Year Eight Project Report

Project ID: SeaBED-A **Title:** Testbed Development at UPRM					
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I. Brief Overview of the Project and Its Significance

The main objective of the SeaBED-A effort is to develop an open testing infrastructure and set of publicly available data for researchers to validate subsurface aquatic remote sensing algorithms. The testBED is currently composed of two distinct analysis systems: a laboratory-based tank configuration and a field site located on nearby Enrique Reef, in southwest Puerto Rico. The purpose behind developing SeaBED-A is to collect multiple levels of image, field, and laboratory data with which to validate physical models, inversion algorithms, feature extraction tools and classification methods for subsurface aquatic sensing. Data produced from the testBED environment currently includes airborne, satellite, and field-level hyperspectral and multispectral images, *in situ* spectral signatures and water bio-optical properties. The laboratory testBED provides a controlled environment for examining subsurface spectral behavior as a function of varying illumination conditions, viewing geometry, water optical properties and target composition. The field site, which includes a heterogeneous mixture of both coral reef and seagrass habitats, offers a system for evaluating analysis techniques under natural environmental conditions. Together, these test facilities provide the flexibility and control to acquire a valuable combination of sensing imagery and fully characterized ground truth information.

As highlighted below, a major milestone was accomplished for SeaBED-A in 2007. An extensive airborne hyperspectral mission was successfully conducted in southwestern Puerto Rico to collect high quality, high resolution hyperspectral imagery over the SeaBED-A field site: Enrique Reef. The image data from this mission will be available in early 2008.

II. State of the Art, Major Contributions and Technical Approach

A. State of the Art

Coral reefs and other benthic habitats are being increasingly threatened by the impacts of anthropogenic stressors and the effects of global change. These ecosystems play a crucial role in overall marine health and biodiversity, as well as providing significant economic, aesthetic and other ecological benefits. The management and preservation of these valuable natural resources requires a set of reliable quantitative tools for mapping and monitoring the dynamics of habitat distribution and condition. Fortunately, advances in remote sensing instrument capabilities and analysis methods are expanding the accuracy and effectiveness of applications directed at classifying habitat composition in shallow aquatic environments. This includes improvements in both multispectral and hyperspectral passive remote sensing investigations, as well as active remote sensing technologies such as bathymetric lidar. Although extensive data sets exist, e.g., Kaneohe Bay, Hawaii and Heron Island, Australia, the lack of readily available, publicly accessible ground truth information makes it difficult to perform algorithm validation and testing. SeaBED was developed to address this shortcoming by providing a multi-level aquatic test environment for creating, refining and evaluating subsurface aquatic remote sensing algorithms (Fig. 1). The resulting analysis capabilities are facilitating enhanced spatial analysis tools for algorithm development, resource management decisions, conservation planning and risk management evaluations.

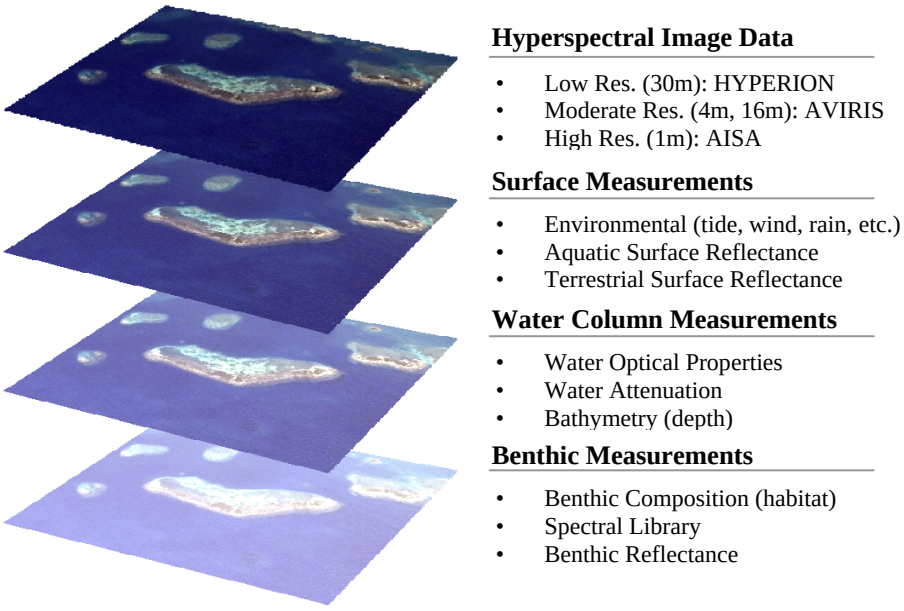

Fig. 1. SeaBED multiple level data collection concept.

