

# **LIVE ROCK AQUACULTURE**

## **FINAL REPORT**

**PREPARED FOR THE NATIONAL SCIENCE FOUNDATION**

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**FIG. 1. FLORIDA AQUACULTURED LIVE ROCK IN OFFICE OF SECRETARY OF COMMERCE EVANS, WASHINGTON, D.C.**

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# INTERDISCIPLINARY LIVE ROCK PROJECT

(1998-2003)

## BACKGROUND

### *Minireefs*

The United States is the world's largest consumer of tropical fish with the marine minireef as the fastest growing segment of the industry. The minireef is an aquarium that can range in size from 15 to several hundred gallons and costs from hundreds to tens of thousands of dollars. When fully stocked, the minireef contains colorful and exotic marine fish and invertebrates. The backbone of the tank is live rock - large pieces of dead coral and non-coral limestone permeated with bacteria and encrusted with an array of algae and other organisms that serve as chemical and biological filters essential to the balance of the ecosystem. Unlike freshwater or saltwater tanks, reef aquaria are self-contained ecosystems. This means that feeding the tank is unnecessary. A symbiosis occurs between the algae, invertebrates and fish. Correct lighting and a balanced biological filter imitate ocean conditions so the ecosystem will survive.

Hundreds of other species of marine organisms can also be present on the live rock. These include: tube worms, tunicates, anemones, sponges, brittle stars, sea urchins, crabs, shrimp, mollusks, sea fans and corals. A minireef requires two pounds of live rock for each gallon of water the aquarium holds. However, the demand for wild live rock and stony corals contributed to the decline of reefs that led to a "collection ban" in both State and Federal waters.

### *State and Federal Ban*

The harvesting of "wild" live rock was prohibited by the Federal government on January 1, 1997, leaving behind an estimated 10 million dollar a year industry in Florida. This ban followed a previous 1989 Florida ban on harvesting in state waters, which extends 3 nautical miles offshore into the Atlantic, and 9 miles in the Gulf of Mexico. The rationale for these bans on harvesting was due to the decline in reefs from over collecting, often done with the aid of destructive chemicals and tools such as explosives and crow bars which chip the rock into small pieces. Florida live rock harvesting prior to the ban had reached an estimated 300 tons annually.

In Florida, the primary sources of "wild" live rock came from the mounds of dead coral along the Florida Reef Tract and the limestone ledges off the Gulf Coast. The Florida Reef Tract, estimated to be 4,000 -7,000 years old, has a base of calcium carbonate. In theory the production of "new rock" on this reef is at best equal and may be falling behind that lost to natural erosion of the reef by the action of water. Around 1986, divers began to extract this material and all of the attached dependant living organisms for sale to salt-water aquarium enthusiasts as a basis to form miniature reefs.

In light of the new ban, the most promising ecological and economical alternative to the previous practice of harvesting wild "live rock" appears to be that of aquaculture. The federal government allows aquaculture in national waters. Permits are required from the State for the shallower water along the coastline. Currently, in the State of Florida 36 live rock aquaculture permits have been issued for sites of approximately one acre each.

## STUDY SITE LOCATIONS

In order to study aquacultured live rock, five study locations have been identified in various locations off the Florida coast. These include two Gulf sites located near Tarpon Springs and Clearwater; one site near Boca Grande in Charlotte Harbor, and two sites in the Florida Keys; one near Marathon Key and one near Islamorada. Figure 2 shows the locations of each of the five sites. Table 1 shows the depth and GPS coordinates of each site.

Live rock substrates, or “seed material,” have been placed at each site. For all sites substrates included: Concrete/Styrofoam, Clay, Suwannee, Bahama, and Miami Limestone.

The area off Tarpon Springs on the West coast of Florida has been reported by the Geothermal Aquaculture Research Foundation (GARF) to be quite rich in benthic fauna. Sub-tropical Gulf waters mix with the coastal river runoffs that filter through extensive grass beds to stimulate a lush growth of diverse organisms on hard bottom in this area.

Unfortunately, rock farming that requires two to four years of in-situ growth faces risks due to both natural and biological disasters. Large storms could move rock and damage the encrusting animals. Additionally, rocks can sink or move with currents. Temperature extremes may also cause slow growth or death. Also sand piles migrate along the ocean floor and can bury a pile of rock and then recede after the organisms have died.

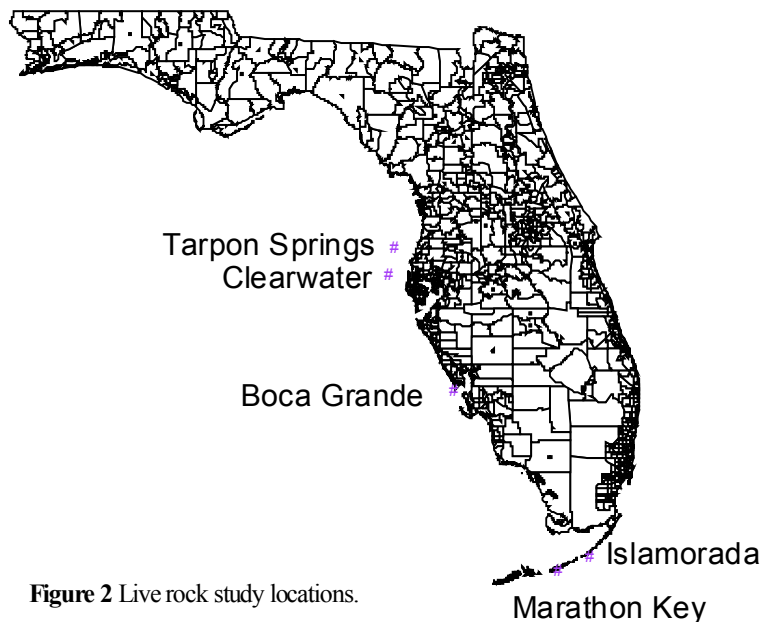


Figure 2 Live rock study locations.

Grazing organisms such as snails, which prevent algal overgrowths, can in large numbers strip the rock clean. Red tide can also kill most of the organisms on the rock.

Two sites in the study were affected by hurricanes and Florida storms. The Islamorada site in the Florida Keys was replanted, however, some of the original rock at the site resurfaced.

Additionally, a site originally planted at a southern Gulf site had to be abandoned. Clearly, there are many hazards associated with the live rock industry.

Video taping and photography of each site was conducted in order to document growth and species diversity at each study site during the course of the three year study. Representative rock specimens from each site and substrate were brought to the laboratory to undergo a full analysis.

After the rock reached full maturity (approximately three years), live rock harvesting was conducted. The rocks were hand collected in baskets and hauled to the surface where they were sorted and undesirable organisms removed. They were placed in buckets of water for transport and brought to large holding tanks where the rocks were spread for observation and analysis.

**Table 1. Depths (ft) and GPS Coordinates of the five study site locations.**

<b>Site Location</b>	<b>Approximate Site Depth (ft)</b>	<b>GPS Coordinates</b>
<b>Boca Grande</b>	12	N/A
<b>Islamorada</b>	21	N24E 51' .846 W80E 35' .914
<b>Marathon Key</b>	21	N24E 40' .250 W80E 58' .528
<b>Clearwater</b>	48	N28E 02' .762 W83E 01' .251
<b>Tarpon Springs</b>	31	N28E 20' .707 W82E 58' .257

## **ENVIRONMENTAL MONITORING**

In order to investigate the potential of artificially culturing and harvesting live rock, the optimal environmental growing conditions must first be identified. Environmental conditions were monitored at coastal locations in the Gulf of Mexico off the coast of Pinellas County, at Boca Grande and at two locations in the Florida Keys, Islamorada and Marathon Key. The environmental parameters and conditions included monitoring of the following:

- Temperature
- pH
- Dissolved Oxygen
- Turbidity
- Nutrients (phosphate/nitrate)
- Salinity
- Light
- Substrate Profile

HCC students have been actively involved in collecting and analyzing data at each of the sites, both in the field and in the laboratory.

## PHYSICAL/CHEMICAL TESTS

Physical/Chemical testing allows information to be gathered about specific water quality characteristics. A variety of water quality tests were conducted--including temperature, dissolved oxygen, pH, turbidity, phosphate, nitrate, salinity and light. Each of the parameters could affect the growth of organisms on rock. A Hydrolab multi-probe was used to measure temperature, ammonia, pH, light transmission, salinity, turbidity, and dissolved oxygen at each location. A water sample was collected from the live rock site and analyzed in the laboratory with a digital spectrometer by HACH. The same tests were done with the HACH as where done on site by the Hydrolab except nitrate and phosphorus. Each site had an Onset Temperature probe that recorded temperature each hour for three years.

This section highlights the chemical and physical tests conducted at each of the selected study sites and presents the results of those tests in the appendix.

### *TEMPERATURE*

Water temperature is one factor in determining which species may or may not be present in the ecosystem. Temperature affects feeding, reproduction, and the metabolism of aquatic organisms. Short time periods with abnormally high or low temperatures may create an unsuitable environment for sensitive aquatic organisms, even though temperatures are within tolerable levels throughout the rest of the year. Not only do different species have different requirements, but optimum habitat temperatures may change for each stage of life.

Temperature preferences among species vary widely, but most species can tolerate slow, seasonal changes better than rapid changes. Thermal stress and shock can occur when water temperatures change more than 1° to 2°C in 24 hours.

Many biological processes are affected by water temperature. Temperature differences between surface and bottom waters help produce the vertical water currents that move nutrients and oxygen throughout the water column.

Reported studies indicate that a constant temperature in the 70's (EF) is optimal for live rock growth.

Figures A-1 through A-5 show temperature data collected during the past year at each of the five sites. Additionally, Figures A-6 and A-7 illustrate the temperature data collected hourly via a thermocouple installed at the Clearwater and Charlotte Harbor study sites. The thermocouple will be placed at each of the other sites over the duration of the project as well in order to map out seasonal temperature fluctuations.

### *pH*

The pH test is one of the most common analyses in water testing. An indication of the sample's acidity, pH is actually a measurement of the activity of hydrogen ions in the sample. PH measurements are on a scale from 0 to 14, with 7.0 considered neutral. Solutions with a pH below 7.0 are considered acids; those between 7.0 and 14.0 are designated bases.

A range of pH 6.5 to pH 8.2 is optimal for most aquatic organisms. Rapidly growing algae or submerged aquatic vegetation remove carbon dioxide (CO<sub>2</sub>) from the water during photosynthesis. This can result in a significant increase in pH levels. Low or high pH can effect

egg hatching, kill sources of food for fish and insects, or make water impossible for any aquatic life to survive.

Figures A-8 through A-12 show the pH profiles for the five study sites.

***DISSOLVED OXYGEN***

Like land organisms, aquatic animals need dissolved oxygen (DO) to live. Fish, invertebrates, plants and aerobic bacteria all require oxygen for respiration.

Oxygen dissolves readily into water from the atmosphere at the surface until the water is "saturated." Once dissolved in water, the oxygen diffuses very slowly, and distribution depends on the movement of aerated water by turbulence and currents caused by wind, water flow and thermal upwelling. Aquatic plants, algae and phytoplankton as a by-product of photosynthesis produce oxygen.

The dissolved oxygen capacity of water is limited by the temperature and salinity of the water and the atmospheric pressure (which corresponds with altitude). These factors determine the highest amount of oxygen dissolved in water that is possible.

The temperature effect is compounded by the fact that living organisms increase their activity in warm water, requiring more oxygen to support their metabolism. Critically low oxygen levels often occur during the warmer summer months when decreased capacity and increased oxygen demand, caused by respiring algae or decaying organic material, coincide.

Additionally, oxygen is more easily dissolved into water that has low levels of dissolved or suspended solids. Therefore salt water tends to have lower concentrations of dissolved oxygen than fresh water. Table 2 illustrates this concept.

The amount of oxygen required varies according to species and stage of life. DO levels below 3 ppm are stressful to most aquatic organisms. DO levels below 2 or 1 ppm will not support fish; levels of 5 to 6 ppm are usually required for growth and activity. Fish and invertebrates that can move will leave areas with low dissolved oxygen and concentrate in areas with higher levels.

**TABLE 2. Solubility of Dissolved Oxygen in Salt Water.**

<b>Temperature, degrees Celsius</b>	<b>PPM O<sub>2</sub> Salinity 20 ppt</b>	<b>PPM O<sub>2</sub> Salinity 35 ppt</b>
10	9.9	9.0
15	8.9	8.1
20	8.1	7.4
22	7.8	7.1
24	7.5	6.9
26	7.2	6.6
28	7.0	6.4
30	6.8	6.2
35	6.2	5.8

A low dissolved oxygen level indicates a demand on the oxygen in the system. Pollutants, including inadequately treated sewage as well as decaying natural organic material, can cause such a demand. Organic materials accumulate in bottom sediments and support microorganisms (including bacteria) that consume oxygen as they break down the materials. Some wastes and pollutants produce direct chemical demands on any oxygen in the water.

Figures A-13 through A-17 show the dissolved oxygen profiles for the five study sites.

## ***TURBIDITY***

Turbidity is a measure of water clarity—how much the material suspended in water decreases the passage of light through the water. Suspended materials include soil particles (clay, silt, and sand), algae, plankton, microbes, and other substances. These materials are typically in the size range of 0.004 mm (clay) to 1.0 mm (sand). Turbidity can affect the color of the water. Higher turbidity increases water temperature because suspended particles absorb more heat. This, in turn, reduces the concentration of dissolved oxygen (DO) because warm water holds less DO than cold. Higher turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis and the production of DO. Suspended materials can clog fish gills, reducing resistance to disease in fish, lowering growth rates, and affecting egg and larval development.

Turbidity is generally measured by using a turbidity meter. A turbidity meter consists of a light source that illuminates a water sample and a photoelectric cell that measures the intensity of light scattered at a 90° angle by the particles in the sample. It measures turbidity in nephelometric turbidity units or NTUs. Meters can measure turbidity over a wide range—from 0 to 1000 NTUs. The higher the NTU, the greater the turbidity.

