

FINAL REPORT

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Prime Award Number: NA03OAR4300088
Awarding Agency: U.S. Department of Commerce/NOAA
Primary Institution: University of North Carolina at Wilmington
Principal Investigator: Steven Miller

Subaward Number: 2003-24A

Subaward Title: Three New Tools for Reef Monitoring and Risk Assessment:
Distinguishing Local from Global Stresses

Project Director: Pamela Hallock Muller (pmuller@marine.usf.edu)
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Project Period: 10/1/03-9/30/05

Objectives of Research:

The major objectives of this project are to streamline procedures for three indices, which were originally developed under funding from the U.S. EPA-NCERQA STAR-Grant Program -- Ecological Indicators initiative (GAD-R8825869), and to test them on samples from the Florida Reef Tract. The project addresses the following NOAA Priority Topics: i) "Recruitment and survival of marine species", specifically the potential effects of ecological parameters on the recovery of benthic communities, and evaluation of factors responsible for the declines; and ii) the decline in coral abundance, specifically the need to distinguish among the effects of local, regional and global causative factors and processes. The three procedures, which utilize proxy indicators -- foraminifera, their shells and the sediments in which they occur -- have been developed to assess reef condition on two time scales, one suitable for resource assessment, and one suitable for risk assessment.

Accomplishments:

- i. The FORAM Index is a single-metric index that can be used in resource assessment to determine if environmental conditions support mixotrophy (algal symbiosis) as a dominant trophic mode for benthic communities on the scale of years. This index, which is based on assemblages of foraminiferal shells within the sediments (Hallock et al. 2003), has been assessed using EPA Evaluation Guidelines for Ecological Indicators (Jackson et al. 2000). The FORAM Index was tested on a suite of 144 sediment samples from Biscayne National Park (BNP); results are presented in a thesis by Carnahan (2005) and are the basis of two manuscripts (Carnahan et al., submitted; Carnahan et al., in prep).
- ii. The SEDCON Index, which is based on reef sediment constituents and the same ecological concepts as the FORAM Index, can also be applied in

resource assessment. Sediment constituents reflect general condition of reef ecosystems, on the scale of years to decades, relative to community structure and bioerosion (Lidz and Hallock 2000). Approximately 100 sediment samples collected from Florida Keys National Marine Sanctuary Coral Reef Monitoring Program (CRMP) monitoring sites have been assessed and reported in the thesis by Daniels (2005); also Daniels et al., in prep.).

- iii. The FoRAM Photic Index (FPI -- aka Amphi Index) is based upon densities and visual assessments of *Amphistegina* populations (e.g., Hallock et al. 1995; Williams 2002), and is designed to be a low-cost risk-assessment tool (Hallock 2000; Hallock et al. 2006). These protists are sensitive to environmental conditions over days to weeks, and provide a method to quickly distinguish between water quality (local) and photooxidative (global) stresses. Data from 2001-2003 quarterly sampling at six sites in FKNMS and two sites in BNP have been analyzed for abundance, as well as prevalence of bleaching, and are being compared with physiological responses of *Montastraea* corals (e.g., Downs et al. 2002) from the same locations. The FPI that has evolved is a dual-metric index based upon the \log_{10} of the population abundance and the percentage of "normal-appearing" post-juvenile individuals (Fisher et al., in prep.).

References:

- Downs, C. A., Fauth, J. E., Halas, J. C., Dustan, P., Bemiss, J., and Woodley, C. M. 2002. Oxidative stress and seasonal coral bleaching. *Free Radical Bio. Med.* 33 (4): 533-534.
- Hallock, P. 2000. Larger Foraminifers as Indicators of Coral-Reef Vitality. In R. Martin (ed.), *Environmental Micropaleontology*, Kluwer/Academic Plenum Press, p. 121-150.
- Hallock, P., Talge, H. K., Cockey, E.M., and R. G. Muller. 1995. A new disease in reef-dwelling foraminifera: Implications for coastal sedimentation. *J. Foram Res.* 25:280-286.
- Hallock, P., Lidz, B.H., Cockey-Burkhard, E.M., and Donnelly, K.B. 2003. Foraminifera as bioindicators in coral reef assessment and monitoring: The FORAM Index. *Environ. Monit. Assess.* 81(1-3): 221-238.
- Hallock, P., K. Barnes, and E.M. Fisher. 2004. From satellites to molecules: A multiscale approach to environmental monitoring and risk assessment of coral reefs. *Journal of Environmental Micropaleontology, Microbiology, and Meiobenthology* 1: 11-39.
- Jackson, L.E., Kurtz, J.C. and Fisher, W.S. (eds). 2000. *Evaluation Guidelines for Ecological Indicators*, EPA/620/R-99/005. U.S. EPA, Office of Res. and Development, Res. Triangle Park, NC, 107 pp.
- Lidz, B.H. and Hallock, P. 2000. Sedimentary petrology of a declining reef ecosystem, Florida Reef Tract (U.S.A.). *J. Coastal Res.* 16:675-697.