B. Major Contributions and Technical Approach

SeaBED addresses the deficiency in available validation data by providing the needed framework to assess physical models, inversion algorithms, feature extraction tools and classification methods for subsurface aquatic sensing. SeaBED is focused on coral reef and seagrass habitats, but is nevertheless applicable across a broad range of shallow aquatic ecosystems. The laboratory tank provides controlled environments for experimentation, while the field site offers the physical reality of a complex natural system for evaluating analysis techniques.

Southwest Puerto Rico Hyperspectral Mission

The major accomplishment in 2007 was the collection of extensive high-resolution hyperspectral imagery over the nearshore reefs and coastal ecosystems in southwest Puerto Rico. Imagery was collected by the Galileo Group Inc. using the AISA Eagle sensor system (http://galileo-gp.com/aisa_eagle.html) as contracted with funding from Gordon-CenSSIS and the Caribbean Coral Reef Institute (CCRI). The total area included in this mission was over 2000 km^2, with enhanced coverage of four science areas, three aquatic and one terrestrial. Although the project was originated to support ongoing research at Gordon-CenSSIS related to hyperspectral remote sensing, the overall mission was significantly expanded to involve additional collaborators with added sensors and instruments that together are addressing an increasing number of scientific questions and application driven objectives.

Mission Study Area

The study area included the following (Fig. 2):

- The overall acquisition area covers 2150 km^2 and includes both land and shallow aquatic habitats. This area was acquired at 4 m GSD;
- Three additional aquatic multi-resolution science areas, totaling 100 km^2, were also included. They include three separate coral reef areas representing different environmental characteristics. These smaller subsets were acquired at multiple spatial resolutions, including 1 m, 2 m, 4 m and 8 m GSD;
- The Guánica Dry Forest, totaling 35 km^2, was also acquired at 1 m and 4 m GSD to facilitate more detailed analysis of this important ecological area. This area is both a UNESCO Biosphere Reserve and monitoring site for the proposed National Ecological Observatory Network (NEON).

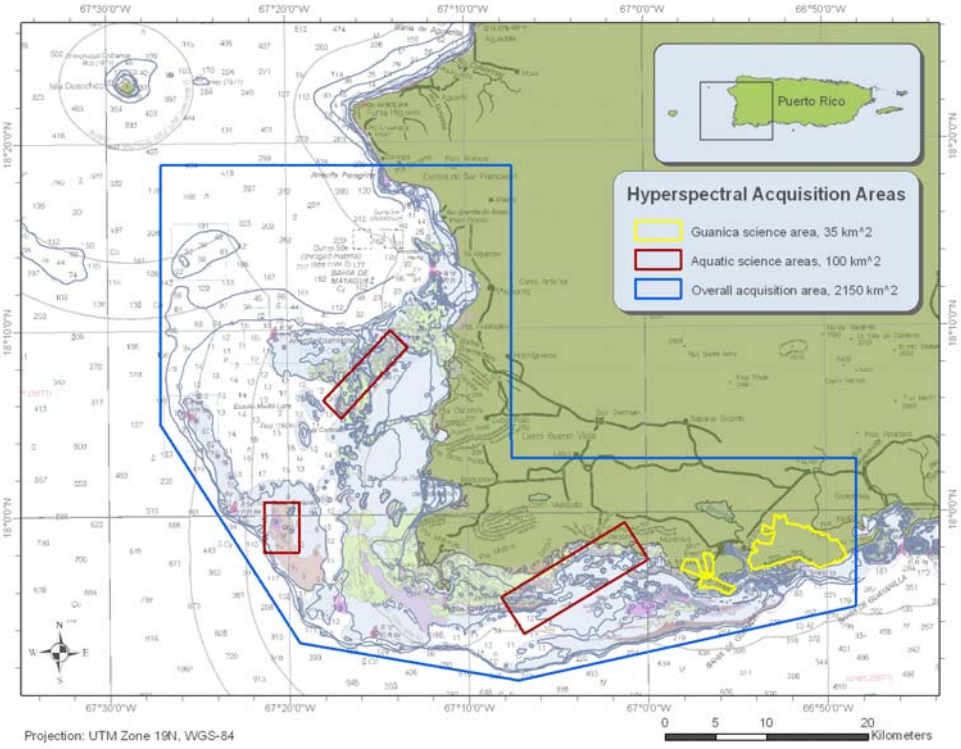

Fig. 2. Mission study area: blue polygon represents data at 4m GSD, red polygons represent science areas at 1m, 2m, 8m GSD and yellow polygons represent terrestrial science area at 1m GSD.