Figures A-18 through A-22 show the turbidity profiles for each of the five study sites.

## ***NUTRIENTS—Nitrate and Phosphate***

The addition of phosphorus, nitrogen and other nutrients to a body of water results in increased plant growth. Plants, especially algae, are very efficient users of phosphorus and nitrogen. Unpolluted waters generally have a nitrate level below 4.4 ppm.

Phosphorus occurs in natural waters in the form of phosphates. Dissolved phosphates are incorporated by plants and passed to animals in the food web. Phosphorus reenters the environment directly by animal excrement and by detritus decay. Each year large quantities of phosphate are washed into the oceans where much of it settles to the bottom and is incorporated into the marine sediments. Sediments may release some of the phosphate needed by aquatic organisms and the rest may become buried.

Test results are expressed as phosphate in mg/l (P04). Phosphate levels higher than 0.03 ppm contribute to increased plant growth. Figures A-23 through A-27 show the nutrient results for the five study sites.

## ***SALINITY***

Salinity can be referred to as the total amount of soluble salts in water or soils. There is a constant ratio between the six major elements (chlorine, sodium, magnesium, sulfur, calcium, and potassium) and the three minor elements (bromine, strontium, and boron) in marine water. Therefore, if the concentration of one element is known, the others can be calculated for salt-water environments. In some fresh water locations, with minimal salts, this may not hold true. Freshwater contains few salts; drinking water usually has a salinity of less than .5 ppt, while seawater averages 33-35 ppt.

With the addition of salt to water osmotic pressure increases, reflected by the increased amount of ions in the water, conductivity increases. Water density increases with increased salinity. The effects of density may result in a majority of functional changes such as feeding, movement, and dispersal differences. Increased salinity results in boiling point elevation and freezing point depression, which can produce temperature differences in shallow systems. Figures A-28 through A-32 show the salinity profiles for each study site.

## ***LIGHT***

Adequate light is considered necessary for sustained live rock growth. Table 3 below illustrates the percent of transmitted light at each of the five study sites.

**Table 3. Depth (m) and % light transmitted at each study location.**

<b>Site Location</b>	<b>Site Depth (m)</b>	<b>% Light Transmitted</b>
<b>Boca Grande</b>	2.03	11.9
<b>Islamorada</b>	6.77	52
<b>Marathon Key</b>	6.3	25.6
<b>Clearwater</b>	15.03	7.2
<b>Tarpon Springs</b>	8.73	10.5

## ***SUBSTRATE PROFILE***

Five different rock substrates are being studied. These include: concrete/Styrofoam, clay (pottery), Miami Limestone, Suwannee Limestone and Bahama Limestone. Each of the substrates was analyzed for their nitrogen, phosphorus, pH and potassium content. Gulf of Mexico sand and rock from Fiji was also analyzed. The results are given in Table 4.

**Table 4. Chemical analyses of the substrates.**

<b>(ppm)</b>	<b>Concrete/ Styrofoam</b>	<b>Clay</b>	<b>Miami Limestone</b>	<b>Suwannee Limestone</b>	<b>Bahama Limestone</b>	<b>Fiji</b>	<b>Gulf Sand</b>
<b>Nitrogen</b>	30	5	5	5	5	30	5
<b>Phosphorus</b>	50	75	12.5	37.5	5	37.5	37.5
<b>pH</b>	11.5	7.5	8.5	7.5	8	8	8
<b>Potassium</b>	200	50	50	70	45	200	200

Figure 3 shows the two artificial substrates used: concrete with Styrofoam beads and clay. Figure 4 shows the three natural limestone substrates used in this study: Ocala, Miami, and Homestead.

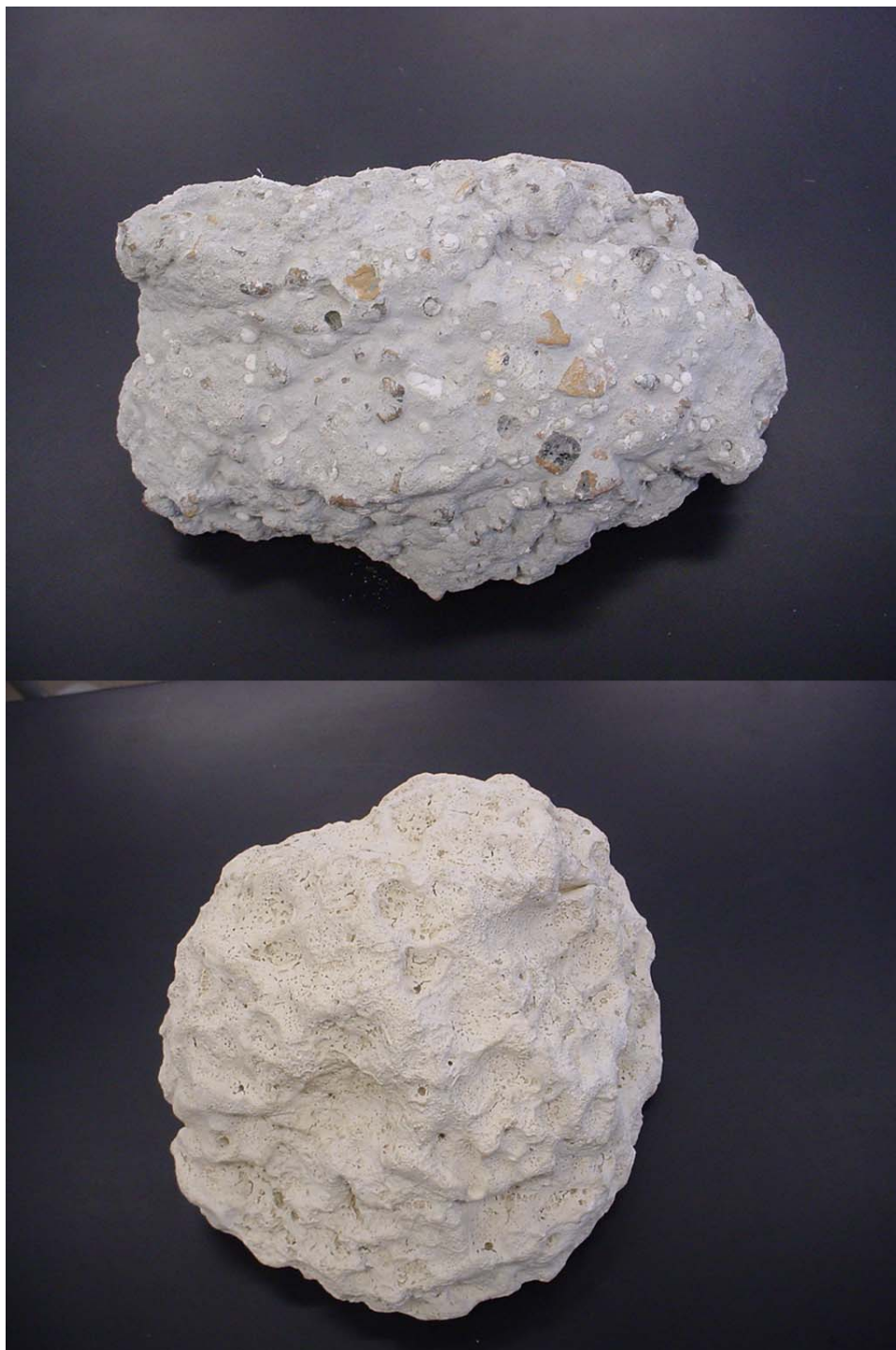


Figure 3. Upper is concrete/Styrofoam and bottom is clay artificial rock.

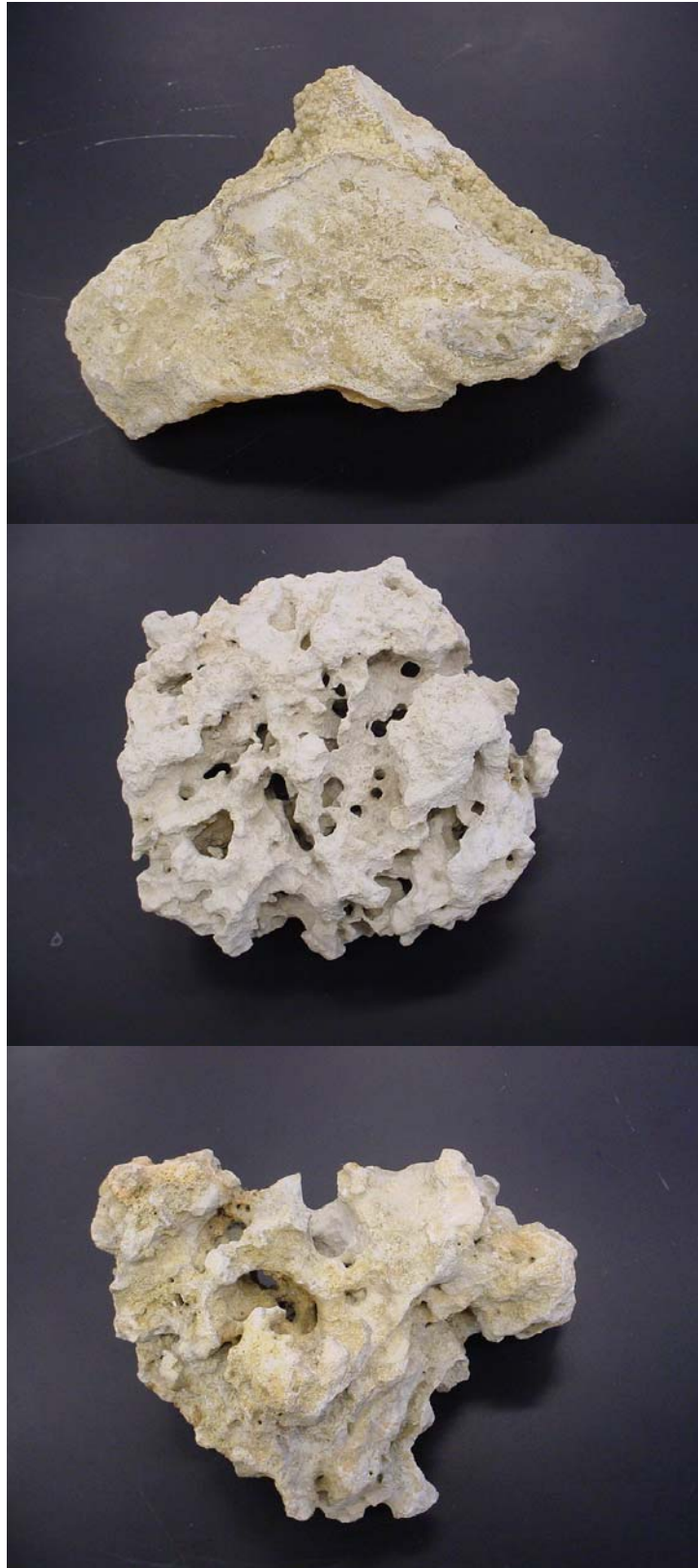


Figure 4. Three natural limestone rocks used in this study: (top) Ocala; (middle) Homestead; and (bottom) Bahama.

## **IDENTIFICATION OF ORGANISMS**

The identification of aquatic organisms on the five substrates took place with rock samples in the college laboratory. The two Gulf sites, Clearwater and Tarpon Springs, had rock under culture for two years on August 18 and 23, respectively. The Charlotte Harbor site was planted on November 11, 1998, the Islamorada site on March 16, 1999 (the third time due to Hurricanes George and Mitch), and the Marathon site was on March 17, 1999. Three rocks of each substrate type have been brought into the lab and maintained in aquaria. Students in the Aquaculture Program identified the organisms to the species level. Aquaculture students also cataloged the species and maintained the database. An HCC Aquaculture graduate who has begun Graduate School at the University of South Florida (USF) assisted in the identification process and used the project as Directed Research under Dr. Falls who is an Adjunct Professor at USF. Faculty worked with the students to teach them identification methods and the counting method used in the analysis.

## **INTERDISCIPLINARY APPROACH**

The interdisciplinary approach, which involves students and professors from the Aquaculture Program, Environmental Program, and the Art Program, has worked well and can be described as multi-disciplinary. Students from all three programs worked side by side at HCC's pottery studio in the summer of 1998 making items for the five sites. Students in biology, education, and geology also worked on the pottery aspect of the project. Students have been involved in all aspects of this project and new students were involved in every aspect of the project each semester.

## **SUMMARY OF ACTIVITIES**

The pre-project activities started in June of 1998 with the purchasing of equipment and rock. Rock was purchased for 5 sites. We were able to plant on five locations by contracting two live rock aquaculturists that have multiple sites in both the Gulf of Mexico and the Florida Keys, and we have a clam company in Charlotte Harbor that bought their own rock and planted it for us to monitor and include in our data.

The project officially started on August 1, 1998 when rock was placed at the first site in Islamorada, FL. On September 25-27, 1998 Hurricane George destroyed the site. Over \$700,000 in damages from live rock aquaculturists were filed from this Federal Disaster Area with the USDA. This site was replanted on October 31, 1998 to have it destroyed by Hurricane Mitch on November 4 -5, 1998. We replanted the third time on March 16, 1999 and added Marathon, FL in the Keys on March 17, 1998.

Sampling was conducted quarterly on all sites, but has been hampered by high seas on several occasions. Students and professors alike saw the constraints that live rock aquaculturists have to contend with. This is an excellent learning tool. The students became professionals at conducting water quality analyses using electronic equipment like the Hydrolab, and spectrophotometer, and the Onset Temperature probes that record temperature every hour for 3000 days.

A live rock workshop was held on July 17, 1998 sponsored by HCC, Sea Critters, and Triton Marine. Law enforcement officers from the USFWS Service, the FL Marine Patrol, US Customs, and representatives from the agencies in Washington, D.C. were present. We focused the workshop on identifying wild "illegal" live rock from the U.S. and aquacultured live rock.