Williams, D.E. 2002. Population Ecology of Bleaching-Stressed *Amphistegina gibbosa* in the Florida Keys (1991-1999): Influence of Solar Radiation on Reef-Dwelling Foraminifera. Ph.D. Dissertation, University of South Florida, Tampa, FL, 163 pp.

Publications:

Hallock, P., K. Barnes, and E.M. Fisher. 2004. From satellites to molecules: A multiscale approach to environmental monitoring and risk assessment of coral reefs. *Journal of Environmental Micropaleontology, Microbiology, and Meiobenthology* 1: 11-39.

Williams, D.E. and P. Hallock. 2004. Light requirements and bleaching in *Amphistegina gibbosa*: Observations from Laboratory Experiments. *Marine Biology* 145: 641-649.

Hallock, P. 2005. Global change and modern coral reefs: New opportunities to understand shallow-water carbonate depositional processes. *Sedimentary Geology* 175:19-33.

Manuscripts accepted/in press:

Fisher, E.M., J. E. Fauth, P. Hallock, C.M. Woodley, Lesion regeneration rates in reef-building corals (*Montastraea* spp.) as indicators of colony condition: strengths and caveats. Accepted for publication in MEPS pending revisions.

Hallock, P., D.E. Williams, S.K. Toler, E.M. Fisher, and H.K. Talge. 2006. Bleaching in Reef-Dwelling Foraminifers: A 20 Year Retrospective. Proceedings, 11th International Coral Reef Symposium, Okinawa, Japan, July 2004. To be released in CD/DVD form.

Manuscripts submitted:

Carnahan*, E.A., A.M. Hoare, P. Hallock, B.H. Lidz, C.D. Reich. Distributions of Heavy Metals and Foraminiferal Assemblages in Sediments in Biscayne Bay, Florida, USA. Submitted to *Journal of Coastal Research*.

Crevison Souder*, H, Hallock, P. Morphological abnormalities in live Archaiasine foraminifers from the Florida Keys, USA. Submitted to the *Journal of Foraminiferal Research*.

Thesis Completed

Carnahan, E. 2005. Foraminiferal Assemblages as Bioindicators of Potentially Toxic Elements in Biscayne Bay, Florida. M.S. Thesis, College of Marine Science, University of South Florida. <http://etd.fcla.edu/SF/SFE0001019/Carnahan-Elizabeth-Thesis.pdf>

Daniels, C. 2005. Coral Reef Assessment: An Index Utilizing Sediments. M.S. Thesis, College of Marine Science, University of South Florida. <http://etd.fcla.edu/SF/SFE0001180/Daniels-Camille-thesis.pdf>

Manuscripts in preparation

Carnahan, L.A., A.M. Hoare, P. Hallock, B.H. Lidz. Foraminifera as Bioindicators of Heavy Metal Pollution in Biscayne Bay, Florida.

Daniels, C., and P. Hallock. Coral Reef Assessment: An Index Utilizing Sediments. (Manuscript in preparation for either Ecological Indicators or Applied Ecology)

Fisher, E.M., P. Hallock, J. E. Fauth, C.M. Woodley, Symbiont-bearing foraminifers as indicators of reef health. (Manuscript in preparation for Environmental Bioindicators)

Presentations:

Carnahan, L.A., A.M. Hoare, P. Hallock, B.H. Lidz, C.D. Reich, and E.A. Shinn. 2004. Foraminifera as Bioindicators of Heavy Metal Pollution in Biscayne Bay, Florida. 2004 Benthic Ecology Meeting, Mar. 25-28, 2004, Mobile, Alabama, Program and Abstracts.

