DIATOMS AS ENVIRONMENTAL INDICATORS: A CASE STUDY IN THE BIOLUMINESCENT BAYS OF VIEQUES, PUERTO RICO

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INTRODUCTION

Diatoms, microscopic, unicellular, eukaryotic algae abundant in most aquatic habitats, are useful proxies for the ecological analysis of three bays on the island of Vieques, Puerto Rico. Acutely sensitive to changes in pH, salinity, temperature, hydrodynamic conditions, and nutrient concentrations, marine diatoms can be identified by their distinct assemblages and frustule shape. The ubiquitous distribution of diatoms, their high species diversity, and their siliceous frustule all enable the diatoms to function as sound environmental indicators. Samples were taken from ten of twenty-seven extruded cores within the three bays, Bahía Tapón (BT), Puerto Ferro (PF), and Puerto Mosquito (PM), and then investigated for the presence and abundance of mid- and late-Holocene marine diatoms. Puerto Mosquito (PM) is renowned for its high content of the bioluminescent dinoflagellate *Pyrodinium bahamense*. Core sites were chosen to represent a series of environmental conditions such as proximity to the mouth of the bay, depth, and presence of mangrove or marsh material. The open-ocean environment of the three bays, their mid-latitude location, and the limited anthropogenic impact provide favorable conditions for paleoclimate and environmental reconstructions. The classical method to infer environmental conditions involves the use of one or multiple indices, such as the Indices of Biotic Integrity (IBI) (Stevenson and Pan, 1999), Metzmeir's Diatom Bioassessment Index, and the Practical Diatom Index (IDP). Although slightly different in taxonomic specificity, all indices are similar in that they yield a numerical value that is constrained by both a minimum and a maximum value. The IDP, as suggested and utilized by Levêque Prygiel in 1996, provided the most straightforward guide during the analysis of diatoms in this study. The paleoecological value of the diatoms has also been well demonstrated by Koizumi (1975). Unfortunately, diatom assessment is challenging due to the developing nature of a formal taxonomy and nomenclature.

Diatoms (Bacillariophyta) are markedly distinguishable into two orders, the Centrales and the Pennales. The Centrales, or centric diatoms, have a radial symmetry and are successful as plankton in marine waters. Their frustules, or shells, can also be triangular or quadrate. The centric diatoms are mostly planktonic and non-motile (Tappan, 1980). The Pennales, or pennate diatoms, occupy and dominate the freshwater, soil, and epiphytic environments. Although they also thrive in marine habitats, their typical environmental niche is in fresh water. The Pennales have bilateral symmetry (Armstrong and Brasier, 2005).

There is a good record of the diatoms from the middle Cretaceous to the Cenozoic, with an evolutionary shift from centric to pennate diatoms in the late Miocene (Tappan, 1980). The evolutionary divergence occurred just after the Miocene, preceded by a surge in the expansion of centric diatoms. Pennate diatoms are regarded as still being in their explosive evolutionary growth stage (Tappan, 1980). Most diatom taxonomy is based on the opaline skeleton or frustule of the diatom (Stevenson and Pan, 1999). The diatom cell wall is composed of approximately 95% opaline silica (Armstrong and Brasier, 2005). Because both forms of diatoms are autotrophic, they are typically limited to the photic zone of the ocean (<200 m) during the duration of their lives. The photosynthetic pigments in marine diatoms include chlorophyll a and c as well as accessory carotenes and xanthophylls. Light availability can have a strong impact on both the growth and seasonal fluxes of the diatoms. Diatoms bloom primarily in the spring and late summer (Armstrong and Brasier, 2005), when light availability, temperature (and therefore salinity) increase.

