

**TITLE: MEASURING METABOLISM OF REEFS IN VIRGIN ISLANDS
NATIONAL PARK AND BISCAYNE NATIONAL PARK: SIGNS OF
TROUBLE?**

Submitted to: Dr. Russ Hall
Dr. Nick Funicelli
Florida Caribbean Science Center
USGS, Biological Resources Division

Prepared by: Dr. Caroline Rogers
June 2, 1999

OBJECTIVES and JUSTIFICATION:

Need — Over the last two decades, a variety of natural and human stresses have caused severe degradation of many reefs in the Caribbean and western Atlantic, including those within Virgin Islands National Park (VINP) and Biscayne National Park (BNP). Reefs are exhibiting declines in living coral and increases in algae. Calcification rates are changing because of a shift in the carbon balance between carbon used for constructing carbonate skeletons and carbon used to grow fleshy tissues of algae ("macroalgae"). To date, monitoring programs in VINP (e.g., Rogers et al. 1997) and BNP (e.g., Porter and Meier 1992) have focused on reef structure (e.g., abundances or cover of organisms) rather than reef function ("metabolism"). Calcification, the most fundamental process of all, involves the deposition of calcium carbonate, primarily by corals and coralline algae, which creates the 3-dimensional structure of the reef (see Hallock 1997). Scientists debate whether reefs are sources or sinks of CO₂, although most consider reefs as sources of CO₂ over the time frame of interest to human beings because CO₂ is released during the production of calcium carbonate (Hallock 1997, Hubbard 1997). Another essential process is productivity (photosynthesis and respiration) of reef organisms, including the zooxanthellae within the stony coral tissues and non-symbiotic algae (both turfs and macroscopic algae, or "macroalgae"). In this proposal we refer to calcification and productivity as reef "metabolism". There is an urgent need to determine the calcification rates of selected reefs within these national parks and to find out if these reefs are actively accreting or if they are unable to maintain their structure because the balance has shifted away from the major framework building organisms, including the scleractinian corals, to non-calcifying (or only weakly-calcifying) organisms (see Kinsey 1985).

Presently, we know of no efforts to monitor calcification rates on reefs as indicators of reef condition. We need to determine if measurements of

calcification rates and photosynthesis are useful tools for quantifying differences among reefs as well as changes on reefs over time (for example, before and during/after bleaching episodes or runoff events). We plan to test and adapt methods which have recently been used successfully in seagrass beds in Florida Bay (Halley and Yates 1999). We propose to measure reef metabolism in Virgin Islands National Park and Biscayne National Park on reefs with a range of live coral cover during times of low and high water temperatures (winter and late summer/fall). Bleaching episodes, such as the most severe on record in 1998, are usually associated with higher than normal water temperatures. Water temperatures in both parks have exceeded 30 C, the temperature above which the symbiosis between corals and their zooxanthellae breaks down (Glynn and D'Croz 1990). We hope to measure reef metabolism before and during bleaching episodes. Additional outcomes of these measurements are an improved understanding of the CO₂ contribution of coral reefs to the atmosphere and a methodology which can help to assess the direct impact of increased CO₂ on coral reefs.

Background: Natural stresses such as hurricanes and coral diseases as well as anthropogenic factors such as increased runoff, damage from boat anchors and groundings, and sewage input have killed corals and altered the relative abundances of reef organisms. In some extreme cases coral reefs have been almost entirely overgrown by algae (Hughes 1994). Coral reefs are also among the ecosystems which could be most vulnerable to changes in climate because increased atmospheric CO₂ could lower calcification rates with far-reaching effects on reef structure (Pennisi 1998, Kleypas et al. 1999). The current warming trend in sea water temperatures also poses serious threats to reefs because corals exist near the maximum temperatures they can tolerate (e.g., Hubbard 1997). Corals are also especially sensitive to elevated CO₂ and increased UV radiation (Brown 1997). Though not the most abundant organisms on Caribbean reefs, corals create the reef's physical structure, providing habitat for fishes and other organisms.

Corals provide clues to the present and to the past. They respond to increased temperatures and UV radiation by "bleaching" (losing color). When corals bleach, they cease reproduction and their growth rates decrease (e.g., Szmant and Gassman 1990). Coral skeletons contain a record of past environmental conditions. For example, they have annual (or near annual) growth bands because skeletal densities vary with cooler and warmer temperatures. Through examination of coral cores ("sclerochronology" studies) one can learn about calcification rates in the past and compare those to present rates (e.g., Hudson et al. 1976).

Monitoring of reef metabolism at selected reefs in Virgin Islands National Park and Biscayne National Park is the central focus of this 2-year project. Detailed information on the structure of each study site will be correlated with the measurements of reef metabolism. (This information is available for some reefs from the USGS/NPS Inventory & Monitoring Program.) Existing data on reef structure and function are severely limited both spatially and temporally, with insufficient data from widely separated geographic areas over long periods of time. To begin to address these scale deficiencies, we will be looking at reefs in subtropical and tropical areas, and we will be examining coral cores for information on past environmental conditions.

PROCEDURES/METHODS:

Selection of Study Sites

Some of the study sites for this project will be areas for which long-term data (both biological and environmental) are already available. Long-term monitoring sites were established on reefs in Virgin Islands National Park and Biscayne National Park under an NPS program which began in 1988, and the DOI Inventory & Monitoring (I&M) program has supported additional work in VINP. Other sites will be chosen to ensure that data are obtained from a variety of different reef types and from sites of particular management concern.

The coral reef monitoring programs which NPS and BRD have conducted in these two parks in conjunction with state and university scientists are some of the few long-term monitoring programs in the Caribbean and western Atlantic (Connell 1997). Data on cover by coral and algae are available for both VINP and BNP, and effects of different stresses have been documented for some reefs. Underwater videotapes which provide a statistically quantifiable and permanent visual record of reef structure are available from both parks.