Hyperspectral Imagery

The Galileo Group Inc. (http://galileo-gp.com/) was selected as the commercial hyperspectral image provider. Galileo provides end-to-end image hyperspectral services, from planning and acquisition logistics to data collection and image processing. The company is experienced with both commercial and research oriented clients. Following a competitive bid process, Galileo was selected as the most appropriate company to meet our specific data requirements.

Mission specifications and deliverables provided by Galileo include the following:

- Sensor system used for acquiring hyperspectral data was an AISA Eagle manufactured by Spectral Imaging Limited (http://www.specim.fi/);
- Spectral range was from 400-1000 nm, with 128 bands at a resolution of 3-5 nm FWHM;
- The 4 m and 8 m GSD data was collected from an altitude of 2900 m with 40% spatial overlap between adjacent flightlines;
- The 2 m GSD data was collected from an altitude of 2600 m with 30% spatial overlap between adjacent flightlines;
- The 1 m GSD data was collected from an altitude of 1200 m with30% spatial overlap between adjacent flightlines;
- Flightline orientation and scheduling was independently optimized for terrestrial and aquatic areas, where aquatic flightlines were acquired in the morning and afternoon to minimize the effects of sunglint and terrestrial flightlines were acquired near mid-day to minimize shadowing effects;
- Imagery delivery from Galileo will occur in early 2008. This will include radiometrically corrected at-sensor upwelling radiance (geocorrected and non-geocorrected), atmospherically corrected surface reflectance (geocorrected and non-geocorrected), geographic lookup tables (GLTs) for performing geocorrection and a natural color mosaic of the hyperspectral imagery;
- Digital aerial photography was also acquired over the Guanica Dry Forest using a Nikon D200 camera system. This will be delivered as individual frames.

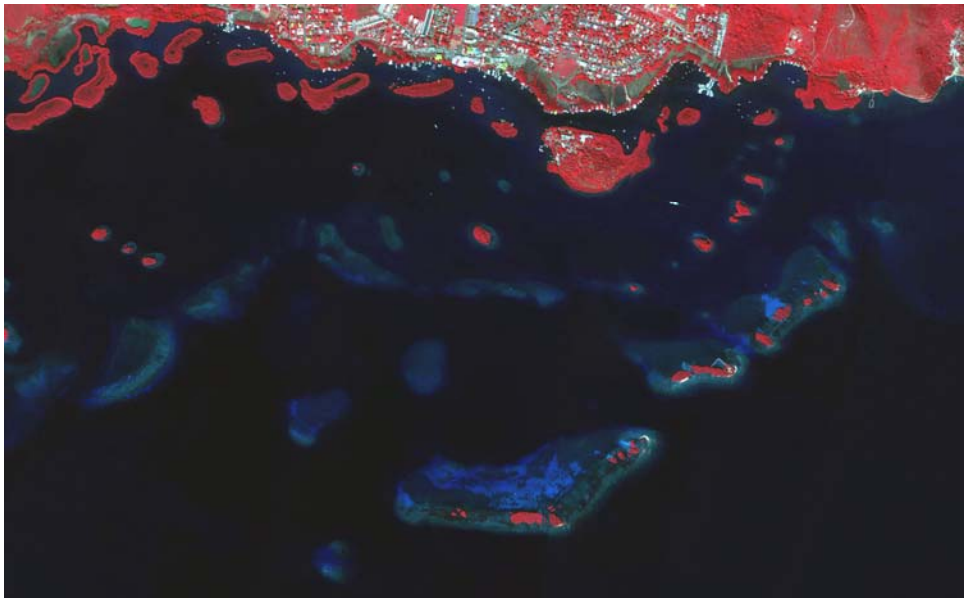

Fig. 3. Example 1 m false-color hyperspectral composite showing the reef systems near La Parguera, including Enrique Reef.

Associated SeaBED Hyperspectral Imagery

Remote sensing image acquisition for Enrique Reef has focused primarily on hyperspectral sensor systems, whose spectral detail provides a greater capacity for resolving the complexities of subsurface aquatic image analysis. Three different hyperspectral sensor systems have been utilized to acquire remote sensing data over Enrique Reef, including both satellite and airborne acquisitions. The aim is to compile a diverse set of imagery with differing spectral, spatial and temporal resolutions covering the same geographic location. As such, in addition to the imagery described below, future plans include incorporating both different sensor systems as well as repeat acquisitions using the same sensors.