Over 25 participants were present and it was well received. Students were involved in the workshop as well.

The NSF Project has been presented at Aquaculture America '99 in January of 2000 in Tampa, at the Florida Aquarium's Lecture Series and live on the local education TV station at the same time, at Sea World of Florida when they hosted the Public Aquarium Aquatic Health Seminar.

In 2001, the results of this project were presented at the 2<sup>nd</sup> International Marine Ornaments Conference, Orlando, FL. The Florida SeaGrant asked offered us a chapter in a book of selects proceedings from this conference. The book "Marine Ornaments" was published inn 2003. Chapter 14 is the chapter on Live Rock Aquaculture. A similar article was published in June 2003 to the World Aquaculture Magazine. Aquacultured live rock made the front cover of the magazine.

The final results in this report were presented in February 2003 at the Aquaculture America 2003 Conference of the World Aquaculture Society in Louisville, KY.

Due to this study there are marine aquaria in the NOAA Sea Grant Office, Silver Springs, Maryland (Fig. 5) and the Secretary of Commerce Evans Office in Washington, D.C. (Figs. 1 & 6).

**Figure 5. Florida Aquacultured Live Rock in NOAA Sea Grant Office, Silver Springs, Maryland.**





**Fig. 6. Florida Aquacultured Live Rock in Secretary of Commerce Evans Office, Washington, D. C.**

## **Analysis Methodology**

Fifteen rocks, three of each substrate type, were analyzed for identification of organisms to the smallest classification possible (species). The organisms were analyzed according to the amount of coverage (cm squared) or number of individuals. A Plexiglas grid was created, laid over the rock, and used to measure the coverage of encrusting organisms on each rock. The data was entered into a database and analyzed. Note: a complete listing of the organisms and their scientific names is located in appendix B.

## **Results**

For each type of rock, the number of organisms was recorded, each organism was identified and counted, and the per cent coverage was determined by the use of an overlay grid. The data was compared per type of rock and per location. The data is broken down per rock, and per location in the following sections.

### **Organism coverage per location**

The top five organisms per location are listed in the following charts (note the numbers represent the top 5 per location according to the total centimeters of coverage of each organism):

**Table 5. Port Charlotte site's top five organisms by centimeter coverage per rock.**

<b>Rank</b>	<b>Organism</b>	<b>Cm</b>	<b>Site</b>
1	Serpulid worm	3022	Charlotte Harbor
2	Coralline algae	2188	Charlotte Harbor
3	Red Bryozoan	1652	Charlotte Harbor
4	Serpulid Worm Long	1000	Charlotte Harbor
5	Brown Algae	400	Charlotte Harbor

**Table 6. Clearwater site's top five organisms by centimeter coverage per rock.**

<b>Rank</b>	<b>Organism</b>	<b>Cm</b>	<b>Site</b>
1	Serpulid worm	4533	Clearwater
2	Coralline algae	3371	Clearwater
3	Red Bryozoan	2563	Clearwater
4	Serpulid Worm Long	1500	Clearwater
5	Red Algae	688	Clearwater

**Table 7. Islamorada site's top five organisms by centimeter coverage per rock.**

<b>Rank</b>	<b>Organism</b>	<b>Cm</b>	<b>Site</b>
1	Serpulid worm	4687	Islamorada
2	Coralline algae	3648	Islamorada
3	Red Bryozoan	2098	Islamorada
4	Serpulid Worm Long	1250	Islamorada
5	Red Algae	793	Islamorada

**Table 8. Marathon site's top five organisms by centimeter coverage per rock.**

<b>Rank</b>	<b>Organism</b>	<b>Cm</b>	<b>Site</b>
1	Serpulid worm	3934	Marathon
2	Coralline algae	3146	Marathon
3	Red Bryozoan	1747	Marathon
4	Serpulid Worm Long	1000	Marathon
5	Red Algae	773	Marathon

**Table 9. Tarpon Springs site's top five organisms by centimeter coverage per rock.**

<b>Rank</b>	<b>Organism</b>	<b>Cm</b>	<b>Site</b>
1	Serpulid worm	3785	Tarpon Springs
2	Coralline algae	2827	Tarpon Springs
3	Red Bryozoan	2165	Tarpon Springs
4	Serpulid Worm Long	1250	Tarpon Springs
5	Red Algae	608	Tarpon Springs

The most abundant organism per centimeter coverage on the rocks is the Serpulid worms. Two types are noted in the above charts. Serpulid worms are polychaete worms of the family Serpulidae. These are tube dwelling polychaetes commonly called “fan worms” or “feather duster worms”. They create protective tubes along the surface of rock. From the rock they extend their feathery tentacles to exchange gases and to suspension feed. For Live Rock usage in aquaria, worms are excellent organisms to have in the tank.

There are no significant differences among the locations of the rocks based upon the coverage of organisms on the rock.

**Organism coverage as a per cent of the total**

As the organisms were identified on each rock, the per cent coverage of each organism was computed to determine which of the organisms was the most dominant per rock and per location. The following charts show the top 5 organisms as a percentage of growth at each location.

**Table 10. Port Charlotte site’s top five organisms by percentage coverage of each rock.**

Rank	Organism	Percent coverage	Site
1	Serpulid worm	17.60	Charlotte Harbor
2	Barnacle	10.00	Charlotte Harbor
3	Red Bryozoan	5.00	Charlotte Harbor
4	Red Algae	3.26	Charlotte Harbor
5	Coralline algae	0.96	Charlotte Harbor

**Table 11. Clearwater site’s top five organisms by percentage coverage of each rock.**

Rank	Organism	Percent coverage	Site
1	Serpulid worm	16.50	Clearwater
2	Barnacle	10.00	Clearwater
3	Red Bryozoan	3.94	Clearwater
4	Red Algae	3.20	Clearwater
5	Coralline algae	0.73	Clearwater

**Table 12. Islamorada site’s top five organisms by percentage coverage of each rock.**

Rank	Organism	Percent Coverage	Site
1	Serpulid worm	16.67	Islamorada
2	Barnacle	10.00	Islamorada
3	Red Bryozoan	3.29	Islamorada
4	Red Algae	3.21	Islamorada
5	Coralline algae	0.64	Islamorada

**Table 13. Marathon site’s top five organisms by percentage coverage of each rock.**

Rank	Organism	Percent Coverage	Site
1	Serpulid worm	15.95	Marathon
2	Barnacle	10.00	Marathon
3	Red Bryozoan	4.77	Marathon
4	Red Algae	3.26	Marathon
5	Coralline algae	0.95	Marathon

**Table 14. Tarpon Springs site's top five organisms by percentage coverage of each rock.**

Rank	Organism	Percent Coverage	Site
1	Serpulid worm	15.71	Tarpon Springs
2	Barnacle	10.00	Tarpon Springs
3	Red Bryozoan	4.18	Tarpon Springs
4	Red Algae	2.97	Tarpon Springs
5	Coralline algae	1.40	Tarpon Springs

The rank order for percentage coverage on rocks is the same for all of the locations. No significant difference is noted. Again, the Serpulid worms are the dominant organisms at all of the locations.

**Organism coverage by type of rock**

In this analysis the growth of organisms is computed per type of rock as centimeter coverage to see if any specific type of rock would grow more organisms or a greater variety of organisms.

**Table 15. Bahama Rock coverage of organisms per centimeter.**

Rank	Organism	Cm coverage	Substrate
1	Coralline algae	1517	Bahama
2	Red Bryozoan	912	Bahama
3	Red Algae	337	Bahama
4	Serpulid worm	258	Bahama
5	Boring Serpulid Worms	240	Bahama

**Table 16. Clay top coverage of organisms per centimeter.**

Rank	Organism	Cm coverage	Substrate
1	Coralline algae	703	Clay
2	Red Bryozoan	374	Clay
3	Serpulid worm	219	Clay
4	Black Bryozoan	178	Clay
5	Red Algae	147	Clay

**Table 17. Concrete coverage of organisms per centimeter.**

Rank	Organism	Cm coverage	Substrate
1	Coralline algae	662	Concrete
2	Red Bryozoan	553	Concrete
3	Barnacle	295	Concrete
4	Striped Barnacle	256	Concrete
5	Serpulid worm	185	Concrete

**Table 18. Homestead rock coverage of organisms per centimeter.**

Rank	Organism	Cm coverage	Substrate
1	Fire Sponge	27	Homestead
2	Red Algae	10	Homestead
3	Pearly Orange Bryozoan	2	Homestead
4	Jewel Box	1	Homestead
5	Red Bryozoan	1	Homestead

**Table 19. Ocala Rock coverage of organisms per centimeter.**

Rank	Organism	Cm coverage	Substrate
1	Coralline algae	1545	Ocala
2	Red Bryozoan	884	Ocala
3	Serpulid worm	880	Ocala
4	Red Boring Sponge	675	Ocala
5	Serpulid Worm Long	250	Ocala

Variations occur among the rock types. In general coralline algae is the dominant organism for most of the rocks except the Homestead rock which has fire sponges covering 27 cm of the surface.

**Organism coverage as a percentage of surface by type of rock**

As the organisms were identified on each rock, the per cent coverage of each organism was computed to determine which of the organisms was the most dominant for each type of rock. The following charts show the top 5 organisms as a percentage of growth per each type of rock.

**Table 20. Bahama Rock coverage of organism by percentage.**

Rank	Organism	Percent coverage	Substrate
1	White encrusting worm	75.00	Bahama
2	Striped Barnacle	33.00	Bahama
3	Eastern oyster	30.00	Bahama
4	Bay Barnacle	20.00	Bahama
5	Brown Algae	11.43	Bahama

**Table 21. Clay coverage of organisms per centimeter.**

Rank	Organism	Percent coverage	Substrate
1	Brown fuzz Algae	90.00	Clay
2	Brown Algae	12.00	Clay
3	Coralline algae	8.88	Clay
4	Red Bryozoan	8.27	Clay
5	Red Algae	3.52	Clay

**Table 22. Concrete coverage of organisms per centimeter.**

Rank	Organism	Percent coverage	Substrate
1	Brown Algae	16.00	Concrete
2	Fine Brown Algae	10.00	Concrete
3	Red Bryozoan	9.68	Concrete
4	Coralline algae	4.76	Concrete
5	Worm Tubes	1.00	Concrete

**Table 23. Ocala Rock coverage of organisms per centimeter.**

Rank	Organism	Percent coverage	Substrate
1	Black Bryozoan	25.00	Ocala
2	Worm Tube	25.00	Ocala
3	Mermaid Cup	17.50	Ocala
4	Red Bryozoan	14.32	Ocala
5	Red Algae	11.35	Ocala

**Table 24. Homestead rock coverage of organisms per centimeter.**

Rank	Organism	Percent coverage	Substrate
1	Red Bryozoan	60.00	Homestead
2	Fire Sponge	1.00	Homestead
3	Jewel Box	1.00	Homestead
4	Pearly Orange Bryozoan	1.00	Homestead
5	Red Algae	1.00	Homestead

The percentage coverage of organisms on the rock varied from one type of rock to another. Sponges, brown algae, and bryozoans were the dominating organisms.

**Organism coverage by rock type per location based on centimeter coverage**

The coverage of organisms was rank ordered by location based upon the type of rock at each location. This was done to determine whether or not a type of rock grew more organisms at one location versus another. The following charts rank order the organisms per centimeter coverage on each rock.

**Table 25. Bahama rock organism coverage in centimeters at each location.**

<b>Rank</b>	<b>Organism</b>	<b>Cm coverage</b>	<b>Substrate</b>	<b>Site</b>
1	Coralline algae	80	Bahama	Tarpon Springs
2	Coralline algae	79	Bahama	Clearwater
3	Red Bryozoan	64	Bahama	Tarpon Springs
4	Red Bryozoan	58	Bahama	Clearwater
5	Red Algae	46	Bahama	Tarpon Springs
6	Red Algae	39	Bahama	Clearwater
7	Red Algae	39	Bahama	Marathon
8	Coralline algae	37	Bahama	Marathon
9	Red Bryozoan	22	Bahama	Marathon
10	Red Bryozoan	13	Bahama	Islamorada
11	Serpulid worm	13	Bahama	Tarpon Springs
12	Bryozoan	12	Bahama	Clearwater
13	Red Algae	12	Bahama	Islamorada
14	Bryozoan	12	Bahama	Tarpon Springs
15	Coralline algae	8	Bahama	Islamorada
16	Red Algae	7	Bahama	Charlotte Harbor
17	Serpulid worm	7	Bahama	Clearwater
18	Serpulid worm	7	Bahama	Islamorada
19	Serpulid worm	7	Bahama	Marathon
20	Red Bryozoan	6	Bahama	Charlotte Harbor
21	Serpulid worm	6	Bahama	Charlotte Harbor
22	Bryozoan	6	Bahama	Islamorada
23	Bryozoan	6	Bahama	Marathon
24	Snail	2	Bahama	Charlotte Harbor
25	Cladophora	1	Bahama	Charlotte Harbor

**Table 26. Clay organism coverage in centimeters at each location.**

<b>Rank</b>	<b>Organism</b>	<b>Cm coverage</b>	<b>Substrate</b>	<b>Site</b>
1	Red Algae	33	Clay	Clearwater
2	Red Algae	33	Clay	Marathon
3	Red Algae	33	Clay	Tarpon Springs
4	Red Bryozoan	28	Clay	Clearwater
5	Red Bryozoan	28	Clay	Marathon
6	Red Bryozoan	28	Clay	Tarpon Springs
7	Coralline algae	13	Clay	Clearwater
8	Coralline algae	13	Clay	Marathon
9	Coralline algae	13	Clay	Tarpon Springs
10	Pearly Orange Bryozoan	2	Clay	Clearwater
11	Pearly Orange Bryozoan	2	Clay	Marathon
12	Pearly Orange Bryozoan	2	Clay	Tarpon Springs
13	Bryozoan	1	Clay	Clearwater
14	Bryozoan	1	Clay	Marathon
15	Bryozoan	1	Clay	Tarpon Springs

