and grazing resistance to increase oxygen, raise pH and reduce excretory ammonia and nutrients. It functions as a microcosm of the main reef tank, but excludes significant secondary productivity. The reef surface is represented by plastic screens of about 2 mm mesh, where algal turfs quickly form. They are removed by scraping every 10–14 days, thus preventing establishment of animal grazers and maintaining the vigorous pionieer stages of the plant population (Brawley and Adey 1982). Regrowth is very rapid, as the plant bases remain in the screen interstices. At an average light intensity of 850 $\mu E/m^2/s$ for 18 h, 10–15 g dry weight/m^2 of scrubber surface is removed from the system via turf harvesting. Removal rate can be carefully controlled by adjusting light period. Variation in oxygen and pH levels is reduced by placing tank lighting and scrubber lighting on alternate timing.

Plankton supplied to a reef system from the open ocean can account for only a small part of the energy utilized there – the estimate for a St. Croix reef is less than 1% (Adey and Steneck, in preparation). Nevertheless, it is probably an important component for filter-feeding animals. Live brine shrimp and dried krill are added to the microcosm to simulate this input; approximately 0.5 g C/day is introduced by this means as compared to about 17 g C/m^2/day from the primary productivity.

Several additional small sanctuary or refugum tanks are placed in the circulation. It is hoped that due to reduced levels of predation on some species, that species diversity can be increased to levels equivalent to much larger areas under natural conditions. A number of plants and animals that cannot be currently kept in the main tank in any numbers due to predation function quite well in refugium tanks.

Biological Community

Seasonal sampling in the fore and back reef areas in St. Croix has produced between 35–50 benthic algal species. The reef microcosm contains at least 35 species at any one time (Table 2). Most of the important turf species are prominent in both places, but several differences have been found: *Smithsoniella subterranea* (Sears and Brawley 1982), which is abundant in the Smithsonian tank, is found only occasionally in St. Croix, while several important elements in the flora there (*Amphiroa fragilissima*, *Taenioma macrourum*, and *Asparagopsis taxiformis*, falkenbergia stage) have not been found in the microcosm. In spite of the deviations, the algal species' diversity appears to be close to natural levels, especially considering the small size of the reef microcosm.

Clones of the turtle grass *Thalassia* have been grown in the associated lagoon for about 3 years. Flowering was observed towards the end of the 1st year. Mature blade length is 10–20 cm, about one-half of that in a typical St. Croix lagoon although well within the range encountered. Short blade length is perhaps related to the lack of surge and relatively thin sediment layer in the present system; normal length is achieved in the larger lagoon now attached to the exhibit microcosm. Blade length, life span, and colonization rate increased markedly when browsing fish (yellow tang) were introduced to remove epiphytes.

The animal community structure in the microcosm is not as complex as that found on a large natural reef; however, most major elements are present except for higher predators. A list of species present in the microcosm and those tallied during the past year are given in Tables 2 and 3.

The vertebrate species have proven to be the easiest segment of the reef biota to maintain (Table 3). The problems of disease, usually common in typical aquarium installations, are virtually nonexistent and fish that have suffered injury through accident or territorial defense return to health spontaneously if they do not undergo further predation. No quarantine procedures are used for the introduction of new fish and on a number of occasions, fish apparently diseased when introduced returned to good health. Behavior patterns are essentially normal and feeding, territorial, and, at least in some cases, reproductive responses parallel those observed in the wild. The population includes common grazers, scavengers, and invertebrate predators. In the system described here, higher vertebrate predators have been exluded because of the depletion that would result in the absence of a large reef surface for feeding and an open ocean pool for recruitment. However, in our newer exhibit tank a barracuda and a jack are maintained without significant predation on other reef fish. These higher predators are fed small goldfish daily and since the goldfish show stress in the sea water, they are attacked instantly in preference to other fish.

