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ARE CURRENT ESTIMATES OF CORAL REEF BIODIVERSITY TOO LOW? THE VIEW THROUGH THE WINDOW OF A MICROCOSM

BY

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ARE CURRENT ESTIMATES OF CORAL REEF BIODIVERSITY TOO LOW? THE VIEW THROUGH THE WINDOW OF A MICROCOSM

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Allegra M. Small[1], Walter H. Adey[1], and Don Spoon[1]

ABSTRACT

Our results have provided an estimate of the biodiversity of pan tropic coral reefs that is more than 3 times higher than that previously published. The biodiversity of global coral reefs has recently been estimated at approximately 1 million species based on what is currently known about tropical rain forests. However, in order to determine the actual biodiversity of even a single coral reef locality, an extensive team effort on the part of hundreds of specialists would be required. Close examination of the mature 5 m^2 Caribbean coral reef microcosm described in this paper provided 534 species, with an estimated 70% tallied. Using the area/diversity relationship $S=kA^Z$, we were able to more accurately assess the probable biodiversity of wild reefs. This outstanding species biodiversity, based in an extensive range of higher taxa, reconfirms the essential need to restore and conserve one of the most precious ecosystems on earth.

INTRODUCTION

In the middle decades of the 20th century, it was widely accepted by biologists that about one million currently-living species occurred on the planet earth. Grave doubts have been raised in recent decades, primarily based on modern studies in tropical rain forests, that this number is even remotely close to reality. Indeed 10 million is currently a low estimate with some scientists citing 30-100 million species (Wilson and Peter, 1988; Ehrlich and Wilson, 1991; Wilson, 1992; Stork, 1993; Lovejoy, 1997).

While coral reef biologists have long known that tropical reefs are rich in species, no serious effort has been made to actually "dissect" a well-developed reef ecosystem to determine a realistic biodiversity number. In truth, a thorough study would be extraordinarily difficult and would require a team effort by hundreds of specialists. A recent analysis of what is known about coral reef biodiversity (93,000 identified species) and what can be estimated about actual biodiversity (950,000 predicted species) has been carried out by Reaka-Kudla (1997). We quote the key elements of Reaka-Kudla's conclusions:

> "These analyses suggest that about 93,000 total described species of all taxa occur on coral reefs, which represents about 5% of the described global biota. These numbers are considerably lower than the number of species that are

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estimated to occur in rain forests. However, coral reefs occupy only 5% of the global area of rain forests. If coral reefs were equivalently studied and contained as much biodiversity as rain forests per km^2, and if rain forests contained 2 million species, then coral reefs should include approximately 950,000 species. The difference between the numbers of described (93,000) versus expected (950,000) species suggests that coral reefs are repositories of very high undocumented species diversity. Most species on coral reefs are relatively small and cryptic, and difficult to observe and collect. This, in combination with the fact that tropical environments and particularly tropical marine habitats receive less study than those of higher latitudes or terrestrial sites, suggests that many coral reef taxa are indeed very poorly known."

Adey (1983) suggested that microcosms of coral reefs could be utilized to better understand the function of these extremely complex ecosystems. Although this approach has not been widely utilized by researchers, more recently, the microcosm described herein has been employed effectively as a tool to better understand reef metabolism, specifically the process of calcification and its relationship to photosynthesis (Small and Adey, in manuscript). As that study has demonstrated, properly constructed microcosms have the ability to maintain a natural reef's physical, chemical and biological characteristics for many years; thus microcosms have the capability to be used as tools in the first approaches to solving many extremely difficult problems, such as the magnitude of biodiversity, the nature of community structure and their controlling factors. The larger, and generally far more remote, reef ecosystems of tropical seas can then be approached *in situ* to test the hypotheses already developed and tested at a more manageable and controllable laboratory scale.

In this paper we present the results of a year-long study of the biodiversity of a mature coral reef microcosm used primarily for metabolism and calcification research. Except for specific, macro species additions for research, amounting to less than 5% of the total flora and fauna, the biota of this system was taken in two distinct collections made in 1983 and 1991 at a single coral reef locality in the tropical West Atlantic. This represents what could be termed two sets of samples from a single habitat (and is therefore a sample of alpha diversity), while the only sufficient comparison that is available is an estimate of gamma or regional reef diversity taken from multiple samples (i.e. many thousands) over long periods of time.

As we describe in this paper, the extraordinary diversity found in this microcosm, based on minimal collections from a single locality in the Tropical Western Atlantic, suggest a considerably larger diversity in tropical reefs than that described above.

MATERIALS & METHODS

The biodiversity of a Caribbean coral reef microcosm, which has been functioning without significant biological input for over 7 years, was determined (Figure 1). Originally set up in 1988, the microcosm is a 400 liter system with a 1,280 liter refugia, and was

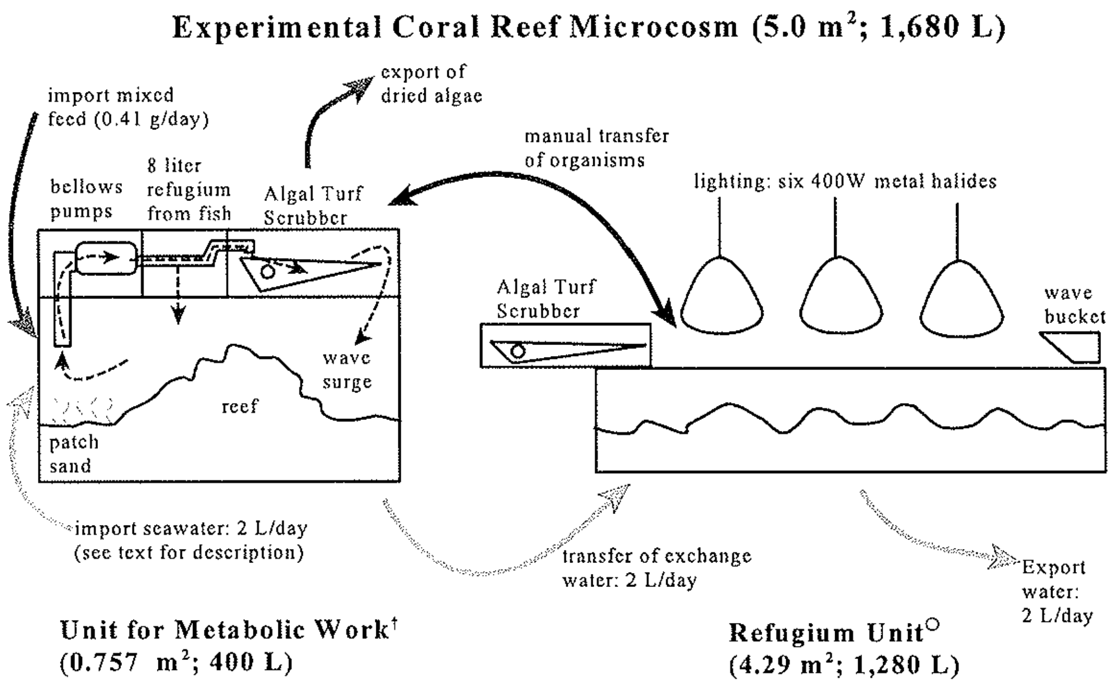

Figure 1. Diagram of the microcosm. Please note the volume of this system is an estimation based on original tank volume minus the estimated volume of the carbonate structure to obtain a water volume. †Lights not shown; See Adey and Loveland (1998) for a detailed mechanical description of this unit. ○Note impeller pumps, (not shown) deliver water from the right hand end of the refugium unit to the Algal Turf Scrubber and the left side of the refugium unit to the wave bucket.

physically and metabolically modeled after the reefs of St. Croix where adequate data were available (e.g. Adey and Steneck, 1985). Significant biological/ecological collections were made from Mayaguana, in the Bahamas, with the last collection occurring in 1991. Refer to Luckett et al. (1996) and Adey & Loveland (1998) for detailed information on construction, microcosm set up, daily maintenance, lighting, pumps, refugia, and algal turf scrubber technology (used to match water chemistry with long and short term conditions on the St. Croix reef). The physical and chemical components of the microcosm and the methods used for collection and identification of its species are discussed below.

