THE HYDRODYNAMICS AND BIOGEOCHEMISTRY OF BIOLUMINESCENT BAYS, VIEQUES, PUERTO RICO

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INTRODUCTION

Bioluminescent bays are rare ecosystems and one of the world's brightest bays, Puerto Mosquito, is found off the Puerto Rican island of Vieques (Carpenter and Seliger,1968, Selliger, 2001) . Here, bioluminescence is caused by persistent high concentrations of the dinoflagellate *Pyrodinium bahamense* var. *bahamense*, which emits bursts of light when agitated. Sustained blooms of marine dinoflagellates are thought to result from a delicate balance of hydrologic conditions, nutrient availability, and biological interactions. Puerto Mosquito and two adjacent bays, Puerto Ferro and Bahia Tarpon were survey in the early 1970's. Results of this survey showed Bahia Tapon to have higher concentrations of *Pyrodinium bahamense* var. *bahamense* than Puerto Mosquito. Lower levels were found in Puerto Ferro (Table 1).

The primary goals of this Keck project was to identify the biogeochemical and hydrodynamic conditions that contribute to such high and variable of *Pyrodinium bahamense* var. *bahamense* concentration in the three bays, compare new measurements with the 1972 measurements (Cintron and Maddux, 1972), and compare the geological and ecological evolution of the bays.

This investigation has direct implications for harmful algal blooms (HAB) as *Pyrodinium bahamense* var. *compressum* produces a neurotoxin that causes paralytic shellfish poisoning (PSP) and harmful algal blooms (Corrales et al., 1995, Riegman, 1998). The results from this investigation will help guide future conservation policies regarding bioluminescent bays and serve as a natural comparison for areas impacted by harmful algal blooms (HABs).

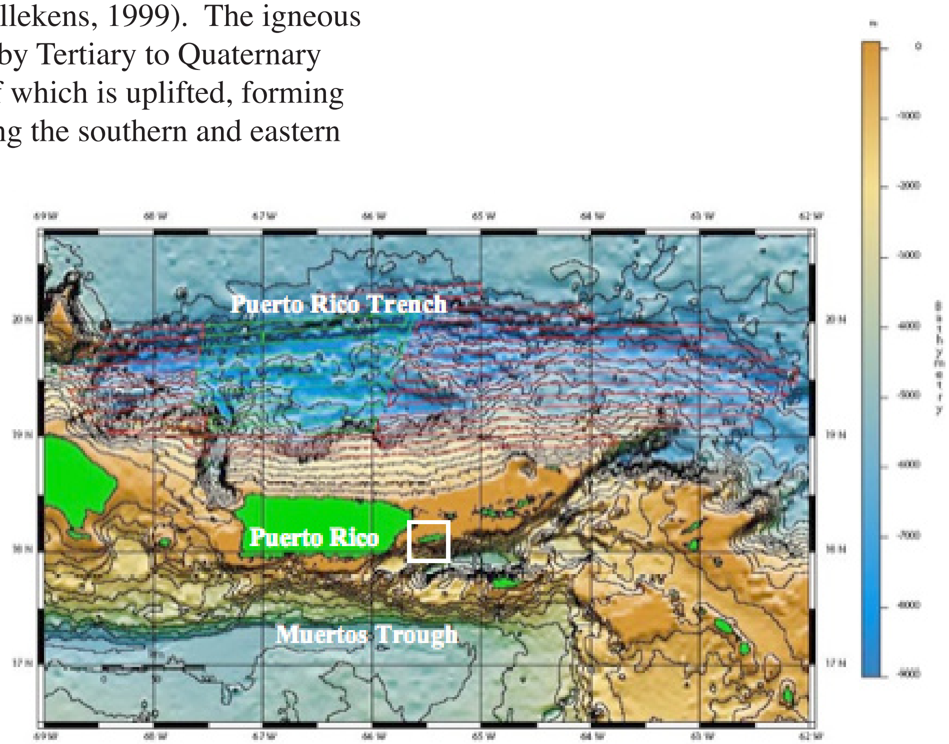
	Puerto Mosquito	Puerto Ferro	Bahia Tapon
Area (m^2)	784,000/*749,000*	929,000/*886,000*	261,000/*252,000*
Size of surrounding mangrove forest (m^2)	764,000*	353,000	177,000
Maximum depth (m)	3.4/*3.4*	?/*9.4*	2/*1.7*
Average depth (m)	2/*2.0*	?/*3.4*	1/*0.84*
Width of mouth (m)	130/*81*	250/*237*	225/*95*
Shape of mouth	thin, canal	wide canal	direct contact
Sill depth (m)	1	?	1
Surface salinity (ppt)	31	?	33.2-34.86
Pyrodinium cells/ml	10-161/*1-20*	<1/*0.04*	80/*0-18*