Of particular interest in a school of striped parrot fish, *Scarus croicensis*. These fish were introduced as small juveniles and have matured to assume the social structure characteristic of the species, including a single brightly colored, terminal male and two heavily contrasted black-and-white dominant females (one dominating the fore reef and one the back reef). Also, two species of damsel fish (the Beaugregory and the Three-sport) repeatedly lay and

Table 2. Algae occurring in the reef microcosm for periods longer than 3 months. * long term dominants

Bacillariophyta			
	Pennales	*Lycomophora* sp.	
		Navicula sp.	
		Nitzschia sp.	*
		Thalassiothrix sp.	
Pyrrophyta			
	Peridiniales	*Peridinium globulum*	*
Cyanophyta			
	Chrooccales	*Chroococcus*	
		Entophysalis	
	Nostocales	*Spirulina subsalsa*	*
		Microcoleus lyngbyaceus	*
		Symploca sp.	
		Oscillatoria submembranacea	*
		Calothrix crustacea	*
		Phormidium sp.	
Chlorophyta			
	Ulvales	*Enteromorpha erecta*	
		Enteromorpha prolifera	*
	Chaetophorales	*Pilinia* sp.	
	Cladophorales	*Cladophora fuliginosa*	
		Cladophora deliculata	
	Siphonocladiales	*Valonia ventricosa*	*
		Dictysphaeria cavernosa	
		Ernodesmis verticillata	
	Siphonales	*Halimeda opuntia*	*
		Halimeda monile	
		Halimeda incrassata	
		Udotea flabellum	*
		Penicillis capitatus	
		Caulerpa racemosa	
		Caulerpa peltata	
		Caulerpa vickersiae	
		Caulerpa prolifera	
		Caulerpa cupressoides	
		Bryopsis hypnoides	*
		Derbesia vaucheriaeformis	
		Derbesia marina	*
Phaeophyta			
	Ectocarpales	*Ectocarpus rhodochortonoides*	
		Giffordia rallsiae	*
	Sphacelariales	*Sphacelaria tribuloides*	*
	Dictyotales	*Dictyopteris deliculata*	
		Dictyota dentata	*
	Fucales	*Sargassum hystrix*	
		Sargassum polyceratium	
Rhodophyta			
	Bangiales	*Bangia fuscopurpurea*	
		Asterocystis ramosa	
	Gelidiales	*Gelidiella trinatatensis*	
		Wurdemannia miniata	
	Cryptonemiales	*Jania adherens*	
		Jania capillacea	*
		Amphiroa rigida	
		Peyssonnelia rubra	*
		Peyssonnelia sp.	
		Lithothamnium ruptile	
		Mesophyllum syntrophicum	*
		Porolithon pachydermum	*
		Neogoniolithon solubile	*
		Lithophyllum congestum	
	Gigartinales	*Hypnea spinella*	*
		Hypnea musciformis	*
		Hypnea cervicornis	
		Gracilaria mammillaris	
	Rhodymeniales	*Chrysymenia okamurai*	*
		Champia salicornoides	
		Lomentaria baileyana	
	Ceramiales	*Ceramium flaccidum*	
		Ceramium rubrum	
		Ceramium corniculatum	
		Centroceras clavulatum	*
		Lophosiphonia saccorhiza	
		Polysiphonia havanensis	*
		Herposiphonia secunda	*

fertilize egg clutches. These eggs are tended by the males and apparently hatch normally. After a clutch has hatched, the larval stages can be found in the tank plankton for 12–24 h. To date, no attempt has been made to raise these larvae and all have been lost to predation.

The most conspicuous sessile organisms are stony corals, gorgonians and anemones (Tables 4 and 5). Of the 40–45 common hermatypic scleractinia of the Caribbean-West Indian area, 24 have been introduced into the tank. Virtually all species survive for at least several months, and some show significant growth; others show little or no growth and eventually shrink marginally. The relatively high density of damsel fish may place extra stress on the slower growing species, which are often overgrown by the dense filamentous algal growth propagated within the damsel territories.