Physical and Chemical Components of the Microcosm

Small and Adey (in manuscript) determined the physical and chemical components of the microcosm to closely match those of St. Croix (Table 1). The yearly mean total of daily radiation was determined with a pyranograph to be 220 Langleys (cal./cm^2). The light levels of the St. Croix fore-reef are approximately 220 Langleys at a depth of 5 meters (Kirk, 1983; Adey and Steneck, 1985), therefore the physical and chemical components of the microcosm were compared to the St. Croix fore-reef (see Table 1 and Adey and Steneck, 1985). During the period of research, the microcosm ranged from 0.21 to 0.71 μM $N\text{-}NO_2 + NO_3$ (with a mean at 0.56 μM; n=6) as compared to 0.35 to 1.05 μM $N\text{-}NO_2 + NO_3$ at St. Croix (based on a skewed distribution of data points where the most data points occurred at 0.35 μM and the points trailed up to 1.05 μM; Adey and Loveland, 1998).

Table 1. Modified from Small and Adey (in manuscript). Comparisons between microcosm and St. Croix reefs (annual mean or mean daily range with standard error). The St. Croix data is from Adey and Steneck (1985). *indicates the data represents tropical Atlantic means from Millero & Sohn (1992); no data available for St. Croix. **indicates the data represents tropical Atlantic means from Sverdrup et al (1942); no data available for St. Croix. ***indicates data represents tropical world wide means (Pichon, 1995); no direct data for St. Croix at this depth.

	Microcosm	**St. Croix Reefs (fore reef)**
Temperature (°C) (am - pm)	26.5 ± 0.03 (n=365) - 27.4 ± 0.02 (n=362)	24.0-28.5
Salinities (ppt)	35.8 ± 0.02 (n=365)	35.5*
pH (am - pm)	7.96 ± 0.01 (n=62) - 8.29 ± 0.02 (n=39)	no am-pm pH data available for St. Croix reefs; however, pH range is similar based on extensive O_2 data.
Oxygen concentration (mg/l) (am - pm)	5.7 ± 0.1 (n=14) - 8.7 ± 0.2 (n=11)	5.8 - 8.5
GPP (g O_2/m^2/day)	14.2 ± 1.0 (n=4)	15.7
Daytime NPP (g O_2/m^2/day)	7.3 ± 0.3 (n=4)	8.9
Respiration (g O_2/m^2/hr)	0.49 ± 0.04 (n=4)	0.7
$N - NO_2^- + NO_3^2$ (μmol)	0.56 ± 0.07 (n=6)	0.28
Calcium (mg/l)	491 ± 6 (n=33)	417.2**
Alkalinity (meq/l)	2.88 ± 0.04 (n=59)	2.47*
Calcification (kg/m²/yr $CaCO_3$) (based on alkalinity depletion - based on calcium input)	4.0 ± 0.2 (n=11) - 4.4 ± 0.1 (n=365)	1-2% of a reef will calcify at 10 kg/m²/yr, 2-4% at 4 kg/m²/yr, and 90-95% at 0.8 kg/m²/yr ***
Light (Langleys/day)	220	430 (surface) 220 (5 meters deep in fore-reef)

The minor variations between the microcosm, as described, and the physical and chemical components of the natural reef are attributed to the maintenance of an enclosed ecosystem separated from the strong open ocean water input characteristic of these reefs.

Without a constant supply of open ocean water, the primary elements of variation (calcium concentrations and alkalinity) continually fall during the day due to calcification, but remain stable at night (Small and Adey, in manuscript). It was therefore necessary to maintain the concentrations of these elements by daily addition of calcium and bicarbonate. In an effort to keep the calcium and bicarbonate in the microcosm from depleting below normal tropical oceanic levels after a full day of calcification, the mean concentrations were maintained at 491 ± 6 mg/l (n=33) and 2.88 ± 0.04 meq/l (n=59), respectively. These elevated levels of calcium and bicarbonate did not significantly effect the calcification rate as demonstrated by student's t-test (Small and Adey, in manuscript). Though the calcification rate of the microcosm ecosystem is 4.0 ± 0.2 kg $CaCO_3/m^2$/year (n=11; based on alkalinity depletion) to 4.4 ± 0.1 kg $CaCO_3/m^2$/year (n=365; based on calcium input), individual coral colonies are calcifying at rates as high as 20 kg $CaCO_3/m^2$/year (e.g. *Acropora sp.*) (see Small and Adey, in manuscript, for rates of all microcosm components).

The gross primary productivity (GPP) of the microcosm (14.2 ± 1.0 g O_2/m^2/day; n=4) is higher than the world-wide averages for tropical reefs (10 g O_2/m^2/day) (Crossland et al, 1991). However, it is 1.5 g O_2/m^2/day lower than that determined for the St. Croix fore-reef by Adey and Steneck (1985). These differences in the mean GPP of the microcosm and St. Croix can be explained by the differences in spatial heterogeneity. Because of the much smaller area of the enclosed microcosm, spatial heterogeneity cannot be developed at levels equivalent to the very high spatial heterogeneity of the well-developed Caribbean fore-reef.

Collection and Identification Procedures

<u>Original Collections</u>

The vast majority of the organisms present in the microcosm came from two original collections on the southwest reef of Mayaguana. Both of the collections were part of larger collections made for an exhibit microcosm in the Smithsonian Institution's Natural History Museum. These collections were mini-ecosystem collections of 50-70, 0.03 m^3 units (lugs), which contained live-sand, live-rock, specific macro-invertebrates, algae and fish. The first collection occurred as several sub-collections from 1980-1983, and was flown in coolers by plane directly to the larger exhibit microcosm at the Smithsonian, and maintained there until 1988 when a small portion was then transferred to establish the microcosm described in this paper. The primary collection (1991) was transported by research vessel with ocean flow-through capability from the Bahamas, up the Gulf Stream to Cape Hatteras. At Cape Hatteras, the collection systems were converted to on board algal turf scrubber control (Adey and Loveland, 1998) for about 24 hours until arrival at the microcosm system on the shore of the Chesapeake Bay. It was from this larger collection that sub-samples were taken to provide the majority of the microcosm ecosystem. The remainder of the collection was then transferred to a rebuilt exhibit microcosm at the Smithsonian.