A temporal summary of all the hyperspectral imagery currently available for Enrique reef is illustrated in Fig. 4. Of particular interest is that this collection of imagery spans the timeframe before and after the Caribbean-wide coral bleaching event occurring in fall of 2005, thus providing a unique opportunity for examining the spatial impacts of this highly significant environmental event. Additionally, the spatial and temporal resolutions represented in this collection allow for comparative analysis of various image classification and change detection techniques.

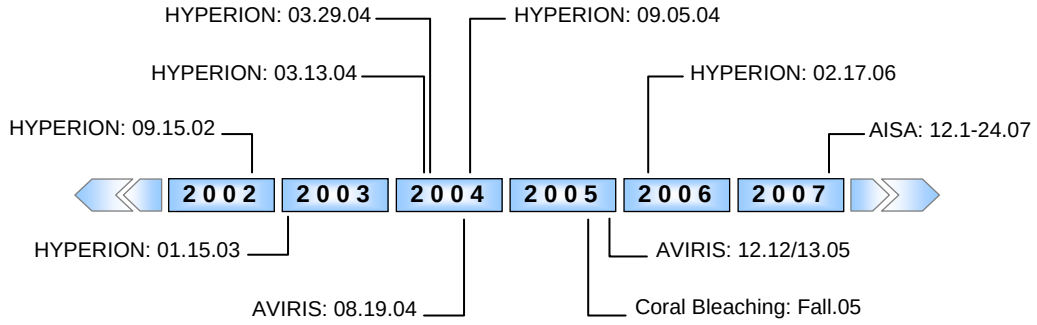

Fig. 4. . Timeline of hyperspectral image acquisition for Enrique Reef.

Coincident Field Data Collection Efforts

A variety of different field data collection efforts were performed before the mission and during the mission coincident with the airborne image acquisition Instrumentation being utilized for the field measurements included two GER-1500 spectrometers (terrestrial), a SVC HR-1024 spectrometer (terrestrial), three custom underwater GER-1500 spectrometers (aquatic), an underwater DiveSpec spectrometer (aquatic), a Satlantic HyperPro (aquatic), a bio-optical rosette with various instruments (CTD, AC-9, HS-6, OCR-200 and a fluorometer) for measuring water properties (aquatic), GPS units and cameras. The data collection efforts included:

- Reflectance characteristics of terrestrial (land) and aquatic (benthic) spectral calibration targets;
- Spectral library of dominant species and substrate types of reef and seagrass communities;
- Spectral profiles and bio-optical properties of the water column;
- Surface reflectance over representative shallow habitats and deep water locations;
- Video mosaics of 10m x 10m areas of the benthic substrate;
- GPS polygons, points and photos of reef, seagrass and mangrove features;
- Linear benthic transects, with GPS locations, measuring detailed reef community characteristics;

- Spectral library of dominant coastal and dry forest vegetation species;
- GPS polygons, points and photos of terrestrial vegetation features.

Mission Collaborators

A number of collaborators were identified and invited to participate in this project, including involvement in mission planning, field data acquisition, image processing and the utilization of image products. This has served to both expand the utility of the image acquisition efforts, as well as develop exciting new research relationships. Additionally, all involved will mutually benefit from the collective expertise and diversity of researchers involved in the mission. Collaborators include:

- University of Puerto Rico at Mayaguez (UPRM) CenSSIS/CCRI (team leaders)
- UPRM Geology Department
- UPRM Biology Department
- UPRM Agronomy and Soils Department
- NASA Ames Research Center
- USDA Forest Service Puerto Rico
- USGS Center for Coastal and Watershed Studies
- NOAA Atlantic Oceanographic and Meteorological Laboratory
- University Miami Rosenstiel School of Marine and Atmospheric Science
- Nova Southeastern University National Coral Reef Institute

Fig. 5. Field team members pictured above (left to right): (*standing*) Randy Berthold (NASA), Miguel Velez-Reyes (UPRM), Roy Armstrong (UPRM), Brad Lobitz (CSU MB); (*seated*) Ricardo Rosado (UPRM), Miguel Goenaga (UPRM), Meghan Dick (Miami), Wilma Pabon (UPRM), Brooke Gintert (Miami), Gwilym Rowlands (NSU); (*floor*) Orian Tzadik (UPRM), Samuel Rosario (UPRM), Carmen Zayas (UPRM), James Goodman (UPRM), Liane Guild (NASA).