Daniels, C.A., Hallock, P., and Lidz, B.H. (2004), Development and Application of the SEDCON Index for Resource and Risk Assessment of Coral Ecosystems, Eos Trans. AGU, 85(47), Fall Meet. Suppl., Abstract OS51C-1312. [AGU Outstanding Student Paper Award for Ocean Sciences]

Fisher, E. M., Hallock, P., Woodley, C. M. 2004. Relationship between sedimentation and regeneration in *Montastrea* spp. (Scleractinia). ASLO/TOS Ocean Research Conference, Feb. 15-20, 2004, Honolulu, Hawaii.

Fisher, E. M., Hallock, P., Fauth, J. E., Downs, C. A., and Woodley, C. M. 2004. Evaluating coral condition in *Montastrea* spp. (Scleractinia) at individual and cellular scales. 2004 Benthic Ecology Meeting, Mar. 25-28, 2004, Mobile, Alabama, Program and Abstracts.

Hallock, P., Barnes, K, and Fisher, E.M. Environmental Monitoring and Risk Assessment of Coral Reefs: A Multi-Scale Approach. Assessing the Health of Coral Reef Ecosystems in the Florida Keys using an Integrated Molecular Biomarker System, Constituents Workshop, Key Largo, FL, January 17-18, 2004.

Hallock, P., D.E. Williams, S.K. Toler, E.M. Fisher, and H.K. Talge. 2004. Photic Stress and Bleaching in Reef-Dwelling Foraminifera: A 20 Year Retrospective. 10th International Coral Reef Symposium, Okinawa, Japan, June 2004. Abstracts, p. 322.

Hallock, P., B.H. Lidz, E. Carnahan, C. Daniels, and A.M. Hoare. 2004. Three Low-Cost Tools for Reef Monitoring and Risk Assessment: Distinguishing Local from Global Stresses. 10th International Coral Reef Symposium, Okinawa, Japan, June 2004. Abstracts, p. 332.

Hallock, P., B.H. Lidz, E. Carnahan, C. Daniels, and A.M. Hoare. 2004. Distinguishing Local from Global Stresses: Low-Cost Tools for Reef Monitoring and Risk

Assessment. The Association for Tropical Biology and Conservation (ATBC Miami 2004), July 14, 2004. p. 75.

Carnahan, L.A., Hoare, A.M., Hallock, P., Lidz, B.H., Reich, C.D., Shinn, E.A. 2005. Foraminiferal Assemblages and Geochemical Properties of Sediments in Biscayne Bay, Florida. Geological Society of America Annual Meeting, Salt Lake City, Utah, October 2005.

Daniels, C., P.Hallock, B.H. Lidz. 2005. Development & Application of the SEDCON Index for Coral Reef Ecosystem. American Society of Limnologists & Oceanographers (ASLO)

Daniels, C., P.Hallock, B.H. Lidz. 2005. Development & Application of the SEDCON Index for Coral Reef Ecosystem. American Geophysical Union (AGU) Joint Assembly, New Orleans.

Daniels, C., P.Hallock, B.H. Lidz. 2005. Development & Application of the SEDCON Index for Coral Reef Ecosystem. Association of the Marine Laboratories of the Caribbean, Curaçao, Netherland Antilles

Hallock, P. 2005. Energetics in acclimation and adaptation to environmental extremes. Geological Society of America Annual Meeting, Salt Lake City, Utah, October 2005.

Fisher, E.M., Hallock, P., and Woodley, C.M. 2005. Atlantic and Gulf Rapid Reef Assessment (AGRRA): A tool for multiscale studies of Florida Coral Reefs. Geological Society of America Annual Meeting, Salt Lake City, Utah, October 2005.

Daniels, C., P.Hallock. 2006. Coral Reef Assessment: An Index Utilizing Sediment. 13th Ocean Sciences Meeting, Honolulu.