In addition to the species from the Mayaguana collections, a few Indo-Pacific species were introduced within the first years of operation (i.e. giant clams, soft corals, fish). These species were bought as individuals, with little possibility of accidentally introducing other organisms. More recently, fish have occasionally been replaced when necessary (as they were lost by internal predation). Finally, in 1996, two species of Indo-Pacific stony coral (*Acropora sp.* and *Montipora digitata*) mounted on plastic holders at Inland Aquatics inTerre Haute, IN (and therefore without other species on their bases) were added for determination of calcification rates (Small and Adey, in manuscript). The only possible source of unknown organism introduction would be through the addition of Chesapeake Bay water that was exchanged in small amounts daily (2 L). In order to reduce the introduction of larvae and microorganisms in the water, the Bay water (~ 18 ppt) was increased in salinity by the addition of aquarium salts to ~50 ppt, and then brought back down with distilled water to normal tropical oceanic concentrations (~35 ppt), over a few days time in a dark holding reservoir. The analysis of the microorganisms present in the Chesapeake Bay, the holding reservoir, and microcosm showed only four possible species that might have been introduced to the microcosm using this technique. These cosmopolitan species occur naturally in brackish and fully saline waters.

With exception of the few selective introductions mentioned above, there has been no significant input of organisms into the microcosm for 7 years. The vast majority of species found in the microcosm today have been maintaining viable populations through reproduction.

Collection of Organisms for Identification

Organisms were identified whenever possible without removal from the microcosm. This was only possible for about 10% of the total species found. To minimize disturbance of the 400 liter portion of the microcosm, only those organisms that could be identified without removal or with minimal disturbance of the entire system, were identified. The much larger refugium allowed for live-rock and sand samples to be taken without impacting the ecosystem. Sand was sieved for removal of larger organisms and the remaining sand was sorted through under a dissecting microscope. Small pieces of live-rock were also placed under the dissecting microscope for locating species on the surface. Larger pieces of live-rock were broken open to reveal species hidden inside. Representative samples of live-rock and sand were taken from different areas and depths within the microcosm.

The majority of macro species were able to be identified by being placed live under the dissecting microscope. These organisms were returned to the system after the identifications were made. Many of the smaller invertebrates were collected and fixed for identification. Arthropods and sponges were fixed and preserved in 70% ethyl alcohol. Polychaete worms were narcotized with 7.5% $MgCl_2$ in seawater, fixed in 10% formalin, and preserved in 70% ethyl alcohol. Sipunculids were relaxed in 7% $MgCl_2$ in freshwater, fixed in 10% formalin, and preserved in 70% ethyl alcohol. Except for about twenty larger species collected individually by hand or forceps, the algae were taken as samples of substrate, teased apart under a dissecting microscope and identified under the compound microscope. A Scanning Electron Microscope (SEM) was used in the identification of diatoms.

Microorganisms were collected and identified alive using an array of techniques. For artificial substrates, inverted 50 mm plastic petri dishes inserted into Styrofoam cup sections were placed on the water's surface (Spoon and Burbanck, 1967), and glass slides with glass coverslips (affixed with thin strips of 50 μm thick Adcom™ double sticky tape) were inserted vertically into the sediment creating horizontal chambers at different depths. Microcompression chambers for detritus samples were created on glass slides by using thin plastic Handiwrap™ film as a gas exchanging coverslip (attached peripherally with Dow Corning™ silicone stopcock grease), which allowed for living preparations to last many hours (Spoon, 1976). In addition, plankton samples were collected by filtering water through 100 μm and 20 μm meshes.

Identifications

The major taxonomic groupings of organisms were divided amongst the authors for identification. Walter Adey was responsible for the algae, including diatoms but excluding dinoflagellates, Allegra Small was responsible for the macroscopic animals, and Don Spoon for the protozoa, dinoflagellata and micrometazoa. Due to high diversity of the macroscopic invertebrates and the difficulty in identification of a great number of species, the majority of invertebrates were identified only to family level and then sent to the appropriate specialist for further identification. Table 2 lists the assisting specialists and their taxonomic group of expertise. For organization at higher taxonomic level, Parker et al (1982) was used as a guideline, except in the case of the Protists, in which (Corliss, 1994) was used.

Approximately one year of roughly one-third time was spent in this collecting/identifying endeavor. Another year of similar time would have been required to nearly complete the tally, and several additional specialists would have been required (nematodes, fungi, bacteria, viruses, parasitic genera and the minor phyla not yet explored). It is our mutual judgement that approximately 30% of species in the system remain uncounted, not including bacteria, viruses and parasites, which would likely add an order of magnitude to the species count. Since bacteria, viruses and parasites are not usually considered in biodiversity estimates, we do not consider them in our calculations for coral reef biodiversity. With increasing intensity of examination of the microcosm, special precautions would have to be taken to avoid altering the ecosystem through collection procedures.

RESULTS

The results of the species collections and identifications are listed in Appendix A. A total of 534 species were found at last count, with several phyla not considered, and approximately 30% of species unaccounted for. At higher taxonomic level, distribution of species number is approximately 25% algae, 45% invertebrates, 30% Protozoa and lower Metazoa, and only a few chordates. These percentages are referring to the number of species in each grouping, not the abundance. Abundances of each species were difficult to estimate with any level of accuracy due to the destructive sampling techniques required to do so. The higher taxonomic diversity, with the 534 species spanning 96 orders and 27 phyla, makes this coral reef microcosm a truly diverse ecosystem.

Table 2. Specialists consulted for the identification of invertebrates.

Taxonomic Group	Identifying Specialist
Subclass Ostracoda	Richard Benson, Smithsonian Institution Louis Kornicker, Smithsonian Institution
Order Tanaidacea	Richard Heard, Gulf Coast Research Laboratory
Subclass Copepoda	Rony Huys, The Natural History Museum, London Sophie Conroy-Dalton, The Natural History Museum, London Chad Walter, Smithsonian Institution
Order Isopoda	Marilyn Schotte, Smithsonian Institution
Order Amphipoda	Sara LeCroy, Gulf Coast Research Laboratory
Class Granuloreticulosea (Foraminifera)	Beth Burkhard, independent contractor, beth@intrepid.net, (collected and identified specimens)
Phylum Mollusca	Raye Germon, Smithsonian Institution
Phylum Nemertea	Jon Norenburg, Smithsonian Institution
Phylum Porifera	Klaus Ruetzler, Smithsonian Institution
Phylum Sipuncula	Mary Rice, Smithsonian Institution Julie Piraino, Smithsonian Institution
Family Terebellidae	Pat Hutchings, The Australian Museum
Family Maldanidae	Andrew Mackie, National Museum of Wales
Family Syllidae	Guillermo San Martin, Universidad Autonoma de Madrid
Family Spirorbidae	Wyn Knight-Jones, University of Wales
Family Cirratulidae	James Blake, ENSR Consulting and Engineering, Inc.
Family Serpulidae	Harry A. ten Hove, Zoological Museum, Amsterdam
Family Sabellida	Kirk Fitzhugh, Los Angeles County Museum of Natural History
Order Eunicida, Families Orbiniidae, Paraonidae, Ctenodriliae, Capitellidae, Oweniidae	Kristian Fauchald, Smithsonian Institution

Using the standard relationship between species diversity and area ($S=kA^Z$) that has been utilized since the 1960's for relating biodiversity to area, and more recently used by Wilson (1992), May (1994) and Reaka-Kudla (1997), it is possible to estimate the total number of species that should appear in natural coral reefs worldwide based on this microcosm. The first step is to determine, based on our diversity of a 5.0 m^2 Caribbean coral reef microcosm, the estimated diversity of the Caribbean reefs. To do this the Z value of 0.25 (Reaka-Kudla, 1997) and the Caribbean coral reef area as determined by Spalding and Grenfell (1997) ($A=23 \times 10^9$ m^2) was used. Note that the value of the constant (k) will be the same for the microcosm and natural reefs, so it can be canceled out on both sides of the equation. The calculations for the first step are as follows:

S_1=predicted Caribbean reef diversity; S_2=diversity of the microcosm (532, without bacteria); A_1=area Caribbean reefs; A_2=area microcosm; Z=0.25

$$k=\frac{S_1}{A_1^Z}=\frac{S_2}{A_2^Z} \qquad S_1=\frac{(S_2)(A_1^Z)}{A_2^Z} \qquad S_1=\frac{(532)(23x10^9)^{0.25}}{(5.0^{0.25})}=138{,}394$$

With the diversity of Caribbean reefs at about 1/12th of that of pan tropic coral reefs (based on Paulay, 1997), and with the estimated Caribbean reef diversity of approximately 138,000, it can be further interpolated that the pan tropic reefs have a diversity of 1,656,000 species. These diversity numbers for the Caribbean and pan tropic coral reefs are a bare minimum. Considering that the actual diversity of the 5.0 m^2 microcosm is more likely to be 30% higher than determined (due to the estimated number of species not yet found and the various phyla not considered), the Caribbean and pan tropic reef diversities can be recalculated to be:

$$S_1=\frac{(692)(23x10^9)^{0.25}}{(5.0^{0.25})}=$$ 180,217 for the Caribbean and 2,162,603 pan tropic.

In addition, the microcosm has been running for 7 years without significant introduction of species. It can be safely assumed that many species were not represented in the original collections, and that additionally some did not survive either translocation, 7 years of life in the microcosm, or were not able to reproduce due to lack of a mate or for other reasons. Conservatively estimating the number of species that did not survive the extended period of time in the microcosm to be approximately 20 ± 10%, we can once again recalculate the predicted diversity of Caribbean and pan tropic reefs to be:

$$S_1=\frac{(830)(23x10^9)^{0.25}}{(5.0^{0.25})}=$$ 216,156 for the Caribbean and 2,593,874 pan tropic.

The difference between this estimated 2.6 million species pan tropic and the previously published estimate of 950,000 species (Reaka-Kudla, 1997) is even greater when considering the differences in coral reef areas used for the respective calculations. Reaka-Kudla used a pan tropic coral reef area of 6.0×10^{11} m^2 for her calculations (a commonly used estimate of reef area; Smith, 1978). For our calculations, we used the more conservative and recent coral reef area estimates of Spalding and Grenfell (1997), 23×10^9 m^2 for Caribbean reefs, and 2.6×10^{11} m^2 pan tropic. For comparison to Reaka-Kudla's numbers, our estimated biodiversity can be further adjusted, using the less conservative area of 6.0×10^{11} m^2 and the formula above, to be approximately 3.2 million species pan tropic. Though the actual current area of worldwide reefs may be debatable, our numbers show that the biodiversity of pan tropic reefs to be more than 3 times what has been previously estimated.

DISCUSSION

The $S=kA^Z$ relationship is basically empirical. Whether it adequately states the difference between alpha (habitat) and gamma (regional) diversity, with the equation allowing for the increase in habitats with greater area, or whether there are significant additional factors probably doesn't matter to its use in this context. What probably does matter is that the relationship was developed largely for vertebrates in island terrestrial communities. It certainly has not been adequately tested for marine ecosystems and especially very high diversity ecosystems. Accepting that this relationship is all we have to work with in this context, and it is widely used, our primary concern for the use of the coral reef microcosm for estimating natural reef diversity is whether or not the Mayaguana reef habitat was adequately sampled.

As was shown by Small et al (1996), for relatively simple stream systems with a macrophyte species count of 30-60 species, at least 10 samples considerably larger (~5 m^2) than that employed here were required to approach local ecosystem diversity. In this case, only a limited taxonomic group was being considered. Gage and Tyler (1991) describe the similar rarefaction technique used in sampling deep sea soft bottom fauna. In one case cited, 168, 0.1 m^2 box cores failed to produce a rarefaction curve that approached the asymptote - or in other terms, 25 species were still being discovered as each m^2 of sample was added, at the limit of the curve. This kind of information is not yet available for coral reef ecosystems. However, it seems reasonable to state that the sampling employed in the collecting process of this investigation (smaller sub-samples of the approximately 120, 0.03 m^3 samples taken at two separate times) could not begin to sample adequately the total biodiversity of the Mayaguana reef. Thus, the samples returned to the microcosm for community and ecosystem development must have considerably understated the actual diversity of the Mayaguana reef.

Although considerable efforts were taken to avoid species loss in transit, certainly some especially larger species were lost in transit or in the process of establishment in the new habitat. Even in newly available wild habitat, a considerable period of time is required to build up to typical species densities. Thus, as large as the species density is in this relatively small microcosm, it almost certainly understates coral reef diversity *in situ*.

Though the microcosm has an inter-reef refugium to aid in larval development outside of predation, it lacks the essential open ocean refuge for those species that live and breed on coral reefs but spend their larval phases in open water where predation is considerably less marked. Many fish species are in this category and spend weeks to months in open ocean plankton. Indeed, coral reef fish often reproduce in microcosms but the larvae do not successfully recruit to the reef unless specific steps are taken to protect them from predation and provide appropriate plankton for feed (this has been accomplished for about two dozen fish species; e.g. Adey and Loveland, 1998). Fish constitute less than 1% of coral reef species and this failure to generally maintain populations would make little direct difference to our overall diversity analysis. However, other invertebrate groups probably also fall into this category and thus would be a missing element in the microcosm. It should be emphasized that this particular microcosm, in part operates with bellows (rather than impeller) pumps and thus, at least in the 400 L section, planktonic stages could theoretically last indefinitely in the water column (and some clearly do so). However, this does not solve the predation issue as it relates to those many species that require an open ocean refugium.

Reaka-Kudla based her calculations on the assumption that tropical rain forests contain 2 million species. She acknowledges that this is a conservative estimate, and predicts that if tropical rainforests contain more species, in turn coral reefs could contain more species. Based on a tropical rainforest diversity of 2 million species and what we now know to be the current estimate of coral reef diversity (2.6 - 3.2 million species, depending on the true area of coral reefs), coral reefs have a much higher species/area density than rainforests. Otherwise, if it is indeed true that coral reefs have the same species/area density of rainforests, than the current estimate of tropical rainforest biodiversity used by Reaka-Kudla (1997) is much too low.

CONCLUSION

Based on the 5.0 m^2 Caribbean coral reef microcosm described in this paper, and the species/area relationship $S=kA^Z$, pan tropic coral reef biodiversity can be conservatively estimated to be approximately 3 million species. While major field efforts and continued microcosm development work is necessary to develop more acceptable numbers, this new estimate shows that the previous estimate of pan tropic coral reef biodiversity developed by Reaka-Kudla (1997) is most certainly low. Whether actual numbers are only three times as much as Reaka-Kudla's estimate or an order of magnitude higher cannot be stated at this time. The importance of coral reef biodiversity can be further recognized when considering that coral reefs have a much higher diversity at higher taxonomic levels than tropical rain forests (Paulay, 1997). As most probably the ecosystem with the highest specific diversity (species per unit area) in the biosphere, each day's decline of coral reefs is a devastating loss to the human race. This concern need not be framed only in esthetic or local concerns. As coral reefs likely bear the highest specific diversity of yet unknown biochemicals, the ongoing loss of reefs is providing considerable loss of potential to the human pharmacopoeia. The clear concern by many scientists for the loss of these very rich ecosystems, before we even understand just how rich they are, is very real (Paulay, 1997; Reaka-Kudla, 1997; Adey, 1998).