Other Accomplishments

In addition to the hyperspectral mission, other work related to SeaBED also made significant progress:

- Work continued on refining the high-resolution basemap for Enrique Reef. This is a project initiated in 2006 to create a high spatial resolution classification map of Enrique Reef using IKONOS imagery (1 m panchromatic; 4 m multispectral). This was accomplished primarily through an intensive manual classification procedure, with the intent of producing a carefully constructed high-resolution basemap for

validating image classification algorithms. This map will also serve as the spatial foundation for cataloging field data and observations acquired on Enrique Reef. Work completed in 2007 included an extensive field survey to confirm and refine polygons of reef features previously identified through image classification. Most recently, the map was used to determine the unmixing abundances for a lower spatial resolution Hyperion image. This allowed for first time an objective measure to be used in comparing the unmixing algorithms using real field data. Fig. 6 shows Hyperion image overlaid on the high resolution basemap.

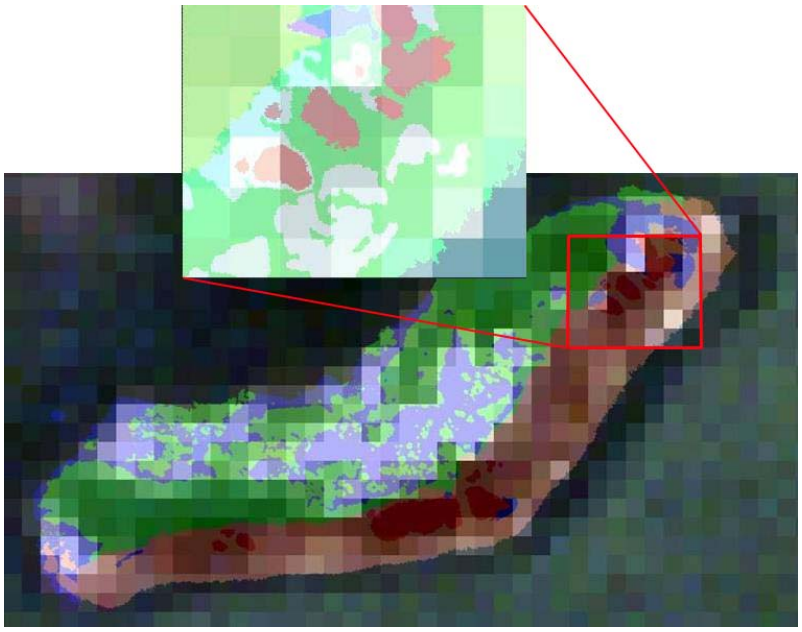

Fig. 6. Low resolution Hyperion pixels overlaid on high resolution basemap.

- Efforts continued on processing the hyperspectral AVIRIS imagery from 2004 and 2005. AVIRIS imagery was acquired over Enrique Reef in both 2004 (17 m spatial resolution from the ER-2 platform) and 2005 (4 m spatial resolution from the Twin Otter platform). The 2004 data were acquired with funding from NASA's Ocean Biology and Biogeochemistry Program through an award to Liane Guild at NASA Ames Research Center, and are currently being utilized in Gordon-CenSSIS research projects. The 2005 data were funded by NASA as part of a multi-agency response headed by the U.S. Coral Reef Task Force (USCRTF) to assess the impacts of the aforementioned massive 2005 coral bleaching event. Center researchers participated in the ground-data collection efforts for this campaign and full image access will become available following the USCRTF investigation. Note that the 2004 and 2005 imagery unfortunately contain an unwanted spectral anomaly that has greatly hindered the effective use of these data. A correction was recently devised by Dr. Liane Guild and her team from NASA Ames and the data are expected to be available in early 2008.
- Fieldwork continued for generating a spectral library of the dominant reef components. Underwater *in situ* reflectance measurements of the benthic substrate (e.g., sand, rubble, mud, etc.) and associated species (e.g., coral, algae, seagrass, sponges, etc.) were acquired using a GER-1500 handheld spectroradiometer contained within a custom underwater housing. The main instrument being utilized for this work is a GER-1500 spectrometer, which collects spectra at 512 bands from

283–1091 nm. The individual field spectra are first visually inspected for quality control, and then combined to generate average spectra for each target type. To facilitate this process, we developed the Spectral Data Analyzer (SDA) software to both visualize the spectral data and to create the average reflectance data (Fig. 7). SDA was developed in Java to increase cross-platform portability of the application and also allow rapid inclusion of future improvements. Future work for SDA includes adding capabilities for other spectral data formats, flexible data input formats, and adding database capabilities.