**Table 26. Concrete organism coverage in centimeters at each location.**

Rank	Organism	Cm coverage	Substrate	Site
1	Red Bryozoan	34	Concrete	Clearwater
2	Red Bryozoan	34	Concrete	Marathon
3	Red Bryozoan	34	Concrete	Tarpon Springs
4	Red Algae	31	Concrete	Clearwater
5	Red Bryozoan	31	Concrete	Islamorada
6	Red Algae	31	Concrete	Marathon
7	Red Algae	31	Concrete	Tarpon Springs
8	Red Algae	25	Concrete	Islamorada
9	Coralline algae	6	Concrete	Clearwater
10	Coralline algae	6	Concrete	Islamorada
11	Coralline algae	6	Concrete	Marathon
12	Coralline algae	6	Concrete	Tarpon Springs
13	Pearly Orange Bryozoan	3	Concrete	Clearwater
14	Pearly Orange Bryozoan	3	Concrete	Marathon
15	Pearly Orange Bryozoan	3	Concrete	Tarpon Springs
16	Coral	2	Concrete	Clearwater
17	Coral	2	Concrete	Islamorada
18	Purple Reef Fan	2	Concrete	Islamorada
19	Coral	2	Concrete	Marathon
20	Coral	2	Concrete	Tarpon Springs

**Table 27. Ocala organism coverage in centimeters at each location.**

Rank	Organism	Cm coverage	Substrate	Site
1	Serpulid worm	4680	Ocala	Islamorada
2	Serpulid worm	4525	Ocala	Clearwater
3	Serpulid worm	3926	Ocala	Marathon
4	Serpulid worm	3771	Ocala	Tarpon Springs
5	Coralline algae	3634	Ocala	Islamorada
6	Coralline algae	3273	Ocala	Clearwater
7	Coralline algae	3090	Ocala	Marathon
8	Serpulid worm	3016	Ocala	Charlotte Harbor
9	Coralline algae	2728	Ocala	Tarpon Springs
10	Red Bryozoan	2442	Ocala	Clearwater
11	Coralline algae	2187	Ocala	Charlotte Harbor
12	Red Bryozoan	2053	Ocala	Islamorada
13	Red Bryozoan	2038	Ocala	Tarpon Springs
14	Red Bryozoan	1662	Ocala	Marathon
15	Red Bryozoan	1644	Ocala	Charlotte Harbor
16	Serpulid Worm Long	1500	Ocala	Clearwater
17	Serpulid Worm Long	1250	Ocala	Islamorada
18	Serpulid Worm Long	1250	Ocala	Tarpon Springs
19	Serpulid Worm Long	1000	Ocala	Charlotte Harbor
20	Serpulid Worm Long	1000	Ocala	Marathon
21	Barnacle	768	Ocala	Islamorada
22	Barnacle	672	Ocala	Marathon
23	Brown Algae	600	Ocala	Clearwater
24	Brown Algae	500	Ocala	Tarpon Springs
25	Brown Algae	400	Ocala	Charlotte Harbor

The dominant organisms for this analysis were red algae, bryozoans, Coralline algae, and Serpulid worms. The four types of organisms were dominant at all locations and for all types of rock. They are all good organisms to have on Live Rock in aquaria.

**Organism coverage by rock type per location based on percent coverage**

The coverage of organisms was rank ordered by location based upon the type of rock at each location. In this section the comparison is based on percentage of total rock by each organism. This was done to determine whether or not a type of rock grew more organisms at one location versus another. The following charts rank order the organisms by per cent coverage on each rock.

**Table 29. Bahama rock at each location (percentage of coverage of each organism).**

Rank	Organism	Percent coverage	Substrate	Site
1	Coralline algae	25.00	Bahama	Charlotte Harbor
2	Coralline algae	8.33	Bahama	Islamorada
3	Coralline algae	5.56	Bahama	Tarpon Springs
4	Coralline algae	5.00	Bahama	Marathon
5	Coralline algae	3.13	Bahama	Clearwater
6	Cladophora	Less than 1%	Bahama	Charlotte Harbor
7	Red Algae	Less than 1%	Bahama	Charlotte Harbor
8	Red Bryozoan	Less than 1%	Bahama	Charlotte Harbor
9	Serpulid worm	Less than 1%	Bahama	Charlotte Harbor
10	Bryozoan	Less than 1%	Bahama	Clearwater
11	Cladophora	Less than 1%	Bahama	Clearwater
12	Cyanobacteria	Less than 1%	Bahama	Clearwater
13	Jewel Box	Less than 1%	Bahama	Clearwater
14	Bryozoan	Less than 1%	Bahama	Islamorada
15	Cladophora	Less than 1%	Bahama	Islamorada
16	Cyanobacteria	Less than 1%	Bahama	Islamorada
17	Red Algae	Less than 1%	Bahama	Islamorada
18	Bryozoan	Less than 1%	Bahama	Marathon
19	Cladophora	Less than 1%	Bahama	Marathon
20	Cyanobacteria	Less than 1%	Bahama	Marathon
21	Red Algae	Less than 1%	Bahama	Marathon
22	Bryozoan	Less than 1%	Bahama	Tarpon Springs
23	Cladophora	Less than 1%	Bahama	Tarpon Springs
24	Cyanobacteria	Less than 1%	Bahama	Tarpon Springs
25	Jewel Box	Less than 1%	Bahama	Tarpon Springs

**Table 30. Clay per location as per cent of coverage of organism.**

<b>Rank</b>	<b>Organism</b>	<b>Percent coverage</b>	<b>Substrate</b>	<b>Site</b>
1	Bryozoan	Less than 1%	Clay	Clearwater
2	Coralline algae	Less than 1%	Clay	Clearwater
3	Fan Worm	Less than 1%	Clay	Clearwater
4	Jewel Box	Less than 1%	Clay	Clearwater
5	Pearly Orange Bryozoan	Less than 1%	Clay	Clearwater
6	Bryozoan	Less than 1%	Clay	Marathon
7	Coralline algae	Less than 1%	Clay	Marathon
8	Fan Worm	Less than 1%	Clay	Marathon
9	Jewel Box	Less than 1%	Clay	Marathon
10	Pearly Orange Bryozoan	Less than 1%	Clay	Marathon
11	Bryozoan	Less than 1%	Clay	Tarpon Springs
12	Coralline algae	Less than 1%	Clay	Tarpon Springs
13	Fan Worm	Less than 1%	Clay	Tarpon Springs
14	Jewel Box	Less than 1%	Clay	Tarpon Springs
15	Pearly Orange Bryozoan	Less than 1%	Clay	Tarpon Springs

**Table 31. Concrete per location as per cent coverage of organism.**

<b>Rank</b>	<b>Organism</b>	<b>Percent coverage</b>	<b>Substrate</b>	<b>Site</b>
1	Red Bryozoan	60.00	Concrete	Charlotte Harbor
2	Red Bryozoan	15.00	Concrete	Islamorada
3	Red Bryozoan	12.00	Concrete	Clearwater
4	Red Bryozoan	12.00	Concrete	Marathon
5	Red Bryozoan	12.00	Concrete	Tarpon Springs
6	Brown Worm	Less than 1%	Concrete	Clearwater
7	Coral	Less than 1%	Concrete	Clearwater
8	Coralline algae	Less than 1%	Concrete	Clearwater
9	Jewel Box	Less than 1%	Concrete	Clearwater
10	Coral	Less than 1%	Concrete	Islamorada
11	Coralline algae	Less than 1%	Concrete	Islamorada
12	Purple Reef Fan	Less than 1%	Concrete	Islamorada
13	Red Algae	Less than 1%	Concrete	Islamorada
14	Brown Worm	Less than 1%	Concrete	Marathon
15	Coral	Less than 1%	Concrete	Marathon
16	Coralline algae	Less than 1%	Concrete	Marathon
17	Jewel Box	Less than 1%	Concrete	Marathon
18	Brown Worm	Less than 1%	Concrete	Tarpon Springs
19	Coral	Less than 1%	Concrete	Tarpon Springs
20	Coralline algae	Less than 1%	Concrete	Tarpon Springs
21	Jewel Box	Less than 1%	Concrete	Tarpon Springs

**Table 32. Ocala rock per location percentage coverage of organism.**

Rank	Organism	Percent coverage	Substrate	Site
1	Red Bryozoan	75.00	Ocala	Tarpon Springs
2	Serpulid worm	18.33	Ocala	Charlotte Harbor
3	Serpulid worm	17.84	Ocala	Clearwater
4	Serpulid worm	17.74	Ocala	Tarpon Springs
5	Serpulid worm	17.50	Ocala	Islamorada
6	Serpulid worm	17.35	Ocala	Marathon
7	Barnacle	10.00	Ocala	Charlotte Harbor
8	Barnacle	10.00	Ocala	Clearwater
9	Barnacle	10.00	Ocala	Islamorada
10	Barnacle	10.00	Ocala	Marathon
11	Barnacle	10.00	Ocala	Tarpon Springs
12	Red Algae	4.07	Ocala	Tarpon Springs
13	Red Algae	4.00	Ocala	Clearwater
14	Red Algae	4.00	Ocala	Marathon
15	Red Algae	3.57	Ocala	Charlotte Harbor
16	Red Algae	3.54	Ocala	Islamorada
17	Red Bryozoan	2.69	Ocala	Marathon
18	Red Bryozoan	2.50	Ocala	Tarpon Springs
19	Red Bryozoan	2.12	Ocala	Clearwater
20	Coralline algae	Less than 1%	Ocala	Marathon
21	Coralline algae	Less than 1%	Ocala	Tarpon Springs
22	Coralline algae	Less than 1%	Ocala	Clearwater
23	Anemone	Less than 1%	Ocala	Charlotte Harbor
24	Brown Algae	Less than 1%	Ocala	Charlotte Harbor
25	Anemone	Less than 1%	Ocala	Islamorada
26	Brown Algae	Less than 1%	Ocala	Islamorada

In this analysis, red algae, bryozoans, Coralline algae, and Serpulid worms were once again the dominant organisms as percentage coverage. Most of the other organisms show less than one per cent of the total coverage per rock.

**Species Richness per Rock**

Species richness is simply the number of species per rock – an actual count. Sometimes the more species there are per rock; the more marketable the rock is for the aquarium trade. Below is the count of species richness for the types of rock in the study.

**Table 33. No. Species/rock type.**

Rock	# species
Ocala	57
Bahama	70
Clay	63
Concrete	48
Homestead	56

There appears to be a greater richness of organisms on the Bahama rock, with the clay coming in

second. The concrete rock and the Homestead rock grew fewer organisms than the other two types of rock.

### **Species Richness per Location**

Species richness can be compared from one location to another. The following is a count of the species per location.

**Table 35. Species/site.**

<b>Location</b>	<b>Species</b>
Charlotte Harbor	19
Clearwater	30
Islamorada	24
Marathon	27
Tarpon Springs	29

There appears to be very little difference between one location and another, with the exception of Charlotte Harbor. This location was in shallower water and subject to more environmental stress than the other locations.

Appendix B lists the complete list of species found on all substrate and locations combined. There were 98 different species of organisms identified to as least genus.

## **Conclusions**

The initial study of live rock centered on the recruitment of benthic organisms to the rock. There was a gradual progression of organisms attaching to the live rock, and over time the diversity and density of these organisms increased. There was a very distinct difference, however in the rock piles created for this project as compared to the live rock reefs constructed by commercial enterprises. The project rock sets were comprised of approximately 7500 pounds, 1500 pounds of each of the five substrate rock types. The 7500 pound rock sites were only 5 to 50 feet in diameter and 3 to 5 feet in height. The small size of the study sites resulted in much lower density and diversity of organisms, both benthic and pelagic compared to the much larger (100,000 to 600,000 pounds) commercial reefs. These large reefs were proficient fish attractors, providing thousands of niches for juvenile fish. They also provided thousands of holes for crustaceans, urchins, shrimp, and worms to take refuge. An evaluation of the first three months of the larger reefs saw primarily juvenile grunts, snapper, and tropical ornamentals inhabiting the reef. By six months a second set of juveniles had arrived and the initial group of fish had grown in size. A few small predator fish had moved in, primarily small grouper and lizardfish. Small soft corals, sea whips had recruited to the edges of the reefs. After one year of growth the reefs exhibited the entire trophic pyramid with hundreds of juveniles, hundreds of sub adults, and numerous adults of practically every fish common to the reef area. In the Keys reefs, dolphins were observed feeding from artificial reef to artificial reef on the abundance of fish. Large barracuda also have stationed themselves on each reef after the first year. The soft corals covered the entire surface of the reefs and scleractinian corals were first observed. Fire coral was present as small patches on most of the surface rock and by 15 months the fire coral had grown from a flat surface up to 6 inches in height. These observations on the commercial reefs, documented by

quarterly video taping, indicate that commercial aquaculture live rock reefs can have a very large, positive impact on the local marine ecosystems.

Five types of rock were placed in five different locations for the purpose of analyzing growth, whether or not it is adequate for live rock use in marine aquaria. The rocks were removed after 3 years, with an analysis of growth conducted; the types of organisms per rock and per location were analyzed. In all of the locations the physical parameters were measured and in all of the locations, they were sufficient to produce growth and have no negative impacts for live rock harvesting. The only physical deterrent to growth that was experienced was that of hurricanes. Growth of live rock can be devastated by a hurricane, as the rocks are scattered and buried by the strong currents associated with the storm.

There are some organisms that could grow on live rock, that are potentially harmful to a marine aquarium. Sponges and barnacles are two such categories. Sponges may spoil an entire aquarium when they die and disintegrate. Barnacles are a nuisance. Some algal species grow too rapidly and may overgrow a tank. In all of the rock harvested for this project, few had sponges and barnacles on them. Only the Ocala Rock contained 10 per cent barnacles, while sponges counted for less than one per cent of all of the organisms catalogued. The only nuisance algal species was the fine brown algae found on ten per cent of some of the rock.