ACKNOWLEDGMENTS

As noted in Table 2, numerous specialists assisted our work in providing or confirming species and generic identifications. Without their expertise and time expenditure, this study would have far less value to furthering our understanding of coral reef ecosystems. The microcosm described in this paper has been operating for many years and the authors could not always be present to provide maintenance. Many Marine Systems Laboratory employees and trained volunteers, too numerous to cite individually, and friends assisted in this effort. Finally, and most importantly, we are grateful for the financial and moral support of Rampa Hormel. Rampa wanted to support coral reef conservation, and we sincerely hope that our work (this is the first of a series of papers resulting from her assistance) will directly or indirectly lead to a more significant effort to conserve coral reefs.

BIBLIOGRAPHY

ADEY, W.H. 1983. The microcosm: a new tool for reef research. Coral Reefs 1:193-201.

ADEY, W.H. 1998. Coral reefs: algal structured and mediated ecosystems in shallow, turbulent alkaline seas. J. Phycology 34:393-406.

ADEY, W.H. AND K. LOVELAND. 1998. Dynamic Aquaria: Building Living Ecosystems. 2nd Ed. Academic Press, New York.

ADEY, W.H. AND R. STENECK. 1985. Highly productive Eastern Caribbean reefs: synergistic effects of biological, chemical, physical, and geological factors. (In) The Ecology of Coral Reefs, Reaka, M. (Ed). NOAA Symposia Series for Undersea Research 3(1):163-187.

CORLISS, J.O. 1994. An interim utilitarian ("user-friendly") hierarchical classification and characterization of the protists. Acta Protozool. 33:1-51.

CROSSLAND, C.J., B.G. HATCHER, AND S.V. SMITH. 1991. Role of coral reefs in global ocean production. Coral Reefs 10(2):55-64.

EHRLICH, P.R., AND E.O. WILSON. 1991. Biodiversity studies: Science and policy. Science 253:758-762.

GAGE, J. AND P. TYLER. 1991. Deep Sea Biology: a natural history of organisms at the deep sea floor. 504 pp. Cambridge University Press.

KIRK, J.T.O. 1983. Light and Photosynthesis in Aquatic Ecosystems. Cambridge University Press, Cambridge.

LOVEJOY, T.E. 1997. Biodiversity: What is it? (In) Biodiversity II: Understanding and Protecting Our Biological Resources. Reaka-Kudla, M.L., D.E. Wilson and E.O. Wilson (Eds). Joseph Henry Press, Washington, D.C. p 7-14.

LUCKETT, C., W.H. ADEY, J. MORRISSEY, AND D. SPOON. 1996. Coral reef mesocosms and microcosms - successes, problems, and the future of laboratory models. Ecological Engineering 6:57-72.

MAY, R.M. 1994. Biological diversity: differences between land and sea. Phil. Trans. R. Soc. Lond. B 343:105-111.

MILLERO, F. J. AND M. L. SOHN. 1992. Chemical Oceanography. CRC Press, Boca Raton, 531 p.

PARKER, S. (Ed). 1982. Synopsis and Classification of Living Organisms. Vol. 1, 1166 pp; Vol. 2, 1232 pp. McGraw Hill, New York.

PAULAY, G. 1997. Diversity and distribution of reef organisms. (In) Life and Death of Coral Reefs. Birkeland, C. (Ed). Chapman & Hall, New York, NY. p 299-353.

PICHON, M. 1995. Coral reef ecosystems. In Encyclopedia of Environmental Biology, V.1, A-E, Nierenberg, W.A. (Ed). Academic Press. pp. 425-443.

REAKA-KUDLA, M.L. 1997. The global biodiversity of coral reefs: a comparison with rain forests. (In) Biodiversity II: Understanding and Protecting Our Biological Resources. Reaka-Kudla, M.L., D.E. Wilson and E.O. Wilson (Eds). Joseph Henry Press, Washington, D.C. p 83-108.

SMALL, A.M., W.H. ADEY, S.M. LUTZ, E.G. REESE, AND D.L. ROBERTS. 1996. A macrophyte-based rapid biosurvey of stream water quality - restoration at the watershed scale. Restoration Ecology 4(2):124-145.

SMALL, A.M. AND W.H. ADEY *(In manuscript)*. Reef corals, zooxanthellae & free-living algae: interactions that optimize calcification and primary production. (submitted to Coral Reefs).

SMITH, S.V. 1978. Coral-reef area and the contributions of reef to processes and resources of the world's oceans. Nature 273:225-226.

SPALDING, M.D. AND A.M. GRENFELL. 1997. New estimates of global and regional coral reef areas. Coral Reefs 16:225-230.

SPOON, D.M. 1976. Use of thin, flexible plastic coverslips for microscopy, microcompression, and counting of aerobic microorganisms. Trans. Amer. Micros. Soc. 95(3):520-523.

SPOON, D.M. AND BURBANCK, W.D. 1967. A new method for collecting sessile ciliates in plastic petri dishes with tight-fitting lids. J. Protozool. 14(4):735-739.

STORK, N.E. 1993. How many species are there? Biodiversity Conservation 2:215-232.

SVERDRUP, H. U., R.H. FLEMING, AND M. W. JOHNSON. 1942. The oceans, their physics, chemistry, and general biology. Prentice-Hall, New York, NY. 1087 p.

WILSON, E. O. 1992. The Diversity of Life. Belknap Press of Harvard University Press, Cambridge, Mass. 424 pp.

WILSON, E. O. AND F.M. PETER. 1988. BioDiversity. National Academy Press. Washington, D.C. 521 pp.

Appendix A. Species list for the 5 m^2 coral reef microcosm. * = pacific species. Total: 534 species, 357 genera, 241 families, 96 orders (with suborders), 44 classes (with subclasses, 27 phyla (+2 subphyla), 4 kingdoms (+3 subkingdoms). Note: bacteria and nematodes are listed only where identification was possible without a specialist. An investigation of fungi, viruses, primarily parasitic genera and the minor phyla Prochlorophyta, Gnathostomulida, Mesozoa, Kinorhyncha, Entoprocta, Phoronida and Echiura not yet initiated, and would provide numerous additional species.

SUPERKINGDOM PROKARYOTAE
KINGDOM MONERA

DIVISION BACTERIA
O. Cytophagales
F. Cytophagaceae
Cytophaga sp.
F. Beggiatoaceae
Beggiatoa sp.