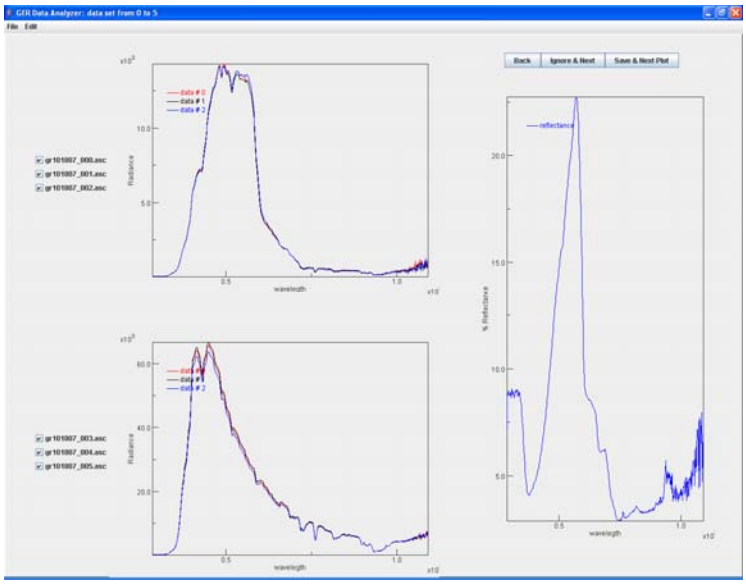

Fig. 7. Screenshot of Spectral Data Analyzer.

- Fieldwork also continued for collecting GPS polygons and point samples defining homogeneous areas of different reef habitats. Data on habitat composition and benthic cover is being collected extensively on Enrique Reef as well as on other nearby shallow reef systems. Data collected for each specific area included benthic reflectance, GPS location and a photograph to assist in both identifying benthic cover and as a permanent record of the conditions at the time of measurement. Benthic cover and GPS location of numerous randomly selected points throughout the study area are also being collected for use in accuracy assessments of image classification algorithms.

Fig. 8. Students collecting GPS on the Enrique Reef.

- Work continued towards developing capabilities for acquiring field-level hyperspectral imagery. This is being accomplished using a portable SOC-700 hyperspectral imaging camera mounted on a 3 m tall tripod, which measures 640x640 pixel images (~1-2 mm spatial resolution) in 120 bands from 400-900 nm at a 4 nm spectral sampling interval. Previous field tests performed by students illustrated the difficulties associated with compensating for the inherent environmental variations (i.e., water surface movement, current, winds and changing solar illumination angle) when acquiring very high spatial resolution data in the field. Developments in 2007 included building a submersible viewport to be placed in the water below the hyperspectral instrument in order to eliminate the effects of a variable water surface.
- In order to improve the remote sensing techniques for estimation of water quality parameters and benthic habitat mapping in coral reef systems it is necessary to determine the spatial and temporal variations of water column bio-optical properties. Therefore, a new effort has been directed toward evaluate such variability in the La Parguera coral reef system. The first bio-optical sampling was performed on May 21, 2007, incorporating a diversity of expected water and reef (e.g,, different oceanographic processes, depth, bottom type, and distance from the coast). These same stations (Fig. 9) were sampled again during October 18, November 20, and December 6 of 2007. This last date coincided with the high spatial resolution AISA mission described above. Quality control analyses and filtering processes are now underway with all data collected. Similar field work and data analyses will be performed during additional monthly samplings already scheduled for 2008.

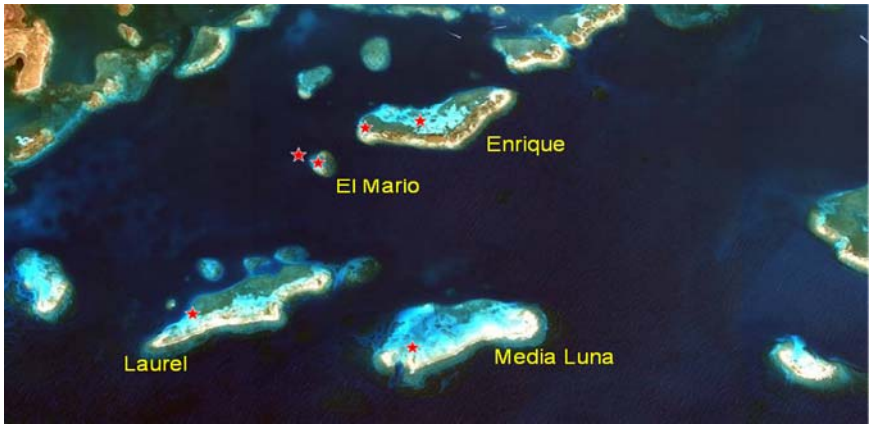

Fig. 9. Sampling stations (red stars) in La Parguera**.**

III. Gordon-CenSSIS Strategic Goals and Legacy

The focus of SeaBED is to provide facilities and data resources for use in the development, testing and validation of image analysis algorithms applied to subsurface sensing of benthic environments. Data with detailed groundtruth will help Gordon-CenSSIS researchers in R2C (multi and hyperspectral image analysis algorithms) and R3 (implementation of algorithms in high performance computing framework) to test and validate information extraction algorithms developed for subsurface sensing and imaging using spectral information. Furthermore, the testBED will enable the demonstration of the relevance of the Center-developed technology to solve benthic habitat mapping and assessment from remote sensing imagery.