A major task for Year 1 will be the selection of each study site based on the need to include reefs with a range of different reef types with variations in coral cover. Reefs in Biscayne National Park generally have less than 5% living coral while some sites in St. John have live cover in excess of 20%. Initially, we will focus on reefs for which data on reef structure are already available. On St. John, we will study sites in Lameshur and Newfound bays, for which we have the longest data sets (10 and 9 years respectively). These sites are also under consideration for inclusion in a "marine reserve" within park waters. Transects in Newfound Bay would have the highest coral cover of all the study sites (23%) while those in Lameshur have a coral cover of about 10%. We may also select Hawksnest Bay for which we have information on siltation effects and coral

growth rates (Hubbard et al. 1987) because it is a shallow reef exhibiting some signs of recovery in elkhorn coral (Acropora palmata) populations. This primary reef-building species was decimated throughout the Caribbean in the 1980's by white band disease.

Reef Function: Calcification and Productivity

Carbonate sediment production, photosynthesis, and respiration will be measured in winter (when temperatures are lowest) and late summer/fall (when temperatures are highest) to determine seasonal and areal variation in tissue/carbonate production and to derive average annual production rates. These parameters will be calculated from total alkalinity, pH, calcium concentrations, salinity, irradiance, temperature, wind and current speed, and air-sea CO₂ and O₂ fluxes measured along transects across reefs.

We propose to work with our primary collaborators, Dr. Robert Halley and Dr. Kim Yates, from the USGS Geologic Division to measure parameters of carbon budgets to assess reef conditions. For many years carbon budgets of reefs have been studied by measuring geochemical parameters of carbon utilization (Smith, 1973). The techniques used to make these measurements have been greatly refined during the past two decades because they are, in part, also the techniques used for measuring global atmospheric CO₂ exchange with the ocean. These refined procedures can now be used again to study coral reefs (Buddemeier and Kinzie 1998).

Dr. Halley and Dr. Yates have developed prototypes of two geochemical monitoring systems including a Submersible Habitat for Analyzing Reef Quality (S.H.A.R.Q.) and an In Site Biogeochemical Analysis System (I.B.A.S) for measurement of geochemical changes associated with benthic and water column carbonate sediment production and metabolic activity, respectively (see Halley and Yates for details). To measure reef metabolism, we will use two primary experimental approaches: 1) upstream-downstream transects across broad sections of the reef, and 2) metabolism of small reef areas enclosed within the SHARQ (see also Rogers 1979).

For upstream-downstream measurements, transects will be located parallel to unidirectional current flow across a given reef. Current velocities will be measured with current meters. Sample stations will be positioned at the upstream and downstream ends of each transect.

Geochemical and physical parameters (including water temperature) will be measured at each station along a transect at different times (and irradiances) during the day and night to determine daily variations in production and to

derive average daily production rates. Recording thermistors are already in place on several reefs in VINP and BNP.

Total alkalinity and pH will be used to calculate calcification and net photosynthesis using the alkalinity anomaly technique of Smith and Key (1975) such that calcification (C) = half the change in total alkalinity, and net photosynthesis (P) = total carbon - calcification. Total carbon will be calculated using carbonate system equations from Millero (1979). Calcium measurements will provide an independent measure of calcification for comparison. Air-sea CO₂ fluxes will be measured directly at each station inside a floating bell (Frankignoulle 1988, Gattuso et al. 1993, Kayanne et al. 1995) using the procedure and calculations of Frankignoulle (1988). Air-sea O₂ fluxes will be determined by measuring atmospheric and water pO₂ and calculating fluxes as described in Wanninkhof (1992). Differences in oxygen and carbon metabolism between upstream and downstream stations will be corrected for O₂ and CO₂ exchange with the atmosphere as described in (Gattuso et. al. 1993).

Productivity and metabolic rates per unit area will be calculated using the difference in concentration between upstream and downstream stations, the volume of water transported along a transect, and the transect area such that the change in concentration of a parameter ($\Delta C/m^2/s = (C/m^3 \times m^3/hr)/m^2$ (Barnes and Devereux 1984). Seasonal production rates will be used to calculate average annual production rates.

Comparison of these data with previous productivity estimates and calcification rates, as well as calcification rates determined from coral cores (Hudson et. al. 1976; Dodge et. al. 1984; Dodge, et. al. 1992) would indicate whether long-term (decades) changes are occurring on the reefs.

We plan to use both the upstream-downstream method and the SHARQ in both national parks. In some cases, upstream-downstream techniques may not be feasible because of local current conditions (i.e., currents are too weak or too complex), or because reef zones are not wide enough to allow detection of changes. In other situations, for example, where the reef has very high relief, it will be more difficult to use the SHARQ. The IBAS will be used to measure metabolism of the water column and to enable quantification of benthic and water column contributions to overall metabolism. Dr. Robert Halley and Dr. Kimberly Yates, our primary collaborators, have successfully done pilot studies of seagrass beds in Florida Bay using these techniques and plan to test them out on reefs soon.

In the fall of 1998, severe bleaching occurred on the reefs around St. John and within Biscayne National Park. We hope to take measurements during future

bleaching events to determine the effects of zooxanthellae loss (which results in bleaching) on productivity and calcification rates.

Reef Structure

It is essential that we have pertinent data on the structure of the transects to accompany the metabolism rates we measure (with both the upstream-downstream technique and the SHARQ). At some study sites, we intend to install the SHARQ over transects for which we already have very detailed information on relative abundances of different organisms ("reef structure"). At other sites, we will collect quantitative information using videography (Rogers and Miller submitted manuscript).