DIVISION CYANOPHYCOTA (Blue-Green Algae)
C. CYANOPHYCEAE
O. Chroococcales
F. Chroococcaceae
Microcystis aeruginosa
Microcystis montana
3 Microcystis spp.
Gomphosphaeria aponina
Johannesbaptista pellucida
O. Pleurocapsales
F. Pleurocapsaceae
4 Pleurocapsa spp.?
"Aplastidallies nsp."
F. (new families being described)
"Amoebabacter nsp."
"Axiobacter nsp."
"Nothrobacter megalum" nsp.
"Nothrobacter nsp."
O. Nostocales
F. Oscillatoriaceae
Porphyrosipho leurzii
Schizothrix mexicana
Schizothrix calcicola
Microcoleus lyngbyaceae
Oscillatoria lutea
Arthrospira sp.
Spirulina subsalsa
Spirulina major
F. Rivulariaceae
Calothrix crustacea
3 Calothrix spp.
F. Scytonemataceae
Scytonema hofmannii

SUPERKINGDOM EUKARYOTAE
KINGDOM PLANTAE

PHYLUM RHODOPHYCOTA (Red Algae)
C. RHODOPHYCEAE
S.C. BANGIOPHYCIDEAE
O. Porphyridiales
F. Goniotrichaceae
Goniotrichum alcidii
Erythrotrichia carnii
S.C.FLORIDEOPHYCIDEAE
O. Nemalionales
F. Acrochaetiaceae
Acrochaetium sagraenum
Rhodochortin corynosporoides
F. Gelidiaceae
Gelidium pusillum
F. Wurdemanniaceae
Wurdemannia miniata
O. Cryptonemiales
F. Peyssoneliaceae
Peyssonnelia sp.
several unidentified spp.
F. Corallinaceae
Mesophyllum mesomorphum
Lithothamnium ruptile
Sporolithon sp.
Neogoniolithon mammilarum
2-3 Neogoniolithon spp.
Lithoporella atlantica
Heteroderma farinosa
Jania capillacea
Amphiroa fragillissima
O. Gigartinales
F. Hypneaceae
Hypnea spinella
O. Rhodymeniales
F. Rhodymeniaceae
Fauchea peltata
Botryocladia occidentalis
Botryocladia pyriformis
F. Champiaceae
Coelothrix irregularis
O. Ceramiales
F. Ceramiaceae
Callithamnion balliae
Centroceras clavulatum
Spyridia filamentosa
F. Delesseriaceae
Hypoglossum tenuifolium
F. Rhodomelaceae
Polysiphonia subtillissima

Herposiphonia secunda
Lophosiphonia cristata
Acanthophora spicifera
Laurencia microcladia
Laurencia corallopsis
Chondria dasyphylla

PHYLUM CHROMOPHYCOTA
C. CRYPTOPHYCEAE
O. Cryptomonadales
F. Cryptomonadaceae
Cryptomonas sp.
Chilomonas sp.
C. BACILLARIOPHYCEAE (Diatoms)
O. Centrales
F. Hemidiscaceae
Actinocyclus sp.
O. Pennales
S.O. Araphidineae
F. Diatomaceae
Microtabella sp.
3 Licmophora sp.
Neosynedra sp.
Catacombas sp.
S.O. Biraphidineae
F. Naviculaceae
Seminavis sp.
Proschkinia sp.
4 Pleurosigma sp.
Gyrosigma sp.
Fallacea sp.
Diploneis sp.
F. Cymbellacea
3 Amphora spp.
F. Entomoneidaceae
Entamoneis sp.
F. Nitzschiaceae
3 Nitzschia spp.
Bacillaria sp.
Hantzschia sp.
Denticula sp.
F. Epithemiaceae
3 Rhopalodia spp.
F. Mastogloiaceae
Mastogloia sp.
S.O. Monorhaphidineae
F. Achnanthaceae
6 Cocconeis spp.
2 Acanthidium spp.
Anorthoneis sp.
C. DINOPHYCEAE (Dinoflagellates)
O. Gymnodiniales
F. Gymnodiniaceae
Amphidinium sp.
Gyrodinium sp.
2 Gymnodinium sp.
2 unidentified spp.
O. Peridinales
F. Gonyaulacaceae
Gonyaulax sp.
O. Prorocentrales
F. Prorocentraceae
2 Prorocentrum sp.
O. Zooxanthellales
F. Zooxanthellaceae
Zooxanthella microadriatica
C. PHAEOPHYCEAE (Brown Algae)
O. Ectocarpales
F. Ectocarpaceae
Giffordia mitchellae
Herponema tortugensis

PHYLUM CHLOROPHYCOTA (Green Algae)
C. CHLOROPHYCEAE
O. Ulvales
F. Ulvaceae
Enteromorpha compressa
O. Cladophorales
F. Cladophoraceae
Chaetomorpha linum
Cladophora crispula
Cladophora crystallina
Cladophora delicatula
O. Siphonales
F. Valoniaceae
Valonia aegagrophila
Dictyosphaeria ocellata
O. Bryopsidales
F. Derbesiaceae
Derbesia vaucherieformis
Derbesia lamarouxii
Derbesia marina
F. Caulerpaceae
Caulerpa taxifolia
Caulerpa mexicana
Caulerpa sertularioides
F. Codiaceae
Avrainvillea asarifolia
Avrainvillea longicaulis
Avrainvillea nigricians
Halimeda opuntia
Halimeda tuna
Halimeda incrassata
O. Coleochaetales
F. Coleochaetaceae
Coleochaete sp.

PHYLUM MAGNOLIOPHYTA
C. LILIOPSIDA
O. Hydrocharitales
F. Hydrocharitaceae
Thalassia testudinum

KINGDOM PROTISTA

PHYLUM PERCOLOZOA
C. HETEROLOBOSEA
O. Schizopyrenida
F. (new family being described)
"Bactoamoeba nsp."
Euhyperamoeba sp.
F. Vahlkampfiidae
2 Vahlkampfia spp.
C. PSEUDOCILIATA
F. Stephanopogonidae
Stephanopogon corona

Stephanopogon mobilensis

PHYLUM EUGLENOZOA
C. EUGLENOIDEA
O. Euglenida
S.O. Eutreptina
Eutreptia sp.
S.O. Heteronematina
Peranema sp.
Perinemopsis sp.
1 unidentified sp.
C. KINETOPLASTIDEA
O. Bodonida
S.O. Bodonina
F. Bondonidae
Bodo saltans
6 Bodo spp.

PHYLUM CHOANOZOA
C. CHOANOFLAGELLATA
O. Choanoflagellata
F. Codosigidae
Codosiga sp.
Monosiga sp.?
F. Salpingoecidae
Salpingoeca sp.

PHYLUM RHIZOPODA
C. LOBOSEA
F. Acanthamoebidae
Acanthamoeba gigantea
F. Hartmannellidae
Hartmannella sp.
F. Hyalodiscidae
Hyalodiscus sp.
F. Mayorellidae
Mayorella sp.
Vexillifera sp.
F. Reticulosidae
2 Penardia spp.
F. Saccamoebidae
Saccamoeba fulvum
F. Thecamoebidae
Thecamoeba sp.
F. Trichosphaeridae
Trichosphaerium platyxyrum
C. FILOSEA
F. Vampyrellidae
Nuclearia sp.
C.GRANULORETICULOSEA (Foraminifera)
F. Allogromiidae
2 Allogromia spp.
F. Ammodiscidae
Ammodiscus sp.
F. Astrorhizidae
Halyphysema sp.
F. Ataxophragmiidae
Clavulina cf. tricarinata
F. Bolivinitidae
Bolivina cf. paula
2 Bolivina spp.
F. Cibicidiidae
Cibicides sp.
F. Cymbaloporidae
Cymbaloporetta squamosa
F. Discorbidae
Discorbis rosea
Discorbis sp.
3 Rosalina spp.
F. Homotremidae
Homotrema rubrum
F. Peneroplidae
Laevipeneroplis protea
F. Miliolidae
8 Quinqueloculina spp.
Triloculina oblonga
Triloculina sp.
F. Planorbulinidae
Gypsina sp.
Planorbulina cf. acervalis
F. Siphoninidae
Siphonina cf. claibornensis
F. Soritidae
Archais angulatus
Cyclorbiculina compressa
Peneroplis pertusus
Sorites orbicula
F. Textulariidae
Textularia cf. conica