Relevant Websites: <http://www.marine.usf.edu/reefslab>

**NURC/UNCW
Management Information System**

Project Summary Report

PI Surname: Hallock Muller **Project #:** **Region:**
Title of Project: THREE NEW TOOLS FOR REEF MONITORING AND RISK ASSESSMENT:
DISTINGUISHING LOCAL FROM GLOBAL STRESSES

Start Date: 10/01/03 **End Date:** 09/30/04 **Year 1 of 1**

Principal Investigator: *complete name, affiliation, department, mailing address, e-mail, phone and fax number*

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Cooperating Institutions: *other institutions involved in the mission that are not shown above*

Number of Participants: *total number of science participants* **3-5**

OPERATIONAL INFORMATION

System	for extended ops only		Weather Days	Other (e.g. mech. prob.)	OPS Days	Total Dives ¹	Total Bottom Time ²
	Port Days	Transit Days					
SCUBA (air)							
SCUBA (nitrox)							
<i>Aquarius</i>							
ROV							
SUB							
Center Facilities: lodging dockage shore lab small boats							
Center Equipment: CTD Video camera(s) still camera(s) Other:							
Support Vessel(s) used:							

1. For SCUBA, SCUBN or Aquarius = man dives or excursions; for ROV/SUB = system dives
 2. Bottom Time = surface to surface interval (hours)

Operating Depth Range (meters):

Project Location(s): geographic name = area of research, e.g., Hatteras slope or Conch Reef; latitude and longitude = center of area; no more than four areas

Site	Geographic Name	Latitude (dd-mm.m N)	Longitude (ddd-mm.m W)
1			
2			
3			
4			

COST INFORMATION

NURC/UNCW Support (input by Center):

Variable Costs = direct costs, including supplies, equipment, services, subcontracts provided by the Center for this project \$ **NURC input** _____

Fixed Costs = value of Center system support based on estimated day rate for the system times number of operations days \$ _____

Total = \$ _____

Co-funding Support (input by PI):

Agency	Status (Approved, Submitted)	Period (dates)	\$ Amount
			\$
			\$
			\$
			\$
			\$
			\$
			\$
Total Co-Funding =			\$

PROJECT DESCRIPTION

I. SUMMARY OF PROJECT: *objectives, methods, and the significance of the proposed activity to the advancement of research field, environmental management, or education. Please avoid use of first person.*

A multi-level approach to monitoring and risk assessment of coral-reef resources has been proposed by Hallock et al. (accepted). This approach, which includes these new indices, can provide managers with affordable procedures to distinguish between local and global stressors. Recommendations are to: a) assess community structure and function of reef resources on 3-5 year intervals, including FORAM and SEDCON indices; b) expand the current global bleaching alert system to include both estimates of radiant energy reaching the sea surface and water transparency anomalies (e.g., 'photooxidative hotspots' and 'plume alerts'); c) expand local *in situ* physical and chemical monitoring to include irradiance parameters at sea surface and depth; and d) assess low-cost, low-impact bioindicators (e.g., Amphi Index, coral-disease and coral-mortality indices) at multiple sites each year in late spring and late summer, or when other evidence such as a disease outbreak indicates a problem. Risk assessments based on low-cost bioindicators, in addition to satellite and *in situ* monitoring, can provide resource managers with information required to decide when more costly molecular or chemical diagnostic procedures are needed to identify local sources of stress. This approach is designed to enable management actions and resources to be focused on protection and restoration of reef resources.

A data base of FORAM and SEDCON indices for CRMP-Coral Reef/Hardbottom monitoring sites will be compiled for comparison with contemporaneous CRMP-derived reef-community data and as baseline data for future resource assessment. Similarly, a data base of Amphi Indices will be compiled for various sites in the keys between 1992 and 2004, identifying sites, years and seasons that the index indicates most favorable environmental conditions, compromised water quality, or acute or chronic photooxidative stress. Sites where any of the indices indicate chronic or acute stress will be identified and the source of stress (i.e., local versus global) will be evaluated. When appropriate, recommendations will be made for further testing using molecular or isotopic techniques.