Coral Cores

Skeletons of some coral species (including Montastraea annularis) provide a record of the environmental conditions under which the corals grew. We propose to examine coral cores which have already been collected from the parks to look for any changes in calcification (deposition of the coral skeleton) which would indicate short-term or long-term changes in environmental conditions. Cores will be used to construct a history of climate conditions over as long a period as possible. We will not be collecting new cores from any of the sites.

The proposed work represents a major study of reef metabolism or "function" as opposed to reef "structure" which is the subject of most monitoring projects. It addresses the fundamental processes required for reef development. The work also relates to the goals of BRD's Global Climate Change Program in several ways. First the proposed measurement of air-sea CO₂ fluxes not only provide basic data for determining the degree to which coral reefs contribute to atmospheric CO₂, but they also provide a way to evaluate the sensitivity of coral reef carbon budgets to future atmospheric CO₂ levels (Goal 1). Second, carbon-budget measurements on reefs will help determine the combined effects of global change and environmental contamination on reefs (Goal 2). Third, the project is being addressed at several spatial and temporal scales in an effort to learn more about responses of coral reefs to global change (Goal 3). Fourth, the proposed experiments provide a basis for a better understanding of how careful management of sediment and nutrient input to reefs (which affects the relative abundances of algae and living coral) could offset effects of increased global CO₂ (Goal 4).

Literature Cited:

- Barnes, D.J. and Devereux, M.J. 1984. Productivity and calcification on a coral reef: a survey using pH and oxygen electrode techniques. *Journal of Experimental Marine Biology and Ecology* 79:213-231.
- Brown, B. 1997. Coral bleaching: causes and consequences. *Proc 8th Int Coral Reef Sym* 1: 65-74.
- Buddemeier, R. W., and Kinzie III, R. A., 1998, Reef Science: Asking all the wrong questions in all the wrong places?, *Reef Encounter*, pp. 29-34.
- Connell, J.H. 1997. Disturbance and recovery of coral assemblages. *Coral Reefs* 16: S101-113.
- Dodge, R. E., and Brass, G. W., 1984, Skeletal extension, density, and calcification of the reef coral *Montastrea annularis*: St. Croix, US Virgin Islands. *Bull Mar Sci* 34: 288-307.
- Dodge, R. E., Szmant, A. M., Garcia, R., Swart, P. K., Forester, A., Leder, J. J., 1992, Skeletal structural basis of density banding in the reef coral *Montastrea annularis*, *Proceedings of the Seventh International Coral Reef symposium, Guam*, 1:186-195.
- Frankignoulle, M. 1988. Field measurements of air-sea CO₂ exchange. *Limnology and Oceanography* 33(3):313-322.
- Gattuso, J.P., Pichon, M., Delesalle, B., and Frankignoulle, M. 1993. Community metabolism and air-sea CO₂ fluxes in a coral reef ecosystem (Moorea, French Polynesia). *Mar Ecol Prog Ser* 96:259-267.
- Glynn, P. W. and L. D'Croz. 1990. Experimental evidence for high temperature stress as the cause of El Nino – coincident coral mortality. *Coral Reefs* 8: 1818-191.
- Halley, RB and K Yates. 1999. Sediment production is critical to reef restoration. Abstract. National Coral Reef Institute Meeting. Florida.
- Hallock, P. Reefs and reef limestones in Earth history. Chapter 2. In (Birkeland, C. ed.) *Life and Death of Coral Reefs*. Chapman & Hall. 536 pp.

- Hubbard, DK. 1997. Reefs as dynamic systems. Chapter 3. In (Birkeland, C. ed.) *Life and Death of Coral Reefs*. Chapman & Hall. 536 pp.
- Hubbard, DK., Stump, J, Carter, B. 1987. Sedimentation and reef development in Hawksnest, Fish, and Reef Bays, St. John, USVI. National Park Service. Biosphere Reserve Research Report No. 21. 104 pp.
- Hudson, J. H., Shinn. E. A., Halley, R. B., and Lidz, B., 1976, Sclerochronology--a tool for interpreting past environments: *Geology*, v. 4, p. 361-364.
- Hughes, T. P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. *Science* 265: 1547-1551.
- Kayanne, H., Suzuki, A., and Saito, H. 1995. Diurnal changes in the partial pressure of carbon dioxide in coral reef water. *Science* 269:214-216.
- Kinsey, D.W. 1985. Metabolism, calcification and carbon production. I. Systems level studies. *Proc. 5th Intern. Coral Reef Congr.* 6: 223-228.
- Kleypas, JA, Buddemeier, D. Archer, J.-P. Gattuso, C. Langdon, B. N. Opdyke 1999. Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. *Science* 284: 118-120.
- Millero, F.J. 1979. The thermodynamics of the carbonate system in seawater. *Geochimica et Cosmochimica Acta* 43:1651-1661.
- Pennisi, E. 1998. New threat seen from carbon dioxide. *Science* 279: 989.
- Porter, J. and OW Meier. 1992. Quantification of loss and change in Floridian reef coral populations. *Am Zool* 32: 625-640.
- Rogers, CS. 1979. The effect of shading on coral reef structure and function. *J. Exp. Mar. Biol. Ecol.* 41:269-288.
- Rogers, C., V. Garrison and R. Grober-Dunsmore. 1997. A fishy story about hurricanes and herbivory: seven years of research on a reef in St. John, US Virgin Islands. *Proc. 8th International Coral Reef Sym* 1: 555-560.
- Rogers, C. and J. Miller. (submitted manuscript). *Proc. National Coral Reef Institute Meeting*, April 1999.
- Smith, S.V. 1973. Carbon dioxide dynamics: a record of organic carbon

production, respiration, and calcification in the Eniwetok reef flat community. *Limnology and Oceanography* 18(1):106-120.