PHYLUM CILIOPHORA
C. KARYORELICTEA
F. Kentrophoridae
Kentrophorus flavum
C. POLYHYMENOPHOREA
S.C. HETEROTRICHIA
F. Blepharismidae
Anigsteinia clasissimum
Parablepharisma sp.
F. Condylostomatidae
Condylostoma sp.
F. Folliculinidae
Folliculina sp.
Magnifolliculina sp.
Metafolliculina sp.
Parafolliculina sp.
F. Peritromidae
2 Peritromus spp.
F. Protocruziidae
2 Protocruzia spp.
S.C. SPIROTRICHIA
F. Aspidiscidae
Aspidisca aculeata
6 Aspidisca spp.
F. Chaetospiridae
Chaetospira sp.
F. Discocephalidae
Psammocephalus sp.
F. Euplotidae
Certesia quadrinulceatum
Diophrys appendiculatus
Diophrys histrix
Diophrys irmgard
Diophrys scutum
Euplotes crassus
5 Euplotes spp.
F. Keronidae
2 Epiclintis spp.
Keronopsis rubra
4 Keronopsis spp.

F. Oxytrichidae
Tachysoma sp.
F. Psilotrichidae
Kiitricha marina
F. Ptycocyclidae
2 Favella spp.
F. Spirofilidae
Stichotricha simplex
F. Strombidiiae
Strombidium sp.
F. Uronychiidae
Uronychia trasfuga
Uronychia sp.
F. Urostylidae
2 Holosticha spp.
Uroleptus sp.
Urostyla sp.
C.OLIGOHYMENOPHOREA
S.C. SCUTICOCILIATA
F. Cinetochilidae
Cinetochilum marinum
F. Cyclidiidae
3 Cyclidium spp.
F. Pleuronematidae
3 Pleuronema spp.
F. Uronematidae
Uronema filicicum
S.C. PERITRICHA
F. Vaginicolidae
Cothurnia sp.
F. Vorticellidae
Vorticella marinum
Vorticella sp.
S.C. PENICULINA
F. Parameciidae
Paramecium sp.?
C. PROTOMATEA
F. Colepidae
2 Coleps spp.
F. Metacystidae
Metacystis elongata
Metacystis tesselata
Pelatractus grandis
F. Prorodontidae
Prorodon sp.
C. LITOSTOMATEA
F. Amphileptidae
Hemiophrys sp.
Litonotus sp.
Loxophyllum sp.
F. Enchelyidae
Enchelyodon sp.
F. Lacrymariidae
Lacrymaria olar
Lacrymaria coronata
2 Lacrymaria spp.

PHYLUM HELIOZOA
C. ACTINOPHRYIDEA
O. Actinophyrida
F. Actinophryidae
Actinophrys sol
Actinophrys vesiculata

KINGDOM ANIMALIA
SUBK. PHAGOCYTELLOZOA

PHYLUM PLACOZOA
Trichoplax adherens

SUBKINGDOM PARAZOA

PHYLUM PORIFERA
5 unidentified spp.
C. DEMOSPONGIAE
O. Homoscleropharida
F. Plakinidae
Plakina sp.
1 unidentified sp.?
O. Astrophorida
F. Geodiidae
2 Erylus spp.
Geodia gibberosa?
2 Geodia spp.
F. Pachastrellidae
Dercitus sp.
O. Spirophorida
F. Tetillidae
Cinachyrella sp.
O. Hadromerida
F. Suberitidae
Laxosuberites sp.
F. Spirastrellidae
Timea sp.
Spirastrella sp.
F. Clionidae
Cliona caribbaea?
2 Cliona spp.
Thoosa sp.
F. Tethyidae
Tethya actinia
Tethya sp.
F. Chondrosiidae
Chondrilla sp.
O. Axinellida ?
F. Axinellidae ?
1 unidentified sp.
O. Agelasida
F. Agelasidae
Scopalina sp.
O. Haplosclerida
F. Haliclonidae
Haliclona tubulifera
Haliclona cf. toxadocia
2 Haliclona spp.
F. Oceanapiidae
Oceanapia fistulosa
O. Poecilosclerida
F. Mycalidae
Mycale sp.
O. Halichondrida
F. Dexmoxyidae
Myrmekioderma sp.?
F. Halichondridae
2 Halichondria sp.?
C. CALCAREA
O. Clathrinida
F. Clathrinidae
Clathrina sp.
O. Leucettida
F. Leucettidae
Leucetta sp.
2 unidentifed spp. incerti-sedis

SUBKINGDOM EUMETAZOA

PHYLUM CNIDARIA
C. HYDROZOA
3 unidentified spp.
O. Hyroida

F. Eudendridae
Eudendrium sp. ?
F. Olindiiae
Microhydrula sp.
C. ANTHOZOA
O. Gorgonacea
F. Plexauridae
Eunicea sp.
F. Anthothelidae
Erythropodium caribaeorum
F. Briareum
Briareum asbestinum
O. Alcyonacea
F. Alcyoniidae
*Sarcophyton trocheliophorum**
*Sinularia sp.**
O. Actinaria
F. Actiniidae
Anthopleura krebsi
Anthopleura sp.
Condylactis gigantea
F. Aiptasiidae
Aiptasia sp.
F. Stichodactylidae
Stichodactyla helianthus
O. Corallimorpharia
F. Actinodiscidae
Rhodactis sanctithomae
2 Discosoma spp.
Orinia sp.
F. Corallimorphidae
Corynactis parvula
Corynactis sp.
Ricordea florida
O. Scleractinia
F. Acroporidae
*Acropora sp.**
Montipora digitata *
F. Caryophylliidae
*Physogyra sp.**
F. Faviidae
Montastrea cavernosa
Diploria clivosa
Diploria labyrinthiformis
F. Mussidae
Isophyllia sp.
F. Poritidae
Porites porites
Porites divaricatus
Porites asteroides
O. Zoanthinaria
F. Zoanthidae
Palythoa caribaeorum
2 Zoanthus spp.
O. Ceriantharia
1 unidentified sp.

PHYLUM PLATYHELMINTHES
O. Acoela
F. ?
Amphiscolops sp.
F. Anaperidae
2 Anaperus spp.
Convoluta sp.
O. Nemertodermatida
F. Nemertodermatidae
Nemertoderma sp.
O. Kalyptorhychia
Gyrotrix sp.

PHYLUM NEMERTEA
C. ANOPLA
O. Palaeonemertea
1 unidentified sp. (new?)
O. Heteronemertea
1 unidentified sp.
F. Micruridae
Micrura vanderhosti
F. Lineidae
Lineus albocinctus?

PHYLUM GASTROTRICHA
F. Chaetonotidae
Chaetonotus sp.
1 unidentified sp.

PHYLUM ROTIFERA
2 unidentified spp.

PHYLUM TARDIGRADA
F. Batillipedidae
Batillipes sp.

PHYLUM NEMATA (Nematodes)
F. Draconematidae
Dracograllus sp.
2 unidentified spp.