Most marine diatoms tolerate a wide range of temperatures (Tappan, 1980), typically ranging from 1.9º C to 30.5º C. The temperatures of the Vieques bays in June, when data were collected, ranged from 29º C to 32º C. Accommodations for changes in temperature can be reflected in alterations of frustule ornamentation, such as thinner walls and elongated spines (Tappan, 1980). Marine diatoms range from marine to brackish water, and the greatest diversity of marine diatoms exists at a neutral pH. The form of silica in the diatoms (orthosilicic acid ($Si(OH)_4$)), is more soluble in alkaline conditions. The nutrients available in the marine environment also greatly affect the concentration and diversity of diatoms present. Whereas some diatoms prefer high nitrogen concentrations, others prefer low nitrogen-to-phosphorus ratios (Tappan, 1980). Diatoms fail to reproduce or divide if the available amount of phosphorus does not exceed $6x10^{-14}$ grams/cell for certain genera.

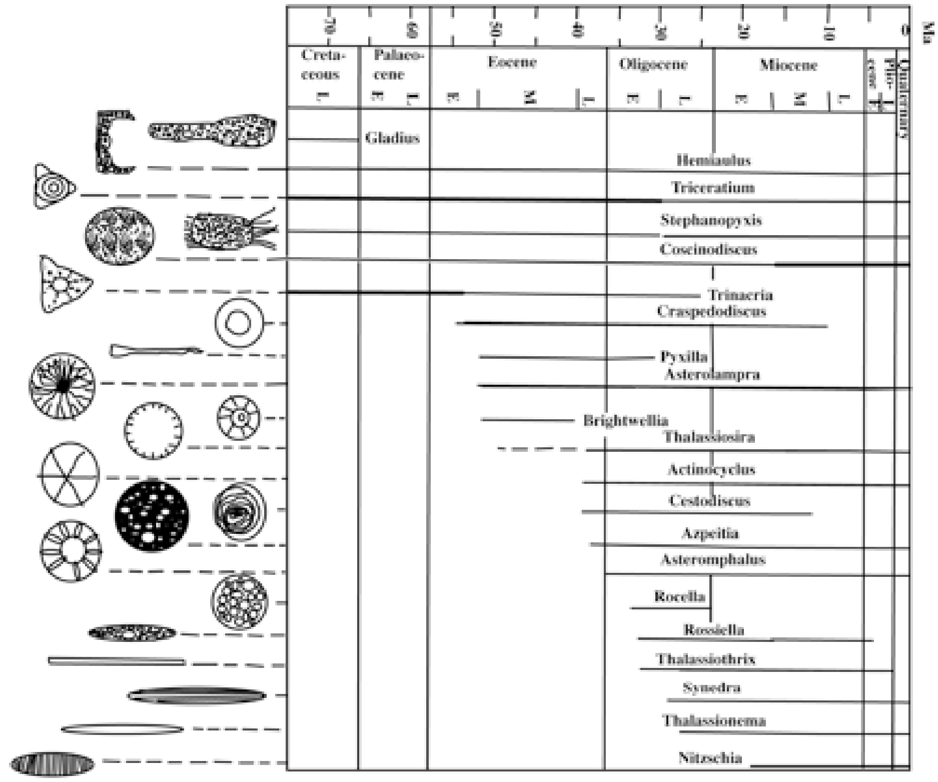


Figure 1. Stratigraphical ranges of important genera of planktonic marine diatoms. The width of the bar indicates the relative abundance of the genus during its range. (Modified by Lipps in Armstrong, 2005, figure 17.5.)

In areas where nutrients are in part derived from the land, diatom assemblage composition tends to change most rapidly. Some environments are more apt to sustain high levels and varieties of diatoms due to their high silica, phosphate, nitrate, and iron content (Burckle, 1971). The tropical climate of Vieques provides a great range of diversity as well as land-derived nutrients to support a rich diversity of diatoms (Figure 1).

METHODS

Field Methods

Coring sites were chosen based on depth, location in the bays, and facility of access. Eleven cores were extruded from Puerto

Mosquito, 6 from Puerto Ferro, and 10 from Bahía Tapón. Depths ranged from approximately 0-4 meters. Coring tubes approximately 1 meter long were transported to the coring sites and cores were taken with a gravity-percussion coring device in polycarbonate tubes. Cores were extruded, measured, documented, and described using Munsell's Color Charts and a USGS Grain Size chart. The six cores selected for this study were chosen based on depth, diversity of locations in the bays, species abundance, and variety of diatoms in each core after analysis with the petrographic microscope.