Individual colonies of *Acropora palmata*, the dominant shallow-water reef builder in the eastern Caribbean (Adey 1978), have been kept in the system for over 3 years, growing at a rate of about 0.7 cm/month, in spite of occasional predation by the crab *Mithrax spinosissimus*. This compares with 0.3 to 0.8 cm/month found by Gladfelter et al. (1977). The morphology of the new growth, however, resembles the short, bushy branches of *Acropora prolifera*, even though the original specimens had the typical blade-like appearance of *A. palmata*. Occasionally portions of colonies die suddenly after months or years of apparent good health, exhibiting symptoms of what has been called "white-band disease" (Gladfelter et al. 1977). The true nature of this rapid death, a feature that is often present in natural reefs, is not known. It is clear that in this microcosm, the abundant occurrence of this "disease" occurs only during periods of high nutrient levels, i.e., greater than 5 µg-at/l. Several *Acropora cervicornis* colonies have shown marked growth, though at a lesser rate than *A. palmata*, during 18 months in the tank. Damsel fish, butterfly fish and bristle worm (*Hermodice carunculata*) predation with resultant algal colonization is a recurrent problem for this coral in the tank as well as in the field. Several species of the hydrozoan *Millepora* are present and are generally long-lived, with considerable but sporadic growth. Octocorals, including species of *Gor-*

Table 3. Comparison of fish species in the SI microcosm and on two St. Croix patch reefs. – absent

Fish occurring in census on two patch reefs 11 out of 12 months[a]	Popular name	Equivalent in microcosm
Pomadasyidae		
Haemulon plumieri	White grunt	–
H. sciurus	Blue striped grunt	*Haemulon sciurus*
H. flavolineatum	French grunt	*H. flavolineatum*
Mullidae		
Mulloidichthys martinicus	Yellow goatfish	–
Chaetodontidae		
Chaetodon capistratus	Four-eye butterfly	*Chaetodon capistratus*
–		*Holocanthus tricolor*
–		*Holocanthus isabelita*
Pomacentridae		
Eupomacentrus fuscus	Dusky damsel	–
E. planifrons	Three-spot damsel	*Eupomacentrus planifrons*
E. leucostichus	Beaugregory	*E. leucostichus*
–	*Trimac-damsel*	*Dascyllus trimaculatus*[b]
–	Chromis	*Chromis cyanea*
(10/12 mos, one reef)	Sargeant major	*Abudefduf saxatilis*
Apogonidae		
(Apogon 2 sp. 6/12 mos)	Cardinal	*Apogon maculatus*
Labridae		
Halichoeres bivittatus	Slippery dick	*Halichoeres* sp.[b]
Thalassoma bifasciatum	Blue-head wrasse	–
–	Spanish hogfish	*Bodianus rufus*
–	Cleaner wrasse	*Labroides dimidiatus*[b]
Scaridae		
Sparisoma viride	Stoplight parrot	–
Scarus vetula	Queen parrot	*Scarus vetula*
S. croicensis	Striped parrot	*S. croicensis*
Acanthuridae		
Acanthurus coeruleus	Blue tang	*Zebrasoma flavescens*[b]
A. bahianus	Ocean surgeon	–
Aulostomidae		
Aulostomus maculatus	Trumpet fish	–
Holocentridae		
Holocentrus rufus	Longspine squirrel	*Holocentrus rufus*
Priacanthidae		
Priacanthus cruentatus	Glasseye snapper	–
Carangidae		
Caranx ruber	Bar jack	–
Lutjanidae		
Lutjanus apodus	Schoolmaster	–
Ocyurus chrysurus	Yellowtail snapper	–
Blennidae		
–		
Cirrhitidae	Red-lipped blenny	*Ophioblennius atlanticus*
–	Hawkfish	*Amblycirrhitus* sp.[b]
Grammidae		
–	Royal gramma	*Gramma loreto*

[a] After Gladfelter et al. (1979)

[b] Indo-Pacific species

gonia, *Eunicea*, *Pseudopterogorgia*, *Plexaura*, and *Briareum*, as well as the soft corals *Zoanthus* and *Palythoa*, do well in the system and have grown moderately. *Zoanthus* tends to colonize and cover the surface of plastic pipe and tubing in the tank. Many filter feeders and detritivors, including numerous sponges, foraminifera and worms, live cryptically within the reef.

The anemones *Stoichactis helianthus*, *Bartholomea annulata*, *Condylactis gigantea*, and *Lebrunia* sp., which are common on Caribbean reefs, are also permanent elements of the Smithsonian microcosm.