PHYLUM MOLLUSCA
C. POLYPLACOPHORA
O. Acanthochitonida
F. Acanthochitonidae
Acanthochitona pygmaea
C. GASTROPODA
O. Archaeogastropoda
F. Fissurellidae
Diadora sp.
Rimula sp.
F. Acmaeidae
1 unidentified sp.
F. Trochidae
Calliostoma sp.
F. Turbinidae
Turbo canicularia
F. Phasianellidae
Tricolia bella
F. Neritidae
Smaragdia viridis
O. Mesogastropoda
F. Rissoidae
Rissoina sp.
F. Rissoellidae
1 unidentified sp.
F. Vitrinellidae
1 unidentified sp.
F. Vermetidae
Petalochoncus varians
F. Phyramidellidae
1 unidentified sp.
O. Neogastropoda
F. Fasciolariidae
Latirus sp.

Fasciolaria hunterii
F. Olividae
1 unidentified sp.
F. Marginellidae
Volvarina albolineata
F. Mitridae
1 unidentified sp.
O. Cephalaspidea
F. Bullidae
Bulla sp.
3 unidentifed spp. incerti-sedis
C. BIVALVIA
1 unidentified sp.
O. Mytiloida
F. Mytilidae
Lithophaga antillarum
Lithophaga bisulcata
O. Arcoida
F. Arcidae
Barbatia domingensis
Barbatia canallaria
F. Glycymerididae
Glycymeris pectinata
O. Pterioida
F. Isognomonidae
Isognomon radiatus
O. Limoida
F. Limidae
Limea bronniana
O. Ostreoida
F. Pectinidae
1 unidentified sp.
O. Hippuritoida
F. Chamidae
Chama sinuosa
O. Veneroida
F. Lucinidae
Lucina sp.
Codakia orbicularis
F. Carditidae
1 unidentified sp.
F. Tridacnidae
*Tridacna maxima**
*Tridacna derasa**
F. Tellinidae
Tellina listeri

PHYLUM ANNELIDA
C. POLYCHAETA
O. Phyllodocida
F. Syllidae
Haplosyllis spongicola
Amblyosyllis speciosa?
1 unidentified sp.
O. Amphinomida
F. Amphinomidae
Pareurythoe sp.
O. Eunicida
F. Eunicidae
Nematonereis sp.
3 unidentified sp.
F. Lumbrineridae
Lumbrineris sp.
F. Dorvilleidae
1 unidentified sp.
O. Orbiniida
F. Orbiniidae
1 unidentified sp.
O. Spionida
F. Spionidae
1 unidentified sp.
O. Chaetopterida
F. Chaetopteridae
Phyllochaetopterus sp.
O. Cirratulida
F. Paraonidae
Cirrophorus sp.
F. Cirratulidae
Timarete sp.
Cirriformia sp.
2 unidentified spp.
O. Ctenodrilida
F. Ctenodrilidae
Ctenodrilus serratus
O. Capitellida
F. Capitellidae
Neoheteromastus sp.
Scyphoproctus sp.
Capitella sp.
F. Maldanidae
Euclymene sp.
O. Oweniida
F. Oweniidae
1 unidentified sp.
O. Terebellida
F. Terebellidae
2 Thelepus spp.
O. Sabellida
F. Sabellidae
2 Notaulax spp.
3 Bispira spp.
8 unidentified spp.
S.F. Fabriciinae
New Genus (to be described)
F. Serpulidae
Vermiliopsis cf. annulata
Semivermilia pomatostegoides
Pomatostegus stellatus
Spiraserpula caribensis
Hydroides gairacensis
Salmacinopsis setosa ?
F. Spirorbidae
Vinearia koehleri
Janua pagenstecheri (epichysis)
O. Dinophilida
F. Dinophilidae
Dinophilus sp.

PHYLUM SIPUNCULA
F. Golfingiidae
Golfinigia sp. ?
F. Phascolosomatidae
Apionsoma misakianum
Phascolosoma perlucens
Phascolosoma nigrescens
F. Phascolionidae
Phascolion gerardi
F. Aspidosiphonidae
Lithocrosiphon cristatus
Aspidosiphon laevis
Aspidosiphon fischeri

PHYLUM ARTHROPODA
C. ARACHNIDA

O. Acariformes
F. Halacaridae
Halacarid mite
C. CRUSTACEA
S.C. OSTRACODA
O. Podocopnia
2 unidentified spp.
F. Cyprididae
Argilloecia sp.
Paracypris sp.
F. Bairdiiae
Bairdia hirsuta
F. Paradoxostomatidae
Paradoxostoma sp.
S.C. COPEPODA
O. Calanoida
F. Pseudocyclopidae
Pseudocylops sp.
F. Ridgewayiidae
Ridgewayia gracilis
Ridgewayia sp.
O. Harpacticoida
F. Ambunguipedidae
Ambunguipes sp.
F. Argestidae
1 unidentified sp. (new)
F. Diosaccidae
Amphiascoides sp.
F. Harpacticidae
Harpacticus sp.
F. Louriniidae
Lourinia sp.
F. Thalestridae
Dactylopusia sp.
F. Tisbidae
Tisbe sp.
S.C. MALACOSTRACA
O. Mysidacea
F. Mysidae
Heteromysis sp.
O. Tanaidacea
F. Apseudidae
2 *Apseudes* nspp.
F. Paratanaidae
Leptochelia dubia
F. Tanaidae
1 unidentified sp. (new)
O. Isopoda
F. Paranthuridae
Accalathura setosa
F. Sphaeromatidae
Paracereis caudata
F. Stenetriidae
Stenetrium stebbingi
F. Janiridae
Carpias algicola
O. Amphipoda
F. Lysianassidae
Shoemakerella sp.
F. Gammaridae
Cerodocus sheardi
Maera sp.
Elasmopus sp.
Parelasmopus sp. ?
F. Leucothoidae
Leucothoe sp.
F. Anamixidae
Anamixis sp.
F. Corophiidae
Bemlos sp.
F. Amphithoidae
Ampithoe ramondi
Cymadusa sp.
O. Decapoda
F. Alpheidae
Alpheus normanni
Snyalpheus townsendi
F. Hippolytidae
Thor dobkini
Thor amboinensis
F. Nephropidae
*Enoplometopus occidentalis**
F. Diogenidae
Clibanarius tricolor
F. Xanthidae
Lobopilumnus agassizii
1 unidentified sp.

PHYLUM ECHINODERMATA
C. STELLEROIDEA
O. Ophiurida
F. Ophiocomidae
Ophiocoma echinata
F. Ophiactidae
Ophiactus sp.
C. ECHINOIDEA
O. Cidaroida
F. Cidaroidae
Eucidaris tribuloides
O. Temnopleuroida
F. Toxopneustidae
Lytechinus variegatus
C. HOLOTHURIIDAE
O. Aspidochirotida
F. Holothuriidae
Holothuria floridana
O. Apodida
F. Chiridotidae
Chiridota rotifera

PHYLUM CHORDATA
SUBPHYLUM TUNICATA
C. ASCIDIACEA
1 unidentified sp.

SUBPHYLUM VERTEBRATA
C. OSTEICHTHES
O. Perciformes
F. Grammidae
Gramma loreto
F. Chaetodontidae
Holocanthus tricolor
F. Pomacentridae
*Chromis caeruleus**
Chromis insolata
*Amphiprion percula**
*Parglyphidodon oxydon**
*Chrysiptera cyanea**
F. Acanthuridae
*Zebrasoma flavescens**