Table 1. Some differences between the bays, as identified in a 1972 study (Cintron and Maddux, 1972) and the 2006 Keck study (italics) Pyrodinium is the dinoflagellate that creates the bioluminescence in the bays. *Including 470,000 m2 which are now tide flats (dead mangrove)

GEOLOGIC SETTING

Vieques is a 54 square mile island off the east coast of Puerto Rico (Figure 1). It consists of Upper Cretaceous volcanic rocks, Upper Cretaceous/Lower Tertiary intrusive rocks. These rocks were deposited between about 135 million years ago and 45 million years ago when Puerto Rico and Vieques were part of an active subduction zone. About 45 million years ago subduction shifted to the Cayman Trench and the active volcanism to the east (e.g. Montserrat), (Schellekens, 1999). The igneous rocks are overlain by Tertiary to Quaternary limestone, some of which is uplifted, forming steep outcrops along the southern and eastern coast.

Figure 1A. Bathymetry of Puerto Rico and Vieques. Box is location of Figure 1B . From http://oceanexplorer.noaa.gov/explorations/03trench/welcome.html



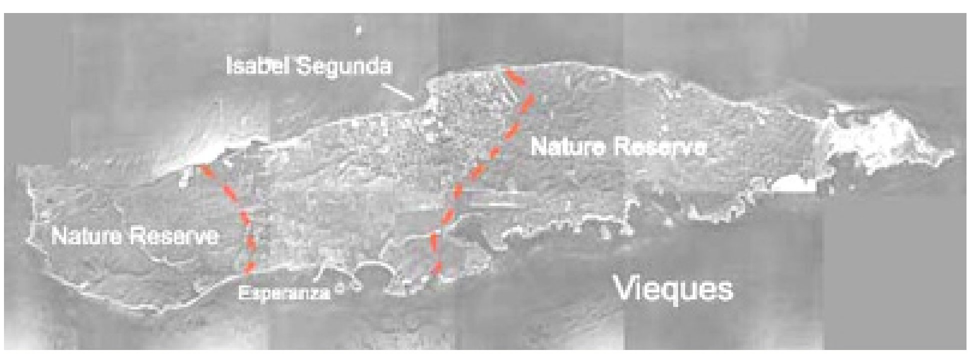


Figure 1B. Aerial Photograph of Vieques, available at: http://terraserver-usa.com/image.aspx?T=1&S=17&Z=20&X=9&Y=78. Box shows location of study area, Figure 1C.

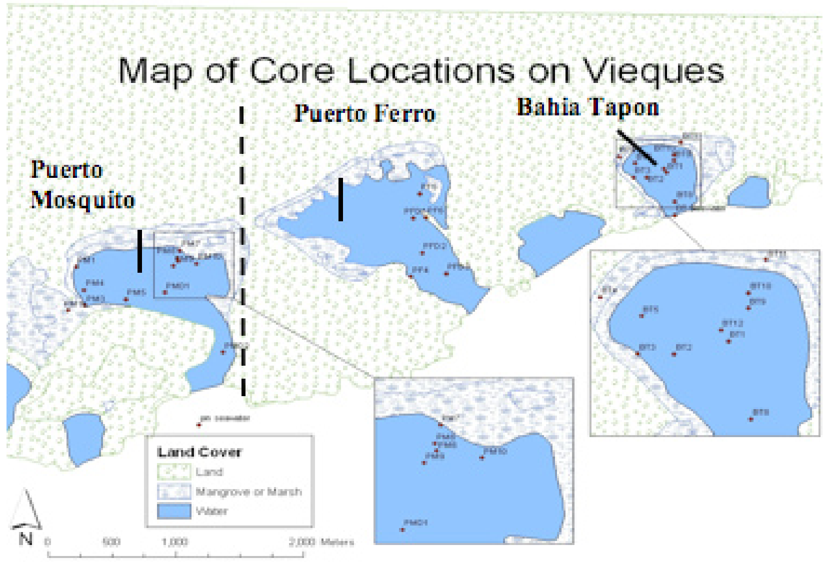


Figure 1C. Sediment coring locations in Puerto Mosquito, Puerto Ferro, and Bahia Tapon from the 2006 Keck Geology program. Dashed line marks the boundary between the Vieques National Wildlife Refuge (VNWR) (east) and non VNWR land (west). (Based on Mitchell, 2005 map.)

Considerable topography is present with the elevation going from sea level to 301 m (Mt. Pirata) in the southwestern island. Water depths off the north, west, and east shores are relatively shallow (Figure 1). In contrast the south coast deepens into the Virgin Island Trough. Although the origin of this trough is unknown, it might be an older version of the Muertos Trough where today the Caribbean plate crust slides under the Antilles (ten Brink, pers. com. 2004).