Larger invertebrates that have been most successful in the microcosm are the lobster *Panulirus argus* and a variety of crabs, including *Mithrax spinosissimus*, *Calcinus tibicen*, and *Pithos* sp. Young specimens of *Panulirus* and *Mithrax* grow so rapidly that the physical damage they cause, "uprooting" of uncemented carbonate, necessitates their removal within 6 months to 1 year. The stomatopod *Pseudosquilla* has been present since the earliest stages of tank development, and probably because of its predation it has not been possible to keep limpets in the reef tank for periods longer than a few months. The grazing gastropods *Cittarium pica*, generally in high energy situations (especially the wave box), and *Strombus gigas* (the queen conch) in the lagoon are also particularly successful. Only a single bivalve, the brightly colored *Lima*, occurs in the main reef tank; and an unidentified mussel has functioned for over 2 years in one of the refugia. Numerous echinoids, including *Eucidaris tribuloides* (the slate pencil urchin) and particularly *Diadema antillarum* are conspicuous nocturnal grazers.

Recent study of the new exhibit tank microfauna has produced over two hundred species of protozoans and micrometazoans (Spoon and Brawley personal communication).

Species Diversity and Scaling Factors

Based on the map of Ogden et al. (1972), the mean number of hermatypic coral species for 20 random 3 m^2 sites on the northeast reef of St. Croix is 2.5. Using the relationship $S = kA^z$ to calculate diversity (S) as a function of the area (A) (the constant k varies for different taxa; see, e.g., Preston 1962); estimating $z = 0.2$ for the St. Croix bank barrier reef area of roughly 20.10^6 m^2, and a potential of thirty coral species), the expected number of species for 3 m^2 can be calculated to be 1.3. The large number of coral species in the microcosm is the result of artificial packing. On the other hand, the microcosm simulates about 20 m^2, rather less than the several hundred square meters of natural reef that we would like to achieve.

Fish diversity of the microcosm (Table 3) seems limited in relation to normal reef conditions – 21 species as compared to a predicted 200 for the 23-mile-long St. Croix reef. However, in a study of patch reefs behind the Buck Island barrier in St. Croix, Gladfelter et al. (1979) found only 22 species to be consistently present. Chief elements of fish community structure in our microcosms are the same as those on these patches; the primary missing elements of the consistent fish fauna are the higher predators, which normally patrol larger territories than contained within the tank microcosm. Although figures on the size of the patch reef worked by Gladfelter et al.

Table 4. Hermatypic Scleractinia (stony corals) occurring in the SI reef microcosm. Note: some mortality is exhibited shortly after introduction. The following refers to species longevity beginning about 2 weeks after introduction

	Species living for at least 1 year and exhibiting growth	Species living for at least 1 year but not exhibiting marked growth	Species living for 6 months or more but tending to gradually degenerate
Pocilloporidae			
		Madracis decactis	
Acroporidae			
	Acropora palmata		
	A. cervicornis		
Agaricidae			
			Agaricia agaricites
Siderastreidae			
		Siderastrea siderea	
		S. radians	
Poritidae			
	Porites astreoides	*Porites porites*	
Faviidae			
	Diploria strigosa	*Diploria clivosa*	
		D. labyrinthiformis	
		Montastrea cavernosa	
	Montastrea annularis		
Meandrinidae			
	Dichocoenia stokesii	*Meandrina meandrites*	
		Dendrogyra cylindrus	
Mussidae			
		Isophyllia sinuosa	*Mussa angulosa*
		Isophyllastrea rigida	*Scolymia lacera*
			Mycetophyllia spp.
Caryophylliidae			
			Eusmilia fastigiata

(1977) are not available, it is very likely that they are considerably larger than the microcosm surface.

In this microcosm most algae and many invertebrates are successful in terms of reproduction, settling and growth to maturity. Some fish have been spawning successfully for over 2 years but hatchlings fail to reach maturity, probably the result of predation. However, it should be expected that a few individuals would have developed to maturity. Most reef fish have planktonic larvae that escape into the open ocean, returning to the reef at a later stage of development, and inclusion of this interaction in the microcosm system would more closely duplicate natural conditions. We are now attempting to develop an open water, planktonic system to attach to the new exhibit tank.