II. SUMMARY OF RESULTS: *Accomplishments, benefits, and new research topics: 1) preliminary results and significance; 2) success of the mission in terms of project goals; 3) plans for use of the data, for example, management needs, publications, or other products; 4) new research ideas or directions generated.*

III. CENTER SUPPORT: *Advantages of NURC/UNCW program, particularly in situ support, to the project and your research program. Please comment on operations and highlight both strong and weak points; suggestions for improvement are appreciated.*

IV. PUBLIC INFORMATION RELEASE: *please help us promote undersea science by writing a paragraph highlighting the importance of the research that may be used for public distribution and press releases.*

**NURC/UNCW
Management Information System**

Project Summary Report

PI Surname: Hallock Muller **Project #: 2004-19B** **Region: Florida Keys**
**Title of Project: THREE NEW TOOLS FOR REEF MONITORING AND RISK ASSESSMENT:
DISTINGUISHING LOCAL FROM GLOBAL STRESSES**

Start Date: 1/01/04 **End Date: 12/31/04** **Year 1 of 2**

Principal Investigator: *complete name, affiliation, department, mailing address, e-mail, phone and fax number*

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Cooperating Institutions: *other institutions involved in the mission that are not shown above*

Number of Participants: *total number of science participants* **8**

OPERATIONAL INFORMATION

System	for extended ops only		Weather Days	Other (e.g. mech. prob.)	OPS Days	Total Dives ¹	Total Bottom Time ²
	Port Days	Transit Days					
SCUBA (air)			5		7		
SCUBA (nitrox)							
<i>Aquarius</i>							
ROV							
SUB							
Center Facilities: lodging dockage shore lab small boats							
Center Equipment: CTD Video camera(s) still camera(s) Other:							
Support Vessel(s) used: Dayboats							

1. For SCUBA, SCUBN or Aquarius = man dives or excursions; for ROV/SUB = system dives
 2. Bottom Time = surface to surface interval (hours)

Operating Depth Range (meters):

Project Location(s): geographic name = area of research, e.g., Hatteras slope or Conch Reef; latitude and longitude = center of area; no more than four areas

Site	Geographic Name	Latitude (dd-mm.m N)	Longitude (ddd-mm.m W)
1	Molasses/Pickles	25 ° 00	80°23
2	Inshore reefs off Key Largo	25 °	80°
3	Conch Reef	24 ° 56	80°27
4			

COST INFORMATION

NURC/UNCW Support (input by Center):

Variable Costs = direct costs, including supplies, equipment, services, subcontracts provided by the Center for this project **\$52,876**

Fixed Costs = value of Center system support based on estimated day rate for the system times number of operations days **\$**

Total = \$

Co-funding Support (input by PI):

Agency	Status (Approved, Submitted)	Period (dates)	\$ Amount
USF Institutional Salary Match	Approved	10/1/03-6/30/05	\$16,853
USF equipment used on project		5/04 – 8/04	>\$50,000
USF personnel time contributed		5/04 – 8/04	~\$5,000
			\$
			\$
			\$
Total Co-Funding =			>\$70,000

PROJECT DESCRIPTION

I. SUMMARY OF PROJECT: *objectives, methods, and the significance of the proposed activity to the advancement of research field, environmental management, or education. Please avoid use of first person.*

A multi-level approach to monitoring and risk assessment of coral-reef resources was proposed by P. Hallock and co-workers in a paper published in 2004. This approach includes three new indices that can provide managers with affordable procedures to distinguish between local and global stressors. Risk assessments based on low-cost bioindicators, in addition to satellite and *in situ* monitoring, can provide resource managers with information required to decide when more costly molecular or chemical diagnostic procedures are needed to identify local sources of stress. This approach is designed to enable management actions and resources to be focused on protection and restoration of reef resources.

The basic objectives of this project were to further develop and assess these indices using guidelines developed by the U.S. EPA for assessing ecological indicators. SEDCON Index is based on the assumption that constituents of reef sediments reflect community structure and bioerosional processes. Thus index is being tested at CREMP-Coral Reef/Hardbottom monitoring sites by comparison with CREMP-derived reef-community data to provide baseline data for future resource assessment. The FORAM-Photic Index (F-PI) utilizes presence and intensity of bleaching in selected reef foraminifers to detect chronic to acute photic stress that could exacerbate bleaching in corals during seasonal thermal maxima. F-PI data are being compiled for sites in the keys sampled between 1992 and 2004 under NURC-UNCW support. A primary goal for field activities in 2004 was to test the hypothesis that high variability in water transparency on inshore reefs contributes to acute or chronic photic stress. *In-situ* radiometers were deployed at two sites with contrasting records of coral condition during early summer to correspond with peak solar irradiance. In addition, irradiance and water transparency data, as well as samples of reef foraminifers, were collect during field activities in May, July and September.