The development of SeaBED represents a valuable component in research relating to the subsurface sensing of shallow aquatic environments. By providing a comprehensive set of imagery and accompanying ground truth data, SeaBED facilitates an improved ability for testing and validating the accuracy of image analysis algorithms. As evident from the above descriptions, much has been accomplished and numerous valuable data sets have already been acquired. Nevertheless, SeaBED represents an ongoing project that is evolving as it progresses. Further, the concept behind SeaBED is to not only develop a facility for Gordon-CenSSIS efforts, but also to provide an open testing infrastructure and set of freely available data. Accordingly, the SeaBED database will soon be available publicly and thus serve as a valuable data repository for researchers worldwide. Efforts are currently underway to develop an appropriate data distribution framework. This will be a valuable legacy to the remote sensing community.

IV. Future Plans

We expect to continue *in situ* data collection efforts over the next year and continue the analysis work in R2C and S4 until year 10.

- Continue assembling a spectral library describing the reflectance characteristics of specific species (i.e., coral, algae and seagrass) and substrates (i.e., sand, rubble and mud) present in coastal Puerto Rico.
- Quantify the spectral variability of bio-optical properties (i.e., due to changing water constituents) in coastal Puerto Rico.
- Continue efforts from 2007 by Gordon-CenSSIS students to perform a detailed field survey of habitat composition of Cayo Enrique and surrounding reefs using the high-precision Trimble GPS Pathfinder Pro XRS receiver system and an underwater camera.
- Expand current field work, image data collection, and algorithms development efforts to other benthic communities that are optically more complex (for example Mayaguez Bay).
- Finalize the IKONOS classification basemap of Enrique Reef. This will entail collecting detailed habitat information from numerous random locations throughout the reef and subsequently using this data to perform an accuracy assessment of the basemap.
- Process hyperspectral imagery and ground truth data collected in December 2007 and perform testing and validation of R2C algorithms.
- Develop website SEAWEB for dissemination of imagery and ground data from SeaBED.

S4 research efforts will also be enhanced through collaboration and interaction with reef scientists and resource specialists at the Rosenstiel School of Marine and Atmospheric Research (RSMAS) at the University of Miami (achieved through Gordon-CenSSIS researcher James Goodman, who has been working as a Visiting Scientist at RSMAS in 2007 and will continue in 2008). This will serve to improve the application potential and ultimate utility of benthic image analysis products by providing a stronger link with some of the intended users of these products.

V. Broader Impact

Remote sensing is increasingly being used as a tool to quantitatively assess the location and relative health of coral reefs and other shallow aquatic ecosystems. These assessments are providing scientists and managers important spatial information on not only habitat distribution but also on the proximity of environmental stressors. It is expected that as image analysis procedures and detector capabilities continue to improve, so too will the effectiveness and

efficiency of aquatic remote sensing applications. However, as the use of subsurface aquatic remote sensing continues to grow and the analysis products become more sophisticated, there is an increasing need for comprehensive ground truth data as a means to assess the algorithms being developed, particularly in the field of hyperspectral remote sensing. Thus, to address this need for validation data, we have developed SeaBED, a multi-level aquatic testBED for evaluating remote sensing information extraction algorithms. Furthermore, the data sets being generated by SeaBED will soon be made available to the remote sensing community via the internet, thus providing a unique opportunity for researchers to have access to a collection of well characterized data sets.

VI. Project Budget and Sustainability

Project Budget

The SeaBED budget for Year 8 was $150k of which a significant component was directed towards the high resolution AISA hyperspectral campaign. In years 9 and 10, funding will be primarily geared towards processing the data collected in 2007. We expect funding levels around $100k for years 9 and 10.

Industrial Collaborations

Collaboration with Spectra Vista Corp. [Tom Corl, President; Poughkeepsie, NY] continued in 2007 with respect to developing improved field equipment for the collection of underwater spectral measurements. Spectra Vista is "*dedicated to the manufacturing, delivery and support of airborne imaging spectrometers and field portable spectroradiometers for the remote sensing community*." The collaboration with Spectra Vista includes designing and testing enhanced capabilities for their GER-1500 underwater spectrometer (extending the initial design completed with Center researcher J. Goodman), as well as developing plans for utilizing southwestern Puerto Rico, including Enrique Reef, as a test area for the deployment and validation of a new airborne imaging spectrometer (sensor system still under development). Note that these collaborations benefit both the S4 driver and data development for SeaBED.