Smith, S. V., and Key, G. S., 1975, Carbon dioxide and metabolism in marine environments. *Limnology and Oceanography* 20:493-495.

Szmant, A.M., Gassman, N.J. 1990. The effects of prolonged bleaching on the tissue biomass and reproduction of the reef coral *Montastrea annularis*. *Coral Reefs* 8: 217-224.

Wanninkhof, R. 1992. Relationship between wind speed and gas exchange over the ocean. *Journal of Geophysical Research* 97:7373-7382.

EXPECTED PRODUCTS:

Scientific papers based on this research will be submitted to peer-reviewed journals. Presentations on the work will be made at national or international conferences, including the 9th International Coral Reef Symposium in 2000.

Other products include CDs with archived videotransect data (and appropriate metadata) and diskettes with results of image analyses. Investigators' Annual Reports will be submitted to VINP and BNP. A video of the procedures used to measure reef metabolism will be produced.

TECHNOLOGY/INFORMATION TRANSFER:

This proposal includes development of protocols which will be transferable to other agencies and individuals with an interest in measuring reef metabolism and in calculating the effects of increased CO₂ associated with climate change. The video of the methods used will be made available upon request.

DATA MANAGEMENT:

Data will be documented using the NBII Metadata Standards. Bibliographic metadata for all information and products will be added to the Biological Resource Division's Bibliographic Metadata Database at <http://biology.usgs.gov/pubs>.

PERSONNEL: (from the initiating Center)

Nick Funicelli

Caroline Rogers

Ginger Garrison

Jeff Miller

Steve Walsh

Doug Weaver
Others from FCSC

COOPERATORS/PARTNERS:

- Our primary partners are the Geology Division of USGS and the National Park Service (Biscayne National Park and Virgin Islands National Park). All will be providing personnel, equipment, and expertise for certain tasks to conduct this research effort.
- Robert Halley, USGS, Center for Coastal Geology, St. Petersburg, Fl p 813 893-3100; f893-3333 (Carbon budget, calcification studies)
- Kimberly Yates, USGS, Center for Coastal Geology (Carbon budget, calcification studies)
- Richard Curry, Biscayne National Park (scientific support in BNP)
- Dennis Hubbard, Oberlin College, 44293 Rt 511E, Oberlin, Ohio 44074; (phone and fax 440 774-5180 (Physical oceanography, coral cores)

BRD PRINCIPAL CONTACT

Dr. Nicholas Funicelli
Chief, Coastal and Marine Ecology Branch
Florida Caribbean Science Center
Gainesville, Florida

FACILITIES/EQUIPMENT/STUDY AREAS:

The BRD field station in the USVI has a Whaler and a diesel boat plus all necessary dive gear to support field work in St. John. Biscayne National Park will support the operations there with one Biological Technician, boats, lab space, current meters, Hydrasondes, etc. The USGS Center for Coastal Geology will supply all necessary equipment for the SHARQ experiments. The 24 hour measurement sessions will probably require rental of a boat large enough to support 4 people.

LEGAL AND POLICY-SENSITIVE ASPECTS:

Research permits will be necessary for both parks. Supt. Russ Berry, Virgin Islands National Park, P.O. Box 710, USVI 00830; ph 340 693-8950.
Supt. Richard Frost, Biscayne National Park, P.O. Box 1369, Homestead, Fl 33090.

BUDGET

Year 1		Matching Contributions			
<i>BRD Salaries</i>		<i>GD Salaries</i>		<i>NPS Salaries</i>	
Rogers (4 pp)	15,655	Halley (8 pp)	40,624	Curry (3 pp)	7,118
Garrison (2 pp)	4,745	Yates (8 pp)	17,424	Tech (2 pp)	3,000
Miller (6 pp)	11,358	Thompson (4pp)	12,952		
FCSC emp. (4 pp)	8,000				
FCSC emp. (2 pp)	4,000				
<i>Equipment</i>					
Current meters		provided			
Boat rental for 24 hr sessions	8,400				
<i>Supplies</i>					
Fuel, videotapes, air fills, stakes	7,500				
<i>Travel to BNP</i>					
Rogers (one week)	1,500	Halley	4,400		
Miller (2 pp)	5,500	Yates	4,400		
FCSC employee (2 pp)	4,750	Thompson	4,400		
<i>Travel to VINP</i>					
		Halley	5,200		
		Yates	5,200		
		Thompson	5,200		
TOTALS	71,408		99,800		10,118

Year 2		Matching funds			
<i>BRD Salaries</i>		<i>GD Salaries</i>		<i>NPS Salaries</i>	
Rogers (6 pp)	23,478	Halley (8 pp)	40,624	Curry	7,118
Garrison (2 pp)	4,745	Yates (8 pp)	17,424	Tech	3,000
Miller (6 pp)	11,358	Thompson	12,952		
FCSC biologist	8,000				
FCSC biologist	4,000				
<i>Equipment</i>					
Boat Rental	8,400				
<i>Supplies</i>					
Fuel, videotapes, air fills, stakes	5,000				
Travel to BNP					
Rogers (one week)	1,500	Halley	4,400		
Miller (2 pp)	5,500	Yates	4,400		
FCSC employee (2 pp)	4,750	Thompson	4,400		
Travel to VINP					
		Halley	5,500		
		Yates	5,500		
		Thompson	5,500		
TOTALS	76,731		99,800		10,118

Note: The budget is based on two 2-week field sessions each year in each park. Three BRD employees (VINP) or two BRD employees and one NPS technician (BNP) would work in the field with three GD employees (VINP) for each sampling period.

WORK AND REPORTING SCHEDULE

To encompass the range of reefs which we hope to monitor for calcification and productivity rates we will need to extend the work over two years. There will be two field sessions in the winter and late summer/fall of each year in VINP and BNP. Each field session will be 2 weeks long.