Research and Education Potential

Only the principal elements of the chemical and physical variables and the biological community have been considered in this comparison of natural and microcosm communities. However, at the level that most marine communities and biomes are currently compared and researched, it seems clear that physical, chemical, and general biotic conditions in the microcosm fall well within the range of field conditions. While our objective has been to simulate a 200–300 m transect across a back barrier reef, we have probably come closer to a lagoon patch of 10–50 m^2. However, many refinements are possible, and we seek to more closely approach our goal in the future. The system as it stands has been used as a manipulative model for examination of animal behavior, the relationship between algal turf community structure and nutrient levels and factors controlling primary production in reef communities. Comparison and verification in the field of data collected from the microcosm community is a necessity; however, simultaneous study of a problem in both environments can make field work far more productive.

As a tool for public education with regard to the nature and function of marine ecosystems, the microcosm is invaluable. Traditional public aquaria demonstrate a highly artificial situation which conveys little of the beauty and complexity of natural reef systems to the viewer.

Construction and Maintenance

The 1982 costs for new construction of the microcosm described here would vary widely depending upon labor cost, safety restrictions, the extent of available heat control, and mode of utilization. Using in-house labor, the research model would cost about $10,000 U.S. The exhibit model, not including exhibitry, but with generally heavier construction and glass and a safety screen would be around $20,000 U.S.

Table 5. Invertebrate taxa tabulated in the reef microcosm from January–March, 1980, and generally exhibiting a long term presence in the system

Protozoa		Terebellidae	
Foraminifera		*Loimia medusa*	
Soritidae	Homotremidae	Sabellidae	
Archaias compressus	*Homotrema rubrum*	*Sabellastarte magnifica*	
	Gypsina sp.	Serpulidae	
Porifera (sponges)		*Spirobranchus giganteus*	
Haliclonidae	Agelasidae	Mollusca	
Niphales erecta	*Agelas conifera*	Gastropoda	
Tethyidae	*Agelas clathrodes*	Acmaidae	Thaididae
Techya actinea	Clionidae	*Acmaea leucopleura*	*Thais deltoide*
Spirastrellidae	*Cliona* sp.	Cymatiidae	Astraeidae
Spheciospongia vesparium	*C. laticavicola*	*Cymatium nicobaricum*	*Astraea tecta*
Adociidae	Clathrinidae	Strombidae	Trophidae
Adocia sp.	*Clathrina* sp.	*Strombus gigas*	*Cittarium pica*
Sigmadocia sp.		Pelecypoda	Limidae
Chondrillidae	Sycettida	Unidentified mussel	*Lima* sp.
Chondrilla nucla	Syconciliatum	Arthropoda	
Coelenterata (Cnidaria)		Crustacea	
Hydroza		Isopoda	
Milleporidae		*Bagatus* sp.	
Millepora complanata	*Millepora alcicornis*	Amphipoda	
Anthozoa (except Scleractinia)		*Ampithoe ramondi*	
Gorgonacea		*Elasmopus* sp.	
Briarium asbestinum	*Eunicia* sp.	Decapoda	
Plexaura homomalla	*Gorgonia ventalina*	*Pitho* sp.	
P. flexuos	*G. flabellum*	*Mithrax spinosissimus*	
Pseudopterogorgia sp.		*Calcinus tibicen*	
Actinanaria		*Pseudosquilla* sp.	
Condylactis gigantea	*Lebrunea corvalligens*	Panulirus argus	
Ricordea florida	*Stoicactus helianthus*	Echinodermata	
Anthopleura sp.		Asteroidea	
Bartholomea annulata		*Astropecten duplicatus*	
Zoanthidae		*Oreaster reticulatus*	
Zoanthus sociatus	*Palythoa mammillosa*	Ophiuroidea	
Annelida (True Worms)		*Ophiothrix* spp.	
Polychaetes		Echinoidea	
Amphinomidae		*Diadema antillarum*	
Hermodice carunculata		*Eucidaris tribuloides*	
		Echinometra lucunter	

An experienced technician can maintain the system described in 20–30 h per week, although daily attention is required to monitor potential component failure. The primary tasks are cleaning of tank glass (every other day), cleaning scrubber (7–14 days), measuring and adjusting temperature and salinity, feeding (brine shrimps, krill, goldfish for higher predators), and checking of lights, pumps, circuit breakers and salinity control, distilled water system. pH and organism appearance generally provides an indication of the health of the system, although occasional nitrate measurements are helpful in adjusting scrubber effectiveness, even if research requiring such measurements is not being carried out.

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