Coralline algae are generally the preferred organisms on live rock. Bahama rock had the most coralline algae growth. Based on species diversity, Bahama rock was the best, however Bahama rock is no longer available. Miami limestone is the closest geologically to it. Both Gulf sites had more species per location than the Keys sites; however the Gulf rock was cultured for seven months longer due to two hurricanes in the Keys that destroyed the sites. The Charlotte Harbor site which was adjacent to aquacultured clam sites was the least preferred site. Light and water quality conditions were least favorable here. In addition, this site attracted stone crabs that preyed on clams and live rock both. This live rock site was referred to by clam farmers as “Stone Crab Hotel.”

Gulf and Keys live rock are not comparable. The environmental conditions and the organisms that grow on the rock are so different between the two areas that it is like comparing apples to oranges. This is good for the ornamental industry. Gulf rock is more tolerant of variable environmental conditions such as low light and colder water, whereas Keys rock has more narrow environmental tolerances, requires more light, constant temperature, but favors coral growth and lack of unwanted organisms such as barnacles and oysters. This difference allows the industry to produce two different products for different markets. It is like selling a utility vehicle and a sports car.

This study shows that Florida is capable of producing a valuable eco-friendly product that in our opinion is better than wild collected live rock. There is a market for this product and room for expansion in Florida and other states and countries. There is also the potential to move live rock aquaculture to land culturing it in closed recirculating or flow-through systems in tanks which is being done in Idaho, Texas, Hawaii, and now Florida. In such systems you can control the environmental conditions year round and do not have to deal with hurricanes. On land or in the sea, aquacultured live rock has a future.

### **Further study recommendations**

Based upon this initial project answers to the following questions are recommended for further live rock research:

1. Are fish recruits to aquacultured reefs coming from existing reefs?

2. Are live rock reefs providing niches for juvenile fish that would not survive because the natural system can not support them, particularly in light of the loss of extensive coral growth from the existing reefs?
3. Are live rock reefs a better method of repairing reefs damaged by ship groundings than current methods? A live rock reef can be transported and placed on the damaged site in a matter of weeks, and it would already be a viable productive reef system. There would be no recovery time. The larger commercial aquaculture reefs have proven to withstand the hurricane damage that buried the smaller test sites and they are constructed without having to cement or epoxy the rocks into place.
4. Are live rock reefs a better method of growing indigenous corals for transplanting to damaged reefs or for the aquarium trade?
5. Can live rock reefs be used exclusively for the production of ornamental tropicals and invertebrates to reduce the stress on natural systems and reduce damage from collection activities?
6. Can live rock reefs provide fish and invertebrate species for restocking areas damaged by pollution, taking the pressure of re-stocking off natural systems?
7. Can live rock be commercial reared economically in tanks?

#### **Other HCC Live Rock Publications:**

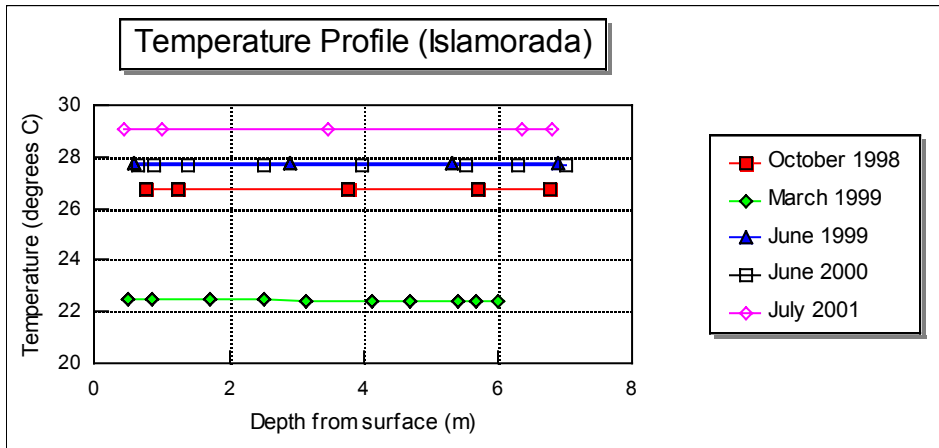
Ehringer, J. N. and F. J. Webb. 1993. Assessment of "Live Rock" Harvesting in Tampa Bay. Occasional Papers of the Institute of Florida Studies. No. 3. 19 pp.

Falls, W. W. and J. N. Ehringer, R. and T. Herndon, M. S. Nichols, S. Nettles, C. Armstrong, and D. Haverkamp. 2003. Aquacultured Live Rock as an Alternative to Imported Wild-Harvested Live Rock: An Update. in Marine Ornamental Species: Collection, Culture and Conservation. Eds. J. C. Cato and C. L. Brown. Iowa State Press. 488 pp.

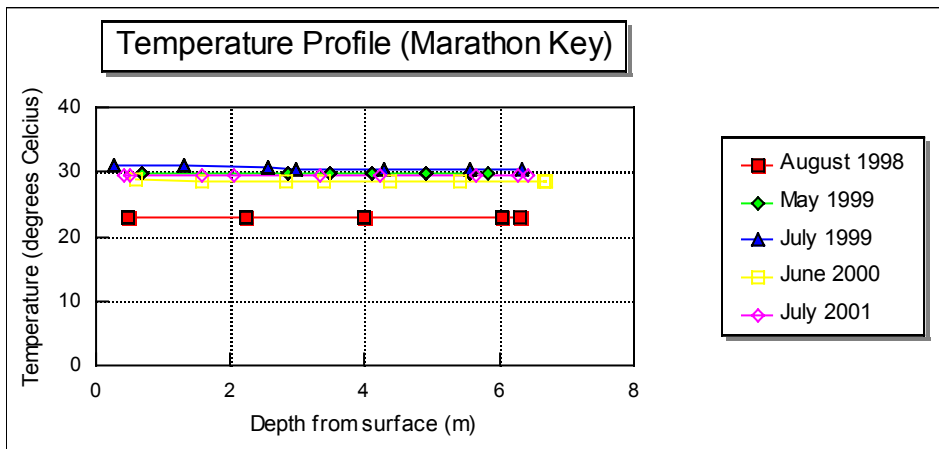
Falls, W. W. and J. N. Ehringer, R. and T. Herndon, M. S. Nichols, S. Nettles, C. Armstrong, and D. Haverkamp. 2003. Aquaculture of Live Rock: An Eco-friendly Alternative. World Aquaculture Magazine. June 2003 Vol. 34, No. 2. pp.39-44 & 72.