We are exploring the possibility of developing collaborations with ITT (http://www.itt.com) in the area of coastal remote sensing hyperspectral image processing. We are in conversations with them about how to establish such collaboration.

External Funding

The following are ongoing projects in 2007 or recently awarded proposals for research using SeaBED data that are directly related to Gordon-CenSSIS work in benthic habitat monitoring. In each case, the projects represent a synergistic combination of existing Center resources and practical applications of image analysis techniques and habitat classification algorithms.

1. *Taking Coastal Mapping to a New Level: Assessing Habitat Composition and Water Properties of Shallow Coastal Ecosystems along the Coast of Puerto Rico Using Hyperspectral Remote Sensing*

Principal Investigator:	James Goodman, UPRM
Funding Source:	NOAA: Caribbean Coral Reef Institute
Status:	Awarded
Duration:	09/06 – 08/08 (2 years)
Award Amount:	$133,296

2. Coral Reef Bleaching and Threats to Biodiversity in Puerto Rico

Principal Investigator:	Liane Guild, NASA ARC
Co-Investigator:	Roy Armstrong, UPRM
Co-Investigator:	James Goodman, UPRM
Co-Investigator:	Brad Lobitz, NASA ARC
Funding Source:	NASA: Interdisciplinary Research in Earth Science
Status:	Awarded
Duration:	05/07 – 04/10
Award Amount:	$731,199 (3 years)

3. Characterization of shallow and deep coral reef communities of Vieques Island, Puerto Rico

Principal Investigator:	Roy Armstrong, UPRM
Co-Investigator:	Fernando Gilbes, UPRM
Funding Agency:	NOAA
Status:	Awarded
Duration:	09/06 – 08/08
Award Amount:	$49,770

VII. Documentation

A. Publications Acknowledging NSF Support (Jan. 1, 2007 to Dec. 31, 2007)

1. Goodman, J.A. and S.L. Ustin, 2007, *Classification of Benthic Composition in a Coral Reef Environment Using Spectral Unmixing*, Journal of Applied Remote Sensing, Vol. 1, 011501.

2. Guild, L., B. Lobitz, R. Armstrong, F. Gilbes, A. Gleason, J. Goodman, E. Hochberg, M. Monaco and R. Berthold, 2007, *NASA Airborne AVIRIS and DCS Remote Sensing of Coral Reefs*, 32nd International Symposium on Remote Sensing of Environment, San Jose, Costa Rica.

3. Vélez-Reyes, M., S. Rosario-Torres, J.A. Goodman, E.M. Alvira-Concepcion and A. Castrodad-Carrau, 2007, *Hyperspectral Image Unmixing Over Benthic Habitats*, SPIE Defense & Security Symposium: Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XIII, Proceedings of SPIE Vol. 6565, Orlando, Florida.

4. Vélez-Reyes, M., J.A. Goodman, S. Rosario-Torres and A. Castrodad-Carrau, 2007, *Subsurface Unmixing with Application to Underwater Classification*, (invited paper), SPIE Europe Remote Sensing: Remote Sensing of the Ocean, Sea Ice and Large Water Regions 2007, Proceedings of SPIE Vol. 6743, Florence, Italy.

B. List of Presentations (not in conference proceedings) (Jan. 1, 2007 to Dec. 31, 2007)

1. Velez-Reyes, M., 2007, *Comparison Of Methods For Unmixing Of Hyperspectral Imagery InLitoral Zones*, 32nd International Symposium, on Remote Sensing of the Environment, San José, Costa Rica.

2. Vélez-Reyes, M., J. Goodman, S. Rosario, E.M. Alvira and A. Castrodad, 2007, *Hyperspectral Unmixing Over Benthic Habitats: A Comparison of Two Algorithms*, 15th AVIRIS Airborne Earth Science Workshop, Pasadena, California.

C. List of Relevant RICC 2007 Posters:

1. Zayas-Santiago, Carmen, C. Rivera Borrero, A. Mundorf, S. Cardona, J. Goodman, R.A. Armstrong, F. Gilbes, S. Hunt, M. Vélez-Reyes and S. Rosario, 2007, *Enrique Reef: A Spectral Library, Habitat Map and Hyperspectral Mission in Southwestern Puerto Rico,* Center for Subsurface Sensing and Imaging Systems, Research and Industrial Collaborations Conference, Northeastern University, Boston.