DRAFT

File name: spcalcif
May 24, 1999 Version
[10:00 AM]

TITLE: MEASURING METABOLISM OF REEFS IN VIRGIN ISLANDS NATIONAL PARK AND BISCAYNE NATIONAL PARK: SIGNS OF TROUBLE?

OBJECTIVES and JUSTIFICATION:

Need – Over the last two decades, a variety of natural and human stresses have caused severe degradation of many reefs in the Caribbean and western Atlantic, including those within Virgin Islands National Park (VINP) and Biscayne National Park (BNP). Reefs are exhibiting declines in living coral and increases in algae. Calcification rates are changing because of a shift in the carbon balance between carbon used for ~~constructing carbonate skeletons~~ ^{reference?} and carbon used to grow fleshy tissues of algae ("macroalgae"). To date, monitoring programs in VINP (e.g., Rogers et al. 1997) and BNP (e.g., Meier and Porter) have focused on reef structure (e.g., abundances or cover of organisms) rather than reef function ("metabolism"). Calcification, the most fundamental process of all, involves the deposition of calcium carbonate, primarily by corals and coralline algae, which creates the 3-dimensional structure of the reef. Another essential process is productivity (photosynthesis and respiration) of reef organisms, including the zooxanthellae within the stony coral tissues and non-symbiotic algae (both turfs and macroscopic algae, or "macroalgae"). In this proposal we refer to calcification and productivity as reef "metabolism". There is an urgent need to determine the calcification rates of selected reefs within these national parks and to find out if these reefs are actively accreting or if they are unable to maintain their structure because the balance has shifted away from the major framework building organisms, including the scleractinian corals, to non-calcifying (or only weakly-calcifying) organisms. definition!
not species specific
need!

Presently, we know of no efforts to monitor calcification rates on reefs as indicators of reef condition. We need to determine if measurement of calcification rates and photosynthesis are useful tools for quantifying differences between reefs as well as changes on reefs over time (for example, before and during/after bleaching episodes or runoff events). We plan to test and adapt methods which have recently been used successfully in seagrass beds in Florida Bay (Halley and Yates ref?) We propose to measure reef metabolism in Virgin Islands National Park and Biscayne National Park on reefs with a range of live coral cover during times of low and high water temperatures (winter and late summer/fall). Bleaching episodes, ~~such as the most severe on record in 1998~~ ^{why specifically during bleaching events?} are usually associated with higher than normal water temperatures. We hope to ~~measure reef metabolism before and during bleaching episodes~~ ^{what is the outcome?}. Additional outcomes of these measurements are an improved understanding of the CO₂ contribution of coral

reefs to the atmosphere and a methodology which can help to assess the direct impact of increased CO₂ on coral reefs.

Background: Natural stresses such as hurricanes and coral diseases as well as anthropogenic factors such as increased runoff, damage from boat anchors and groundings, and sewage input have killed corals and altered the relative abundances of reef organisms. In some extreme cases coral reefs have been almost entirely overgrown by algae (Hughes 1994). *what about over fishing and removal of herbivores?*

Coral reefs are also among the ecosystems which could be most vulnerable to changes in climate because increased CO₂ could lower calcification rates with far-reaching effects on reef structure (Pennisi 1998, Kleypas et al. 1999). Though not the most abundant organisms on Caribbean reefs, corals create the reef's physical structure, providing habitat for fishes and other organisms. *Important point*

Corals provide clues to the present and to the past. They are also sensitive to several physical factors associated with future climate---elevated CO₂, higher temperatures, and increased UV radiation. They respond to increased temperatures and UV radiation by "bleaching" (losing color). When corals bleach, they cease reproduction and their growth rates decrease (e.g., Szmant and Gassman 1990). *How?* *Poorly worded! How can something be sensitive to something that has not happened?* *Q do they stop calcifying?*

Coral skeletons contain a record of past environmental conditions. For example, they have annual (or near annual) growth bands because skeletal densities vary with cooler and warmer temperatures. Through examination of coral cores ("sclerochronology" studies) one can learn about calcification rates in the past and compare those to present rates (refs.).

Monitoring of reef metabolism at selected reefs in Virgin Islands National Park and Biscayne National Park is the central focus of this 2-year project. Detailed information on the structure of each study site will be correlated with the measurements of reef metabolism. (This information is available for some reefs from the USGS/NPS Inventory & Monitoring Program.) Existing data on reef structure and function are severely limited both spatially and temporally, with insufficient data from widely separated geographic areas over long periods of time. To begin to address these scale deficiencies, we will be looking at reefs in subtropical and tropical areas, and we will be examining coral cores for information on past environmental conditions.. *Poorly worded.*

PROCEDURES/METHODS:

Rationale for Selection of Study Sites

Some of the study sites for this project will be areas for which long-term data (both biological and environmental) are already available. Long-term monitoring sites were established on reefs in Virgin Islands National Park and Biscayne National Park under an NPS program which began in 1988, and the DOI Inventory & Monitoring (I&M) program has supported additional work in VINP. Other sites will be chosen to ensure that data are obtained from a variety of different reef types and from sites of particular management concern.