**APPENDIX A**

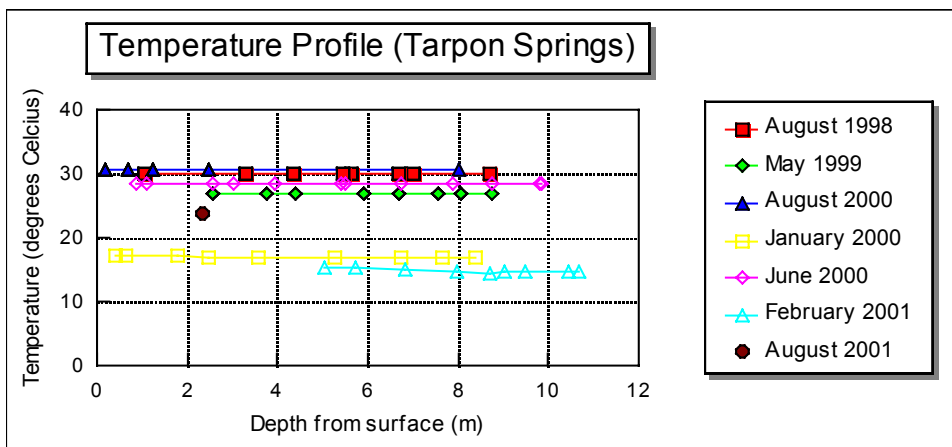
**Selected Water Quality Graphs**



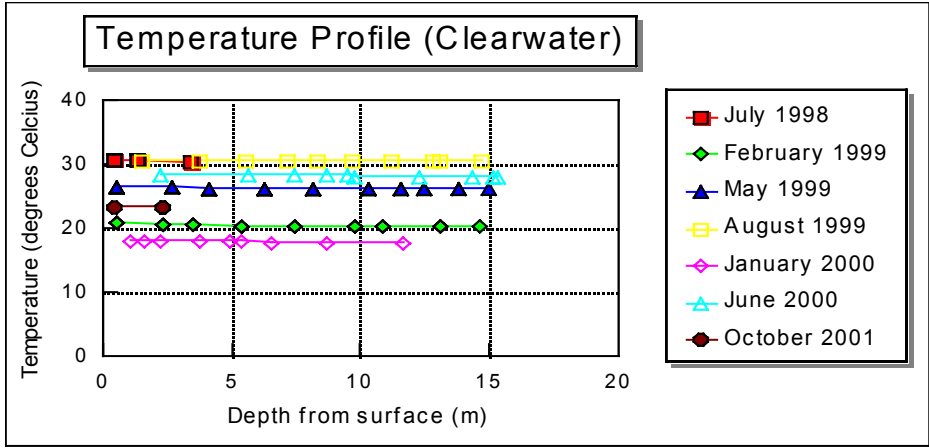
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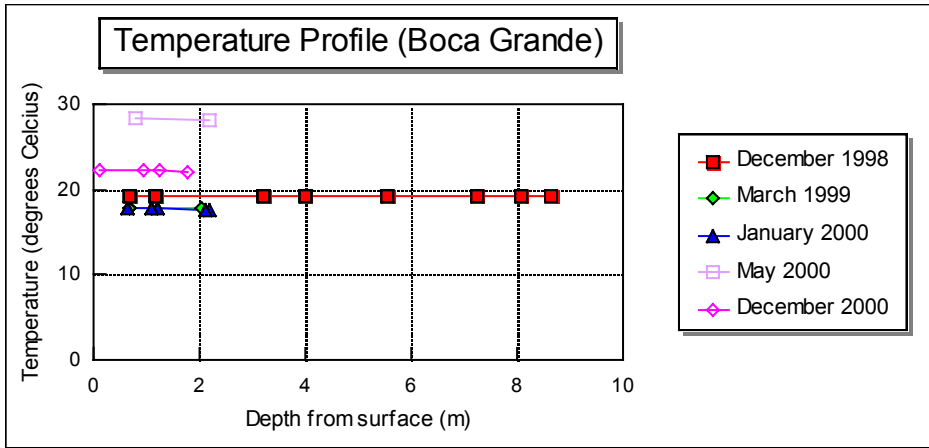
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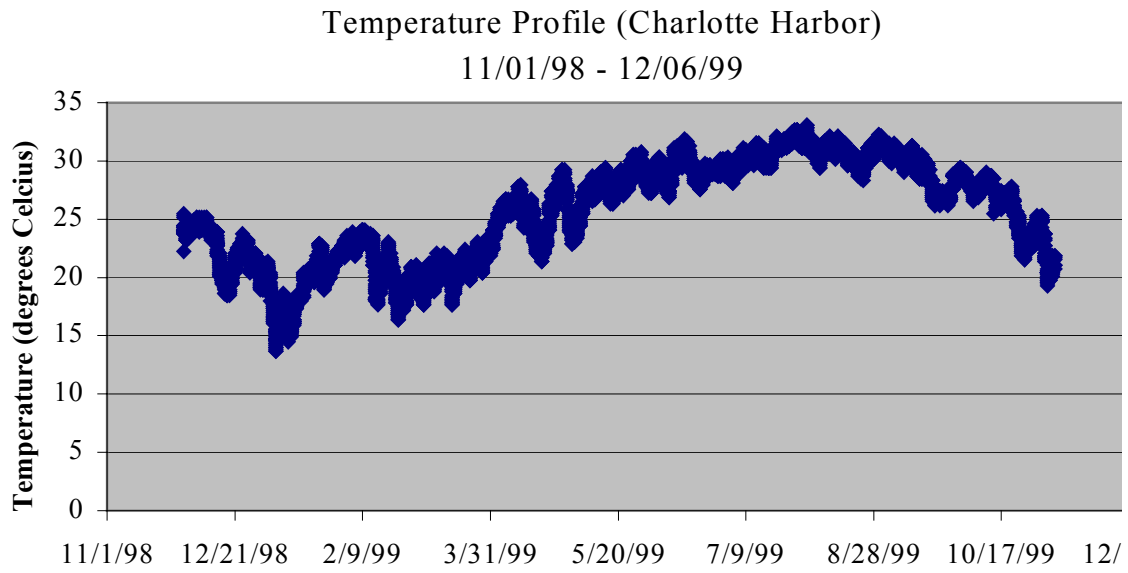
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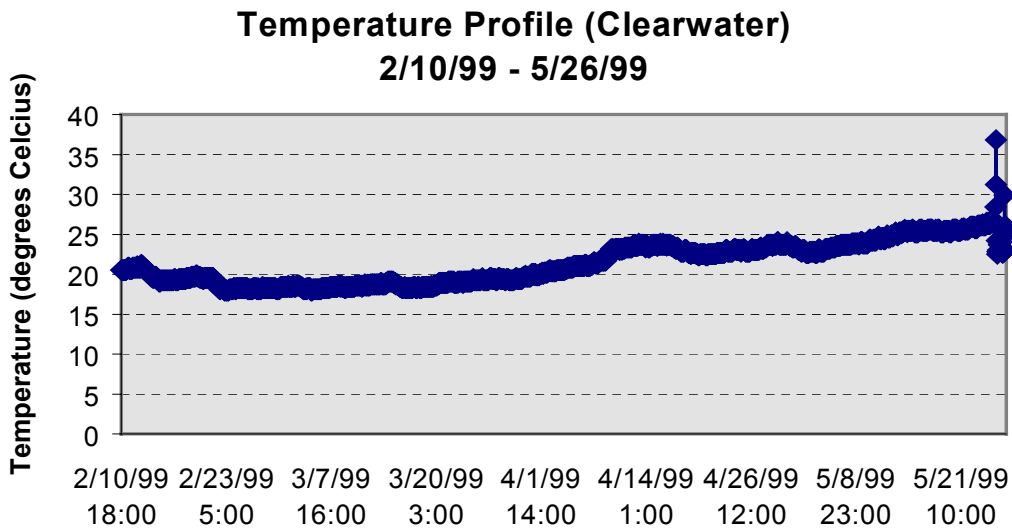
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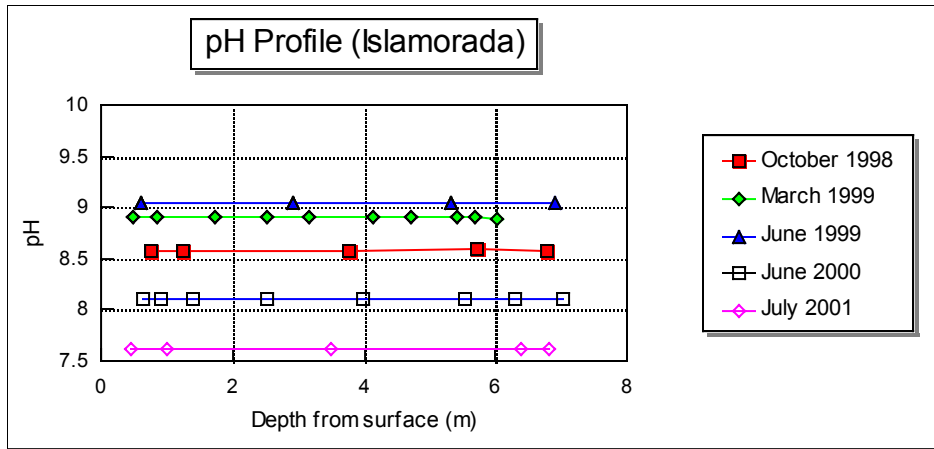
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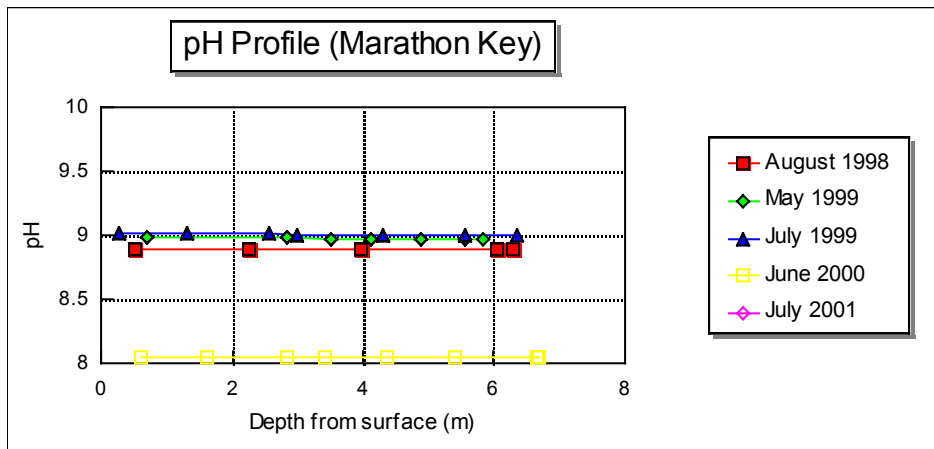
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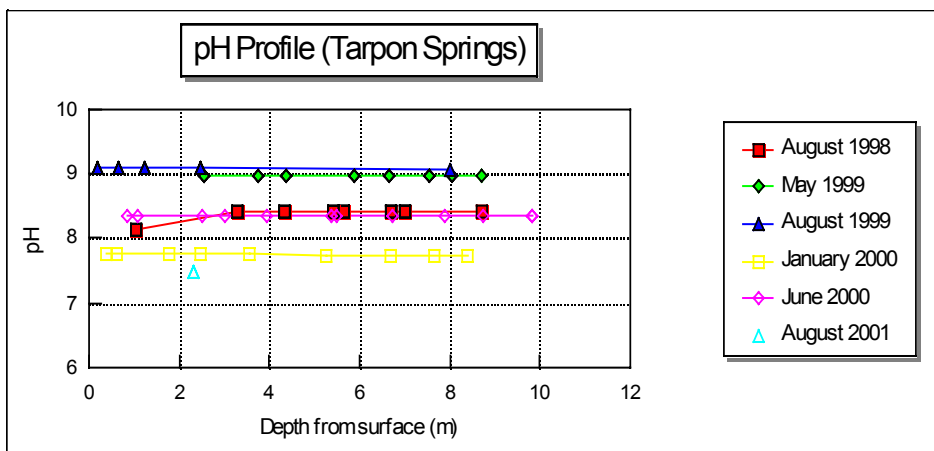
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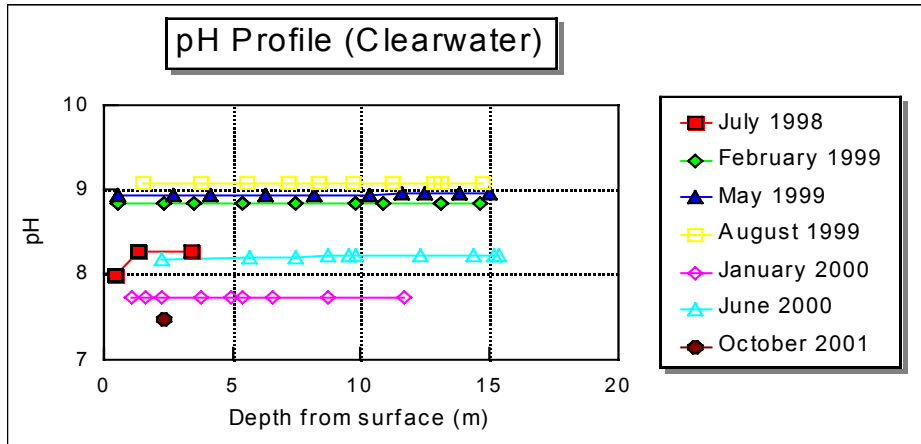
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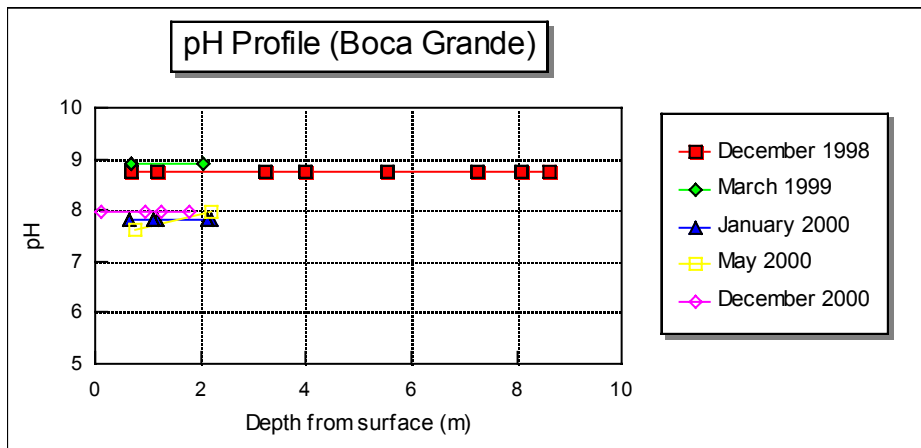
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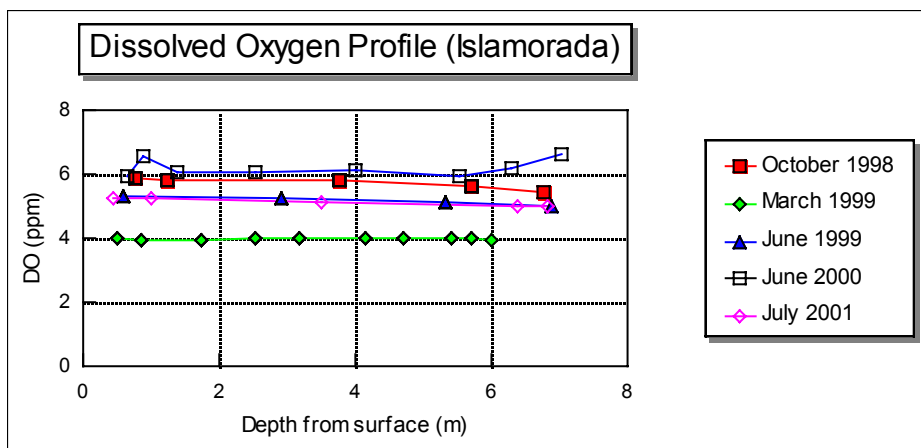
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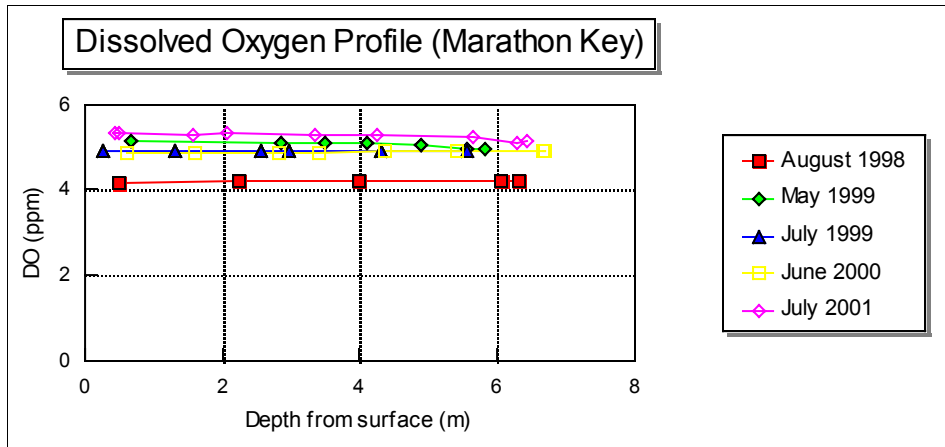
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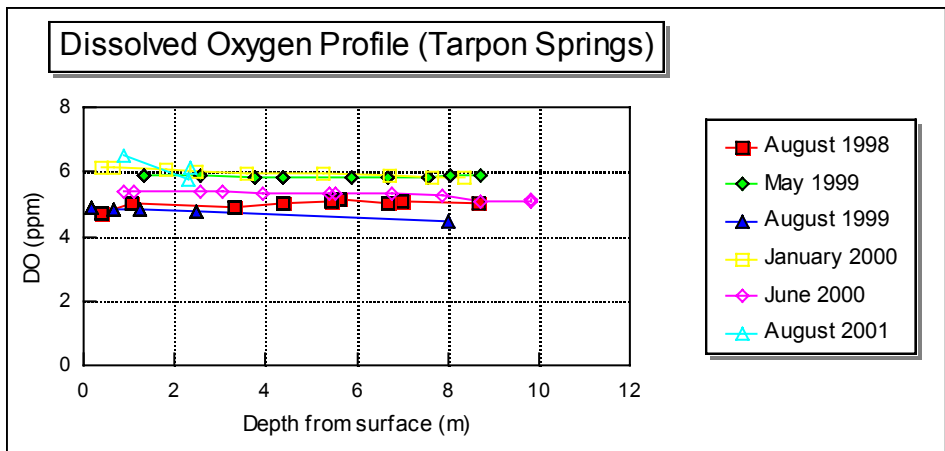
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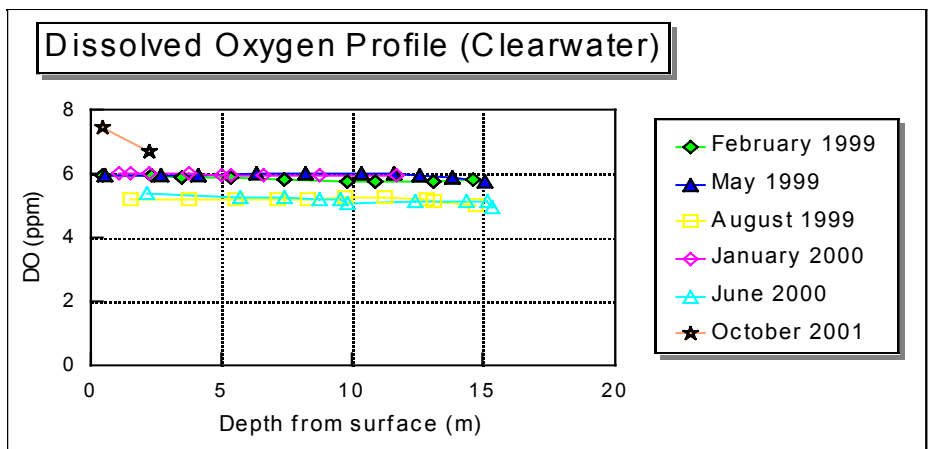
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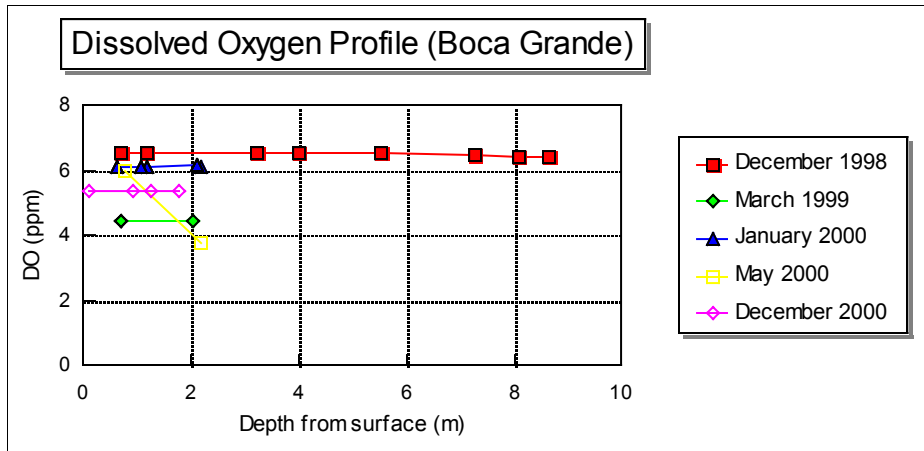
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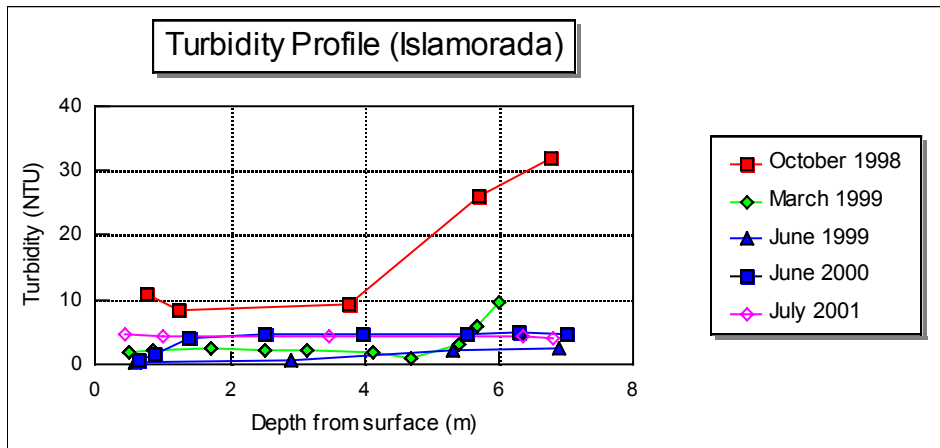
**Figure A-15**