Humans have inhabited Vieques for about 5,000 years (Langhorne, 1987). During the time of European exploration attempts were made by French, English, Dutch, Danes and Spanish to colonize the island, with the Spanish dominating. At the end of the Spanish-American war, Vieques and Puerto Rico became territories of the United States (Langhorne, 1987). The land was used for farming; particularly sugar cane and introduced species dominate the flora.

In the early 1940's the U.S. Navy acquired 79% of the island. The eastern portion was used for amphibious training operations, including bombing, and the western portion was used for ammunition supply. Because of the military presence, the island was not attractive to most tourists and Vieques avoided major condominium –style development and overdevelopment. When the Navy left Vieques in 2001, the land was given to the department of the interior and is managed as a wildlife refuge by the U.S. Fish and Wildlife Service.

The landscape and ecology are controlled by the arid climate. Vieques receives about 44 inches of rain/year (vs. 60 inches in San Juan) with a range of 26-72 inches (Frank, 1972). There are no permanent streams and the rainfall increases from east to west, as the higher elevations in the western part of the island intersect the trade winds. The southern shore contains several small bays surrounded by mangroves (Figure 2), some with adjacent saltwater lagoons (Phlips et al., 2002). These are habitats for many invertebrates, fishes, birds and nesting places for four types of sea turtle.

Figure 2. Students preparing to take core samples.

RESEARCH APPROACH

Vieques Keck participants spent two weeks in Vieques collecting sediment cores, seawater and porewater samples and bathymetric data (Figure 3).

Figure 3. Andrew Nelson bringing sediment core to boat.

Cores sites were chosen to provide a broad geographic and depth coverage for each bay (Figure 1C). Cores were described, photographed and subsampled on Vieques (Figure 4). Field techniques included measuring pH, alkalinity, and Amonia and conducting whole-core incubation and sediment-water flux experiments (Figure 5). Additional samples were preserved for future chemical and biological analyses

Figure 4. Kelly Hereid and Laura Robertson subsampling cores for future research.

Figure 5. Hilary Palevsky subsampling incubation core in oxygen free environment.

Participants spent two weeks after the field program at Amherst College and Wesleyan University. Sample processing and chemical analysis continued and samples were package for students to continue analyses at their home institutions. Student research projects were identified based upon interest and the availability of equipment at their home institutions.

STUDENT PROJECTS

Caitlyn Florentine (Colorado College) investigated the sources of sedimentary organic matter and the potential importance of mangrove decomposition to the overall nutrient budget by analyzing the carbon and nitrogen isotope ratios of organic matter and mangrove clippings,, the sedimentary organic carbon/nitrogen ratio, and total inorganic carbon concentrations.

Sara Gasparich (Whitman College) collected water samples from the three bays and preserved them for dinoflagellate identification and counting at Whitman College. This will provide us with an updated concentration distribution of the dinoflagellates in these three bays.

Anda Greeney (Wesleyan University) investigated the residence time of water in each bay. Calculations are based upon tidal measurements collected (Solinst Level Loggers and Yellow Springs Instruments), bay and channel dimensions, and the tidal record of the area and rainfall history.

Kelly Hereid (Carleton College) isolated *P. bahamense* cysts from the sediment cores to determine past abundances of *P. bahamense* in Puerto Mosquito and asses the viability of using cysts as an indicator past concentrations of *P. bahamense*. She also tested a sediment digest method that did not use hydrofluoric acid.

Jenna Hunter (Beloit College) identified and counted diatoms to determine species and abundance, both spatially and through time. This provides us with a comparative ecology of the three bays and helps determine which environmental factors may have changed through time.

Andrew Nelson (Colorado College) constructed a surface environment facies map for Puerto Mosquio, Puerto Ferro, and Bahia Tapon and investigated the sedimentary history of the bays by examining the distribution of these facies through time. This allows him to describe variations in sedimentary sequences with depth and proximity to shore.

Hilary Palevsky (Amherst College) analyzed major, minor, and trace elements in seawater and porewaters, and investigated the use of protein concentrations as a proxy for sediment microbial abundances. This will provide information about organic mater decomposition and the spatial distribution of microbial activity.

Laura Robertson (College of William & Mary) analyzed ostracode assemblages and features of sieve-poreand calculated sediment ages based on ^{210}Pb. Ostracodes are abundant in the sediments and can be used to identify salinity changes with time. Lead-210 dating will allow calculation of sediment and accumulation rates.

Erin Tainer (Washington & Lee University) used aerial photographs (going back to 1936) and satellite images to develop watershed, bay shape and land use maps for the study area.

ACKNOWLEDGEMENTS

We wish to thank the Vieques Conservation and Historical Trust (VCHT) for use of their kayaks and facilities and Mark Martin for a variety of assistance; Oscar Diaz for access to the Vieques National Wildlife Refuge to carry out this study and Sandra Ortiz for facilitating the access; Suzanne Easterling, Sarah Sidor, Kelly Fetzer, and Lori Bettison-Varga for logistic support.

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