The coral reef monitoring which NPS and BRD have conducted in these two parks in conjunction with state and university scientists are some of the few long-term monitoring programs in the Caribbean and western Atlantic (Connell 1997). Data on cover by coral and algae are available for both VINP and BNP, and effects of different stresses have been documented for some reefs. Underwater videotapes which provide a statistically quantifiable and permanent visual record of reef characteristics are available for reefs in both of these parks. *In Biscayne? If so, where? Better data?*

data sets of what? pH, Dissolved?
A major task for Year 1 will be the selection of each study site based on the need to include reefs with a range of different reef types with variations in coral cover. Reefs in Biscayne National Park generally have less than 5% living coral while some sites in St. John have live cover in excess of 20%. Initially, we will focus on reefs for which data are already available. On St. John, we will study sites in Lameshur and Newfound bays, for which we have the longest data sets (10 and 9 years respectively). These sites are also under consideration for inclusion in a "marine reserve" within park waters. Transects in Newfound Bay would have the highest coral cover of all the study sites (23%) while those in Lameshur have a coral cover of about 10%. We may also select Hawksnest Bay for which we have information on siltation effects and coral growth rates (Hubbard et al. 1987) because it is a shallow reef exhibiting some signs of recovery in elkhorn coral (*Acropora palmata*) populations. This primary reef-building species was decimated throughout the Caribbean in the 1980's by white band disease. *why should that be a factor?*
are we trying to determine "why" metabolism of coral cover should not be a major concern (see definition on page 1)
I am not sure of this fact

Managers of Biscayne National Park have recommended the following sites:

Richard — please recommend specific study sites in BNP if possible, sites which might help answer "management concerns" — it could actually be cool to look at calcification at one of the areas which is recovering from a boat grounding -- just a thought

REEF FUNCTION: CALCIFICATION AND PRODUCTIVITY

Carbonate sediment production, photosynthesis, and respiration will be measured in winter (when temperatures are lowest) and late summer/fall (when temperatures are highest) to determine seasonal and areal variation in tissue/carbonate production and to derive average annual production rates. These parameters will be calculated from total alkalinity, pH, calcium concentrations, salinity, irradiance, *rough estimated* *How does seasonal measurement give you areal information?*

④

temperature, wind and current speed, and air-sea CO_2 and O_2 fluxes measured along ^{the same complex} transects across reefs.

We propose to work with our primary collaborators, Dr. Robert Halley and Dr. Kim Yates, from the USGS Geologic Division to measure parameters of carbon budgets to assess reef conditions. For many years carbon budgets of reefs have been studied by measuring geochemical parameters of carbon utilization (Smith, 1973). The techniques used to make these measurements have been greatly refined during the past two decades because they are, in part, also the techniques used for measuring global atmospheric CO_2 exchange with the ocean. These refined procedures can now be used again to study coral reefs (Buddemeier and Kinzie 1998). ^{might want to be more specific}

Dr. Halley and Dr. Yates have developed prototypes of two geochemical monitoring systems including a Submersible Habitat for Analyzing Reef Quality (S.H.A.R.Q.) and an In Site Biogeochemical Analysis System (I.B.A.S) for measurement of geochemical changes associated with benthic and water column carbonate sediment production and metabolic activity, respectively (see Halley and Yates for details). To measure reef metabolism, we will use two primary experimental approaches: 1) upstream-downstream transects across broad sections of the reef (), and 2) metabolism of small reef areas enclosed within the SHARQ (see also Rogers 1979).

For upstream-downstream measurements, transects will be located parallel to unidirectional current flow across a given reef, characterized using a series of current meters, with sample stations positioned at the upstream and downstream ends of each transect.

Geochemical and physical parameters (including water temperature) will be measured at each station along a transect at different times (and irradiances) during the day and night to determine daily variations in production and to derive average daily production rates. Recording thermistors are already in place on several reefs in VINP and BNP.

Total alkalinity and pH will be used to calculate calcification and net photosynthesis using the alkalinity anomaly technique of Smith and Key (1975) such that calcification (C) = half the change in total alkalinity, and net photosynthesis (P) = total carbon - calcification. Total carbon will be calculated using carbonate system equations from Millero (1979). Calcium measurements will provide an independent measure of calcification ^{what procedure?} for comparison. Air-sea CO_2 fluxes will be measured directly at each station inside of a floating bell (Frankignoulle 1988, Gattuso et al. 1993, Kayanne et al. 1995) using the procedure and calculations of Frankignoulle (1988). Air-sea O_2 fluxes will be determined by measuring atmospheric and water pO_2 and calculating fluxes as described in Wanninkhof (1992). Differences in oxygen and carbon metabolism between upstream and downstream stations will be corrected for O_2 and CO_2 exchange with the atmosphere as described in

(Gattuso et. al., 1993).

concentration of water
Productivity and metabolic rates per unit area will be calculated using the difference in concentration between upstream and downstream stations, the volume of water transported along a transect, and the transect area such that the change in concentration of a parameter $(\Delta C/m_2/s) = (C/m^3 \times m^3/hr)/m_2$ (Barnes and Devereux, 1984). Seasonal production rates will be used to calculate average annual production rates.

Comparison of these data with previous productivity estimates and calcification rates, as well as calcification rates determined from coral cores (Hudson et. al., 1976; Dodge et. al, 1983; Dodge, et. al, 1992) would indicate whether long-term (decades) changes are occurring on the reefs.

We plan to use both the upstream-downstream method and the SHARQ in both national parks. In some cases, upstream-downstream techniques may not be feasible because of local current conditions (i.e., currents are too weak or too complex), or because reef zones are not wide enough to allow detection of changes. In other situations, for example, where the reef has very high relief, it will be more difficult to use the SHARQ. The IBAS will be used to measure metabolism of the water column and to enable quantification of benthic and water column contributions to overall metabolism. Dr. Robert and Dr. Kimberly Yates, our primary collaborators, have successfully done pilot studies of seagrass beds in Florida Bay using these techniques and plan to test them out on reefs soon.

some bleaching - but not very severe
In the fall of 1998, severe bleaching occurred on the reefs around St. John and within Biscayne National Park [### is this true, Richard???]. We hope to take measurements during future bleaching events to determine the effects of zooxanthellae loss (which results in bleaching) on productivity and calcification rates. *what kind?*

REEF STRUCTURE

It is essential that we have pertinent data on the structure of the transects to accompany the metabolism rates we measure (with both the upstream-downstream technique and the SHARQ). At some study sites, we intend to install the SHARQ over transects for which we already have very detailed information on relative abundances of different organisms ("reef structure"). At other sites, we will collect quantitative information using videography (Rogers and Miller submitted manuscript).