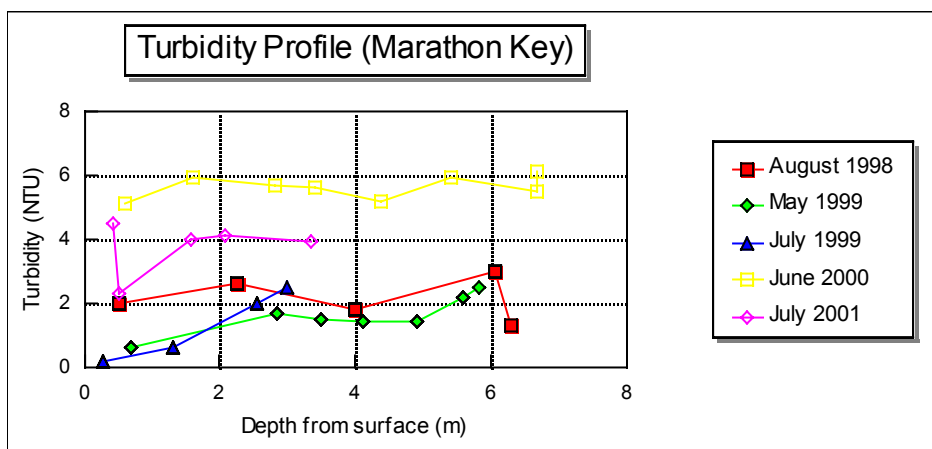
**Figure A-16**



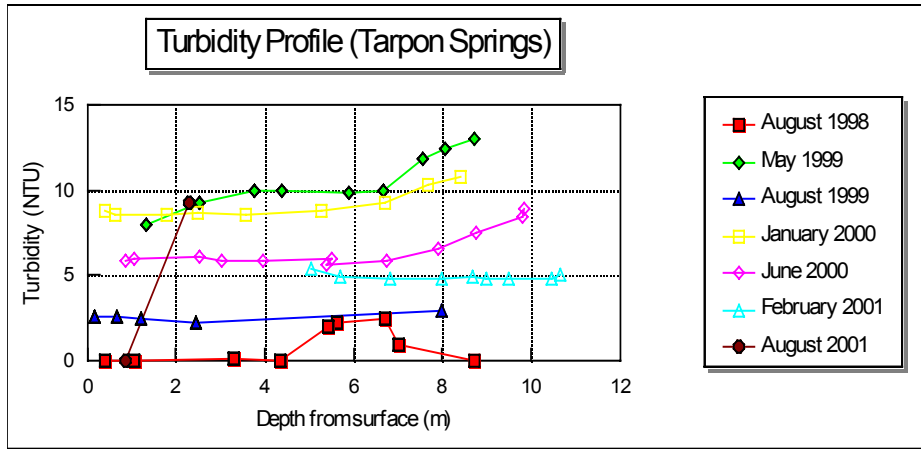
**Figure A-17**



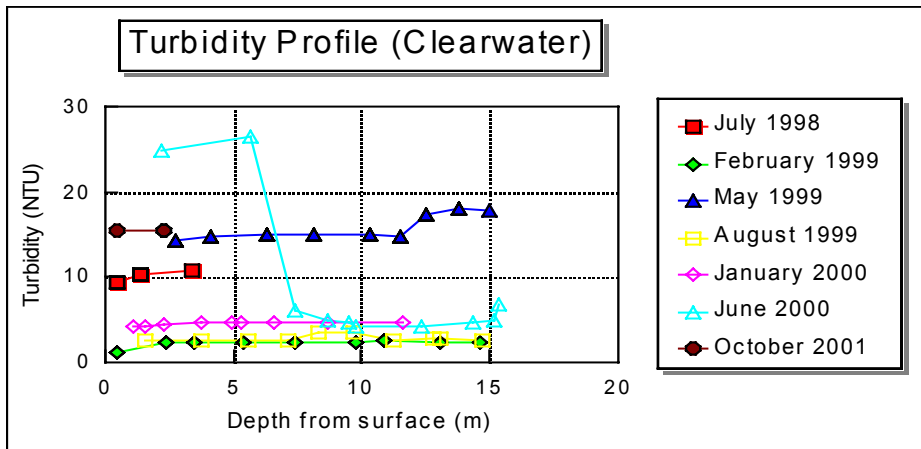
**Figure A-18**



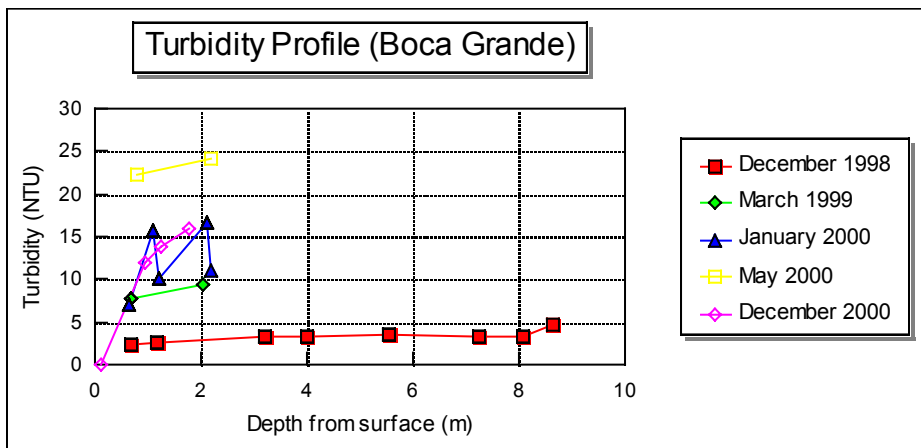
**Figure A-19**



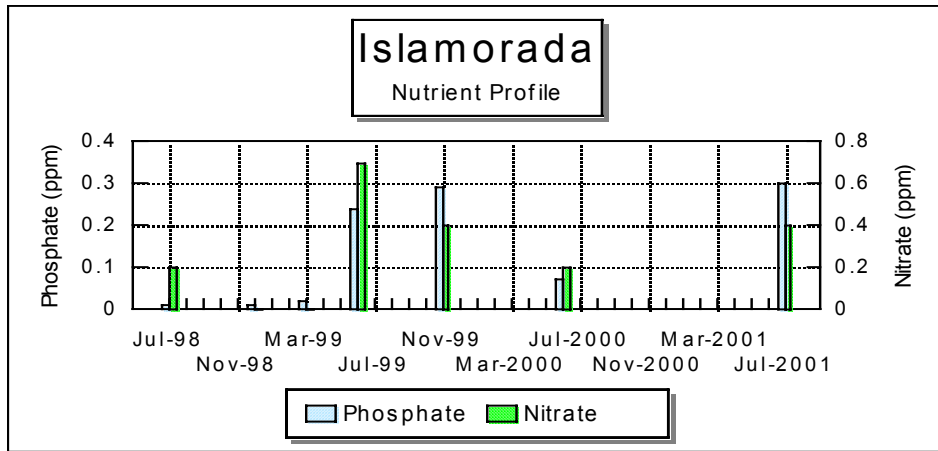
**Figure A-20**



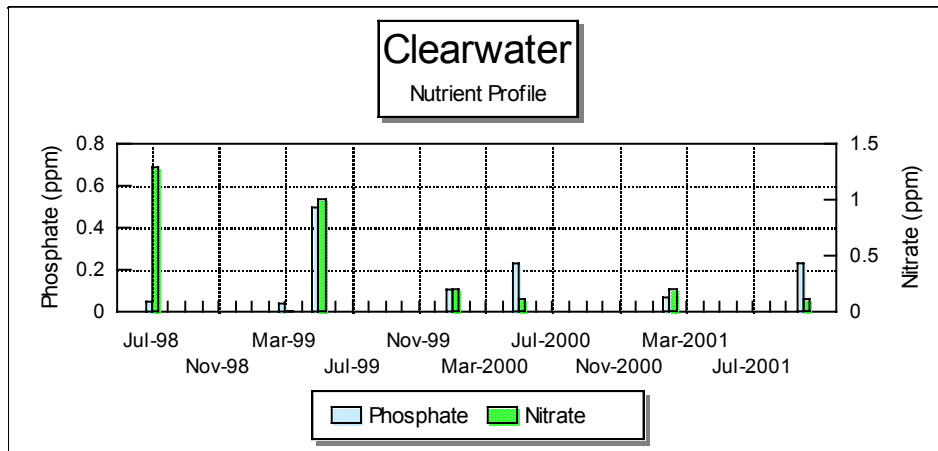
**Figure A-21**



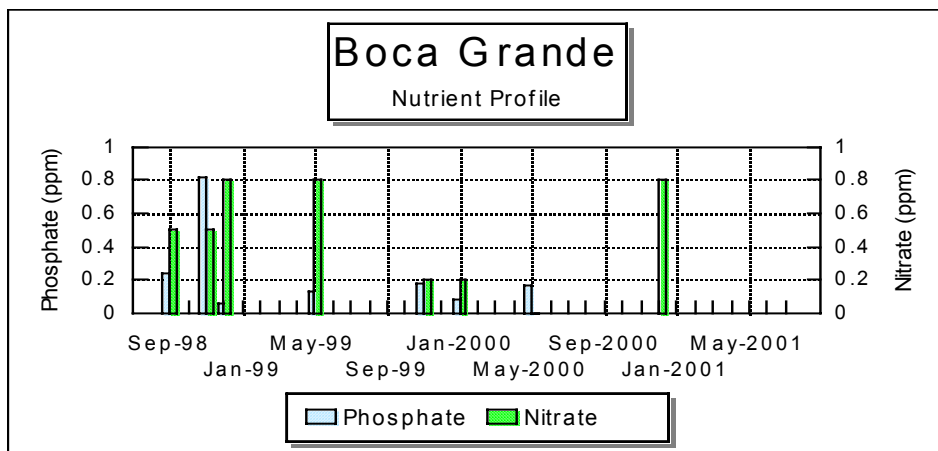
**Figure A-22**



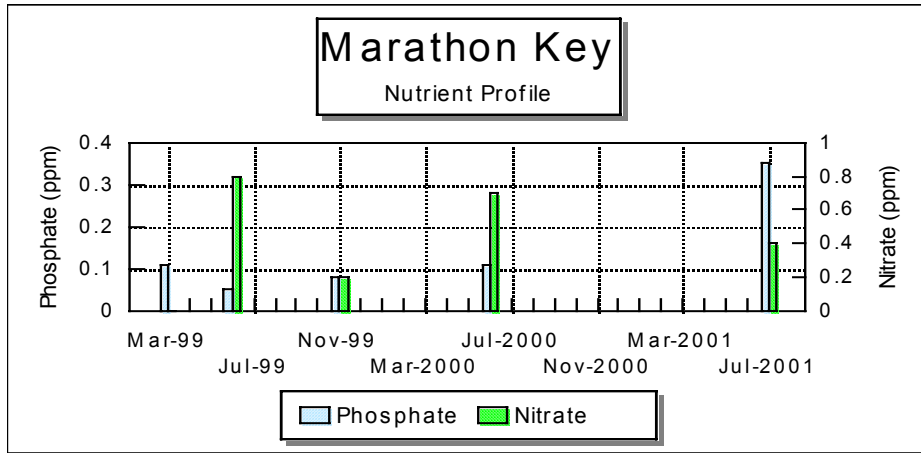
**Figure A-23**



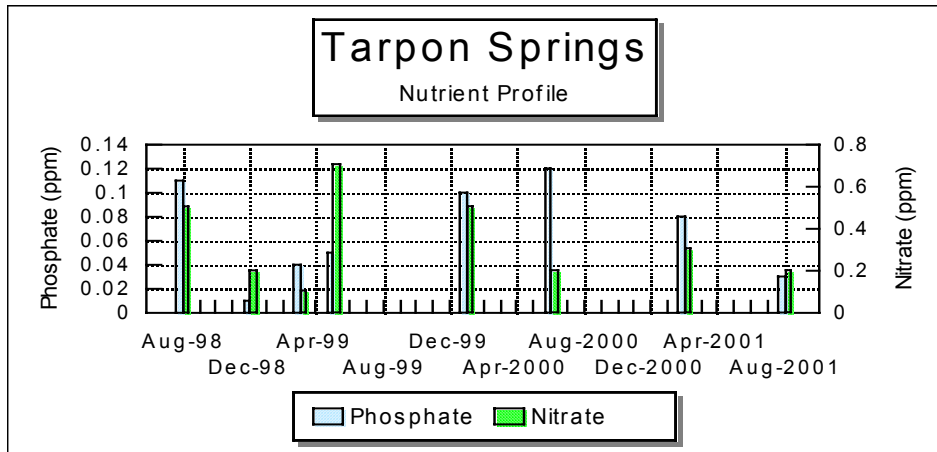
**Figure A-24**



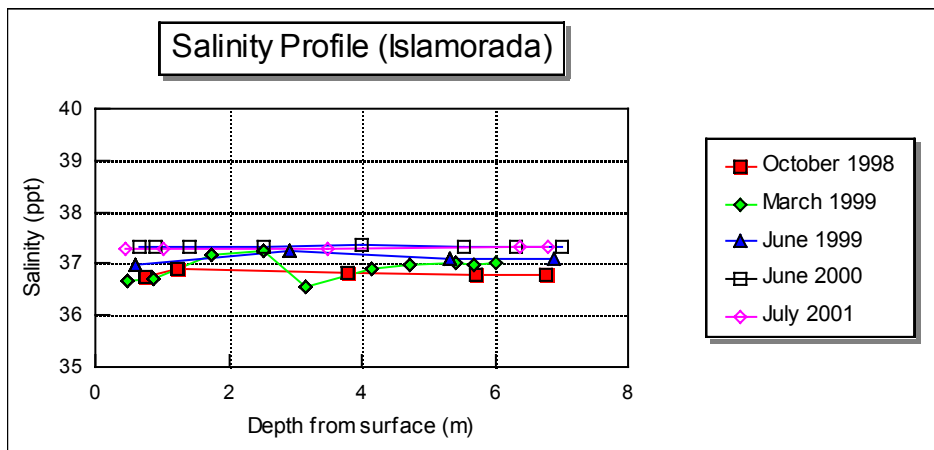
**Figure A-25**



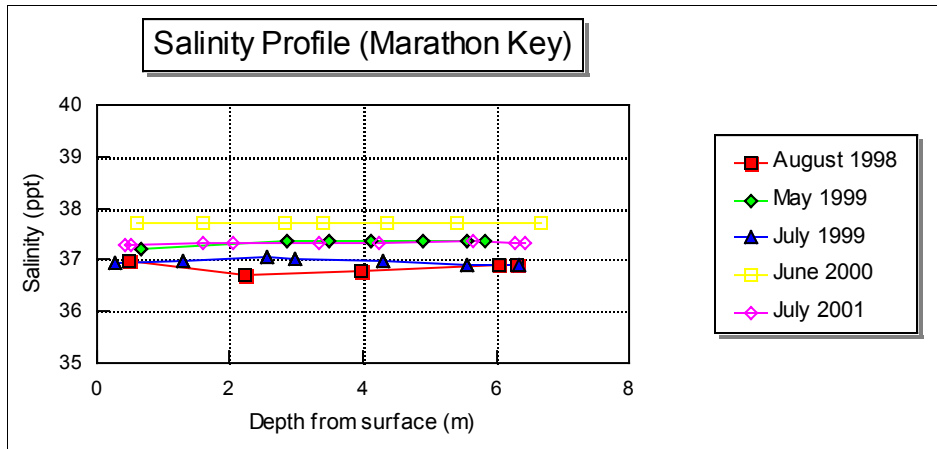
**Figure A-26**



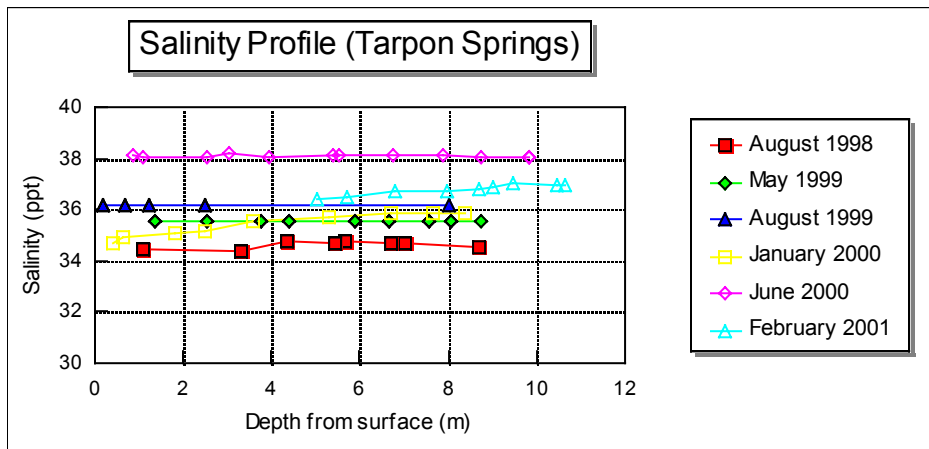
**Figure A-27**



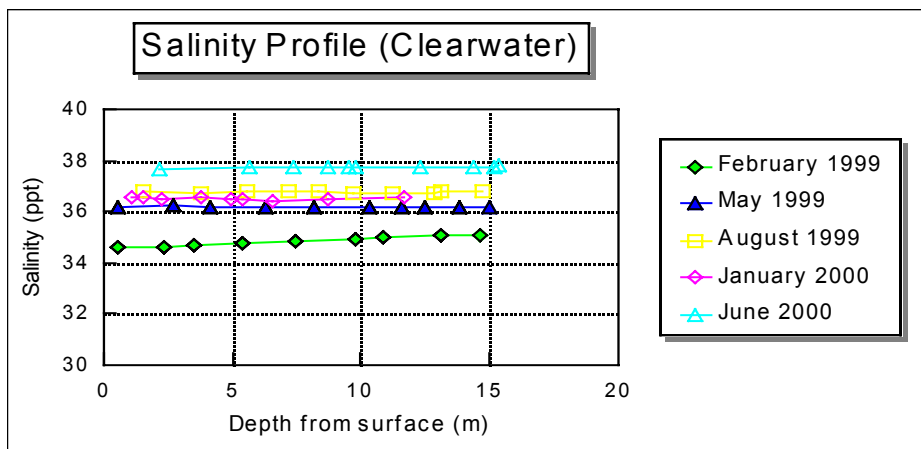
**Figure A-28**



**Figure A-29**



**Figure A-30**



**Figure A-31**

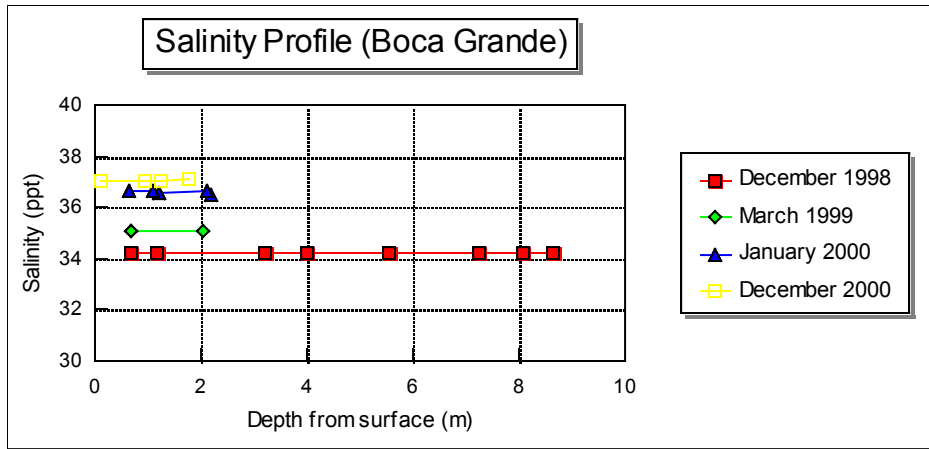


Figure A-32

# **Appendix B**

**A Complete list of all of the Organisms**

**Plus Their**

**Scientific Names**

<b>Scientific Name</b>	<b>Category</b>	
<i>Acetabularia crenulata</i>	Green Algae	1
<i>Acetubularia calyculus</i>	Green Algae	2
<i>Amphiroa fragilissima</i>	Red Alga	3
<i>Anomia sp.</i>	Mollusk	4
<i>Aptasia</i>	Anemone	5
<i>Arabcia</i>	Urchins	6
<i>Balanus</i>	Barnacle	7
<i>Balanus amphrite</i>	Barnacle	8
<i>Balanus improuisus</i>	Barnacle	9
<i>Balanus nubulis</i>	Barnacle	10
<i>Bispara brunnea</i>	Worm	11
<i>Bispara variegata</i>	Worm	12
<i>Botrylloides sp.</i>	Tunicates	13
<i>Bugula minima</i>	Bryozoans	14
<i>Caulerpa paspaloides</i>	Green Algae	15
<i>Caulerpa sertularioides</i>	Green Algae	16
<i>Ceramium sp.</i>	Red Alga	17
<i>Cerithium lutosum</i>	Snails	18
<i>Chalmys sp.</i>	Clams	19
<i>Chama congregata</i>	Clams	20
<i>Chama macerophylla</i>	Clams	21
<i>Chondilla nuclea</i>	Sponge	22
<i>Chondria sp</i>	Red Alga	22
<i>Cladocora arbuscula</i>	Coral	24
<i>Cladophora prolifera</i>	Green Algae	25
<i>Cladophoropsis macromeres</i>	Green Algae	26
<i>Clathrina carariensis</i>	Sponge	27
<i>Clavelina sp.</i>	Tunicates	28
<i>Cliona canarieusis</i>	Sponge	29
<i>Cliona delitrix</i>	Sponge	30
<i>Cliona sp</i>	Sponge	31
<i>Clodium</i>	Sponge	32
<i>Crassostrea virginica</i>	Mollusk	33
<i>Cystoseira myrica</i>	Brown Algae	34
<i>Dasycladus vermicularis</i>	Green Algae	35
<i>Derbesia osterhoutii</i>	Green Algae	36