II. SUMMARY OF RESULTS: *Accomplishments, benefits, and new research topics; 1) preliminary results and significance; 2) success of the mission in terms of project goals; 3) plans for use of the data, for example, management needs, publications, or other products; 4) new research ideas or directions generated.*

1. Preliminary results:

The SEDCON Index has been compiled for reef sites throughout the Florida Keys and has been shown to correlate with coral cover, as determined by the CREMP monitoring project. Irradiance and water transparency data collected in reef waters during May, July and September off Key Largo support the hypothesis that reefs in waters with limited variability in transparency are in better condition than reefs with high variability, but are too sparse to be conclusive.

2. Success of the mission in terms of project goals

2004 was the year of bad weather and bad luck with instruments. Despite flexibility in scheduling on the part of both NURC-Florida Keys and our field team, only 7 of the allotted 12 field days could be utilized in 2004. Bad weather repeatedly postponed initial deployment of our *in situ* radiometers from March to May. Unfortunately, once deployed, both instruments failed, so no multi-day comparative data could be obtained to effectively test the variability hypothesis. One instrument was repaired in time for August redeployment, but the hurricane season set in, interrupting further work until late September.

3. Plans for use of the data:

Despite the bad luck with weather and in situ equipment, the water transparency data collected during

field sampling, combined with the foraminiferal data and previous work at the sampling sites, are providing essential preliminary results needed to support a funding proposal in progress; a manuscript is also planned for submission after the proposal is submitted. One of the graduate students involved in the data collection also is utilizing the data in her dissertation proposal. She will be presenting the data at a regional meeting in March. All three indices were presented in a poster at the International Coral Reef Symposium in Okinawa in July and the SEDCON Index was presented at the fall meeting of the American Geophysical Union.

4. New ideas or research directions

This project provided opportunities for researcher from the USF Ocean Optics Laboratory utilize their equipment for measuring solar irradiance and water transparency at the same time as the Reef Indicators team was collecting in situ irradiance data and samples to assess photic stress in foraminifer populations. As a consequence, a joint funding proposal is in progress to more effectively test the hypothesis of variability in photic stress as a factor in reef decline.

III. CENTER SUPPORT: *Advantages of NURC/UNCW program, particularly in situ support, to the project and your research program. Please comment on operations and highlight both strong and weak points; suggestions for improvement are appreciated.*

The NURC/UNCW program, particularly the day-boat operation of the Florida Keys facility, is an absolutely invaluable resource in support of research on the Florida Keys reef tract. Having a facility where the researchers can stay so that they can be up and ready to embark on their field activities without extraneous transport of personnel and gear from lodging site to dockside saves hours of time. Having available scuba and Nitrox tanks and other gear on site are an additional invaluable benefit of the facility. Having basic laboratory and gear fabrication facilities can make the difference between success and failure in field activities. And finally, having reliable day boats operated by competent captains who are also handling at part of the responsibility for diving safety greatly contributes to productivity. When the researchers must handle all of these factors themselves, the productivity of the field activities and the overall project is greatly diminished. The NURC/UNCW Florida Keys facility is the single best operation I have worked with in my 30+ years as a reef researcher.

IV. PUBLIC INFORMATION RELEASE: *please help us promote undersea science by writing a paragraph highlighting the importance of the research that may be used for public distribution and press releases.*

A research team from the College of Marine Science at the University of South Florida in St. Petersburg, led by Dr. Pamela Hallock Muller, is asking the question: Are patch reefs off coastlines with coastal hammocks and mangroves in better condition than patch reefs off developed shores? Using a variety of approaches ranging from high-tech instruments for measuring sunlight and water clarity to simple microscopic examination of the kinds of shells in reef sediments, these researchers hope to determine if greater variability in the amount of sunlight reaching the reefs increases susceptibility of corals to bleaching and disease. If so, their results may provide resource managers and coastal planners with new strategies for protecting the reefs.