Coral cores:

Skeleton
Skeletons of some coral species (including Montastraea annularis) provide a record of the environmental conditions under which the corals grew. We propose to examine coral cores which have already been collected from the parks to look for any changes in calcification (deposition of the coral skeleton) which would indicate short-term or long-

term changes in environmental conditions. Cores will be used to construct a history of climate conditions over as long a period as possible. We will not be collecting new cores from any of the sites.

The proposed work represents a major study of reef metabolism or "function" as opposed to reef "structure" which is the subject of most monitoring projects. It addresses the fundamental processes required for reef development. The work also relates to the goals of BRD's Global Climate Change Program in several ways. First the proposed measures of air-sea CO₂ fluxes not only provides basic data for determining the degree to which coral reefs contribute to atmospheric CO₂, but they also provides a way to evaluate the sensitivity of coral reef carbon budgets to future atmospheric CO₂ levels (Goal 1). Second, carbon-budget measurements on reefs will help determine the combined effects of global change and environmental contamination on reefs (Goal 2). Third, the project is being addressed at several spatial and temporal scales in an effort to learn more about responses of coral reefs to global change (Goal 3). Fourth, the proposed experiments provide a basis for a better understanding of how careful management of sediment and nutrient input to reefs (which affects the relative abundances of algae and living coral) could offset effects of increased global CO₂ (Goal 4)

TIMELINE

To encompass the range of reefs which we hope to monitor for calcification and productivity rates we will need to extend the work over two years. There will be two field sessions in the winter and late summer/fall of each year in VINP and BNP. Each field session will be 2 weeks long..

Literature Cited:

PLEASE NOTE—I HAVE NOT CHECKED THE REFERENCES YET FOR ACCURACY, OMISSIONS, ETC.

Barnes, D.J. 1983. Profiling coral reef productivity and calcification using pH and oxygen electrodes. *Journal of Experimental Marine Biology and Ecology* 66:149- 161.

Barnes, D.J. and Devereux, M.J. 1984. Productivity and calcification on a coral reef: a survey using pH and oxygen electrode techniques. *Journal of Experimental Marine Biology and Ecology* 79:213-231.

Bohlen, S. R., Halley, R. B., Hickman, S. J., Johnson, S. Y., Lowenstern, J.

B., Huhs, D. R., Thompson, G. A., Trauger, D. L., Zoback, M. L., 1998, Geology for a Changing World, A Science Strategy for the Geologic Division, U. S. Geological Survey Circular 1172, 59p.

Buddemeier, R. W., and Kinzie III, R. A., 1998, Reef Science: Asking all the wrong questions in all the wrong places?, Reef Encounter, pp. 29-34.

Connell, J.H. 1997. Disturbance and recovery of coral assemblages. Coral Reefs 16: S101-113.

Dodge, R. E., and Brass, G. W., 1984, Skeletal extension, density, and calcification of the reef coral *Montastrea annularis*: St. Croix, US Virgin Islands. Bull of Mar Science, v. 34, 288-307.

Dodge, R. E., Szmant, A. M., Garcia, R., Swart, P. K., Forester, A., Leder, J. J., 1992, Skeletal structural basis of density banding in the reef coral *Montastrea annularis*, Proceedings of the Seventh International Coral Reef symposium, Guam, 1:186-195.

Field, M et al. 1998. America's Coral Reefs. A program for mapping, research, and assessment to insure vitality, protect resources, and understand change. USGS workshop, Univ. of Hawaii, March 1998.

Frankignoulle, M. 1988. Field measurements of air-sea CO₂ exchange. Limnology and Oceanography 33(3):313-322.

Frankovich, T.A. and Zieman, J.C. 1994 Total epiphyte and epiphytic carbonate production on *Thalassia testudinum* across Florida Bay. Bulletin of Marine Science 54(3):679- 695.

Gattuso, J.P., Pichon, M., Delesalle, B., and Frankignoulle, M. 1993. Community metabolism and air-sea CO₂ fluxes in a coral reef ecosystem (Moorea, French Polynesia. Mar Ecol Prog Ser 96:259-267.

Ginsburg, R.N. Compiler. 1994. Proc. of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards, and History, 1993. Univ. of Miami.

Hubbard, DK., Stump, J, Carter, B.. 1987. Sedimentation and reef development in Hawksnest, Fish, and Reef Bays, St. John, USVI. National Park Service. Biosphere Reserve Research Report No. 21. 104 pp.

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

Hughes, T. P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science 265: 1547-1551.

Kayanne, H., Suzuki, A., and Saito, H. 1995. Diurnal changes in the partial pressure of carbon dioxide in coral reef water. Science 269:214-216.

Kleypas, J.A., Buddemeier, D., Archer, J.-P., Gattuso, J.-P., Langdon, B. N., Opdyke
1999. Geochemical consequences of increased atmospheric carbon dioxide on coral
reefs. *Science* 284: 118-120.

Millero, F.J., 1979, The thermodynamics of the carbonate system in
seawater. *Geochimica et Cosmochimica Acta* 43:1651-1661.

Pennisi, E. 1998. New threat seen from carbon dioxide. *Science* 279: 989.

Smith, S.V., 1973. Carbon dioxide dynamics: a record of organic carbon
production, respiration, and calcification in the Eniwetok reef flat
community. *Limnology and Oceanography* 18(1):106-120.

Smith, S. V., and Key, G. S., 1975, Carbon dioxide and metabolism in marine
environments. *Limnology and Oceanography* 20:493-495.