<i>Dictyopteris sp.</i>	Brown Algae	37
<i>Dictyota cervicornis</i>	Brown Algae	38
<i>Dictyota divaricata</i>	Brown Algae	39
<i>Ethelia sp.</i>	Red Alga	40
<i>Eudistoma</i>	Tunicates	41
<i>Eunicea sp.</i>	Coral	42
<i>Eupolymnia crassicornis</i>	Worm	43

<i>Filignanella sp.</i>	Worm	44
<i>Filograna huxleyi</i>	Worm	45
<i>Filigranella sp.</i>	Worm	46
<i>Gelidium sp</i>	Red Alga	47
<i>Gracilaria</i>	Red Alga	48
<i>Haematocelis sp.</i>	Red Alga	49
<i>Halicystis sp</i>	Green Algae	50
<i>Halimeda cryptica</i>	Green Algae	51
<i>Halimeda opuntia</i>	Green Algae	52
<i>Haloplegma duperreyi</i>	Red Alga	53
<i>Halymenia sp</i>	Red Alga	54
<i>Hermodice carunculata</i>	Worm	55
<i>ippopondina feegeensis</i>	Bryozoans	56
<i>Hydrolithon boergesenii</i>	Red Alga	57
<i>Hydrolithon farinosum</i>	Red Alga	58
<i>Hypnea cervicornis</i>	Red Alga	59
<i>Laurencia cervicornis</i>	Red Alga	60
<i>Lithophyllum congestum</i>	Red Alga	61
<i>Loimia medusa</i>	Worm	62
<i>Maculosa</i>	Mollusk	63
<i>Menippe mercenaria</i>	Crab	64
<i>Meristiella echinocarpum</i>	Red Alga	65
<i>Montastrea cavernosa</i>	Coral	66
<i>Ophioneris sp.</i>	Echinoderm	67
<i>Peyssonnelia sp</i>	Red Alga	68
<i>Phorbis amaranthus</i>	Sponge	69
<i>Phylangia sp.</i>	Coral	70
<i>Phyllangia Americana</i>	Coral	71
<i>Pincata radiate</i>	Mollusk	72
<i>Polycarpa sp.</i>	Tunicates	73
<i>Polycarpa spongiabilis</i>	Tunicates	74
<i>Pomatostegus stellatus</i>	Worm	75
<i>Porolithon pachydermum</i>	Red Alga	76
<i>Reteporellina sp.</i>	Bryozoans	77
<i>Rgaphidoplud vennsus</i>	Sponge	78
<i>Rhipocephalus phoenix</i>	Green Algae	79
<i>Sabell melanostigma</i>	Worm	80
<i>Sargassam hystrix</i>	Brown Algae	81
<i>Sargassum sp.</i>	Brown Algae	82
<i>Schizoporella sp.</i>	Bryozoans	83
<i>Scinaia complanata</i>	Red Alga	84
<i>Siphonocladus tropicus</i>	Green Algae	85
<i>Spirobranchus gigas</i>	Worm	86
<i>Spondycus americanus</i>	Mollusk	87
<i>Sporolithon episporum</i>	Red Alga	88

<i>Spyridia filamentosa</i>	Red Alga	89
<i>Steginoporella sp</i>	Red Alga	90
<i>Tedania ignis</i>	Sponge	91
<i>Terebellidae sp.</i>	Worm	92
<i>Titanoderma sp.</i>	Red Alga	93
<i>Udotea cyathiformis</i>	Green Algae	94
<i>Urosalpinx cinera</i>	Mollusk	95
<i>Valonia utricularis</i>	Green Algae	96
<i>Ventricaria ventricosa</i>	Green Algae	97
<i>Wrangelia argus</i>	Red Alga	98