Sugiura, Y., Ibert, E.R., and Hood, D.W. 1963. Mass transfer of carbon
dioxide across sea surfaces. *Journal of Marine Research* 21(1):11-24.

Szmant, A.M., Gassman, N.J. 1990. The effects of prolonged bleaching on the tissue
biomass and reproduction of the reef coral *Montastrea annularis*. *Coral Reefs* 8: 217-224.

Wanninkhof, R. 1992. Relationship between wind speed and gas exchange
over the ocean. *Journal of Geophysical Research* 97:7373-7382.

Wilkinson, C. 1992. Coral reefs of the world are facing widespread devastation: can we
prevent this through sustainable management practices? *Proc. Of the 7th Int. Coral Reef
Sym* 1: 11-21.

EXPECTED PRODUCTS:

Scientific papers based on this research will be submitted to peer-reviewed journals.
Presentations on the work will be made at national or international conferences,
including the 9th International Coral Reef Symposium in 2000.

Other products include CDs with archived videotransect data (and appropriate
metadata) and diskettes with results of image analyses.

Investigators' Annual Reports will be submitted to VINP and BNP.

A video of the procedures used to measure reef metabolism will be produced.

TECHNOLOGY/INFORMATION TRANSFER:

This proposal includes development of protocols which will be transferable to other
agencies and individuals with an interest in measuring reef metabolism and in
calculating the effects of increased CO₂ associated with climate change.

The video of the methods used will be made available upon request.

DATA MANAGEMENT:

Data will be documented using the NBII Metadata Standards. Bibliographic metadata
for all information and products will be added to the Biological Resource Division's
Bibliographic Metadata Database at <http://biology.usgs.gov/pubs>.

PERSONNEL: (from the initiating Center)

Nick Funicelli

Caroline Rogers

Ginger Garrison

Jeff Miller

Steve Walsh (need to check with him!)

Doug Weaver (need to check with him!)

COOPERATORS/PARTNERS:

- Our primary partners are the Geology Division of USGS and the National Park Service (Biscayne National Park—maybe VIIS?). Both will be providing personnel, equipment, and expertise for certain tasks to conduct this research effort.
- Robert Halley, USGS, Center for Coastal Geology, St. Petersburg, FL p813 893-3100; f893-3333 (Carbon budget, calcification studies)
- Kimberly Yates, USGS, Center for Coastal Geology
- Richard Curry, Biscayne National Park
- Dennis Hubbard, Oberlin College, 44293 Rt 511E, Oberlin, Ohio 44074; (phone and fax 440 774-5180 (Physical oceanography, coral cores)

FACILITIES/EQUIPMENT/STUDY AREAS:

The BRD field station in the USVI has a Whaler and a diesel boat plus all necessary dive gear to support field work in St. John. Biscayne National Park will support the operations there with one Biological Technician, boats, lab space, current meters, Hydrasondes, etc. The USGS Center for Coastal Geology will supply all necessary equipment for the SHARQ experiments.

LEGAL AND POLICY-SENSITIVE ASPECTS:

Research permits will be necessary for both parks. Supt. Russ Berry, Virgin Islands National Park, P.O. Box 710, USVI 00830; ph 340 693-8950.

Supt. Richard Frost, Biscayne National Park, P.O. Box 1369, Homestead, FL 33090.

BUDGET

Year 1		Matching Contributions			
<i>BRD Salaries</i>		<i>GD Salaries</i>		<i>NPS Salaries</i>	
Rogers (4 pp)		Halley (8 pp)		Curry (3 pp)	

Garrison (2 pp)		Yates (8 pp)		Tech (2 pp)	
Miller (6 pp)		Tech. (4 pp)			
FCSC emp. (4 pp)					
FCSC emp. (2 pp)					
<i>Equipment</i>					
<i>Supplies</i>					
Fuel, videotapes, air fills, stakes					
<i>Travel to BNP</i>					
Rogers (one week)		Halley			
Miller (2 pp)		Yates			
FCSC employee (2 pp)		Tech.			
<i>Travel to VINP</i>					

Year 2		Matching funds			
BRD Salaries		GD Salaries		NPS Salaries	
Rogers (6 pp)		Halley (8 pp)		Curry	
Garrison (2 pp)		Yates (8 pp)		Tech	
Miller (6 pp)		Tech.			
FCSC biologist					

FCSC biologist					
Equipment					
Supplies					
Fuel, videotapes, air fills, stakes					
Travel to BNP					
Rogers (one week)		Halley			
Miller (2 pp)		Yates			
FCSC employee (2 pp)		Tech.			
Travel to VINP					

Note: The budget is based on two 2-week field sessions each year in each park. Three BRD employees (VINP) or two BRD employees and one NPS technician (BNP) would work in the field with three GD employees (VINP) for each sampling period.

From: Shana Curry <mattnshana@mattsmith.net>
To: spm2u@mindspring.com <spm2u@mindspring.com>
Date: Thursday, May 27, 1999 11:00 PM
Subject: FW: proposal

-----Original Message-----

From: Caroline Rogers [SMTP:Caroline_Rogers@usgs.gov]
Sent: Monday, May 24, 1999 11:57 AM
To: richard@mattsmith.net
Subject: proposal

Hi Richard--

Hope you are having a great vacation. I don't think there is anything I absolutely have to have from you before I submit this proposal to Russ Hall (within the week). There are two things which would help, however-- Am I correct that there was severe bleaching in BNP in late summer/fall of 1998? Also, are there any particular reefs (of special importance to park managers, or sites with long-term data, NOT Porter's photostations please!) which you want me to list as study sites in this proposal?

If you can stand to skim through the attached, revised proposal, I would really appreciate your comments.

Cheers-

Caroline

5/29/99

22