Laboratory Methods

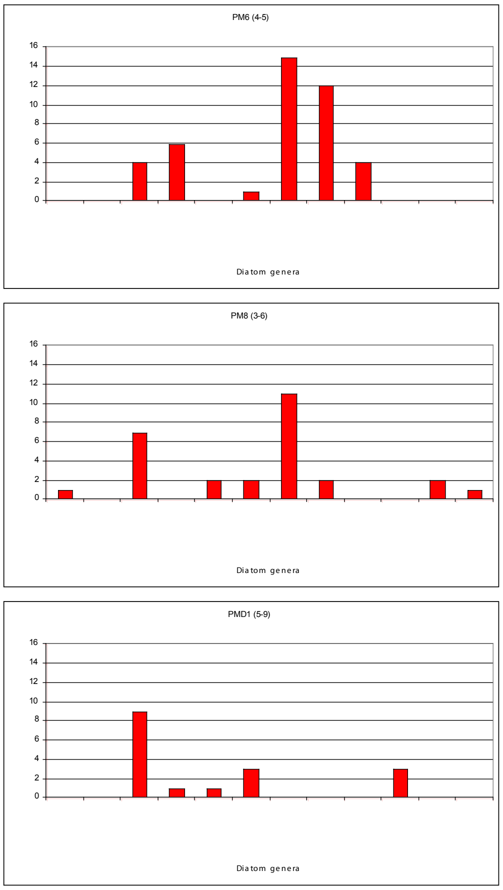
Samples were cleaned of mud and sediment particles with a method adapted by Battarbee et al. (1984), in which 50 mL of a 10% HCl solution was added to the sample and stirred on a 115-volt Magnestir for fifteen minutes. Six mL of a 30% H_2O_2 solution were then added to 1 gram of sample before placing the sample into a 40°C water bath. Samples remained in the water bath for 20 minutes and then cooled. A drop of NH_3 was added with a small pipette to deflocculate the leftover clay particles and the diatoms. The sample was then centrifuged for 5 minutes at 4,000 revolutions per minute in a 20°C centrifuge and decanted. Two more drops of NH_3 were added before decanting the sample again, leaving primarily diatoms in the bottom of the centrifuge tube. Permanent slides were then mounted using Norland Optical Cement and a short-wavelength UV light for 30 minutes. The slides were analyzed under a petrographic microscope and examined for presence, abundance, and specific genera of diatoms. Slides were scrutinized for ten minutes each so as to remove any time duration biases from the process of their examination. The slides from similar depths with an abundance of diatoms were selected to be observed with the Scanning Electron Microscope. One drop of sample was put on a cover slip, dried, and gold-coated before being placed into the Scanning Electron Microscope.

RESULTS

The prevailing diatom in all three bays was *Gyrosigma* Hassal. *Gyrosigma* was found in Puerto Mosquito cores D1, D2, 6, 8, 9, 10, and 11, in amounts ranging from 1 to 15 over the course of a ten-minute count. Displayed (Figure 2) are quantities of diatom species at similar depths in cores PM 6, PMD1, PM8, PM9, PM10, BT9, and PFDIC. *Gyrosigma*, approximately 100 micrometers in length (Figure 3), *Amphipleura* Kutzing, and *Stephanodiscus* Ehrenberg (Figure 4) dominate most slides from Puerto Mosquito. Although pennate diatoms dominate the observed specimens, both pennate and centric diatoms were found in the Puerto Mosquito and Bahía Tapón samples, as can be seen by the presence of both *Stephanodiscus* (Figure 4) and *Campylodiscus* Ehrenberg, both centric diatoms. The most diverse cores were PM6 (0-1) and PM6 (4-5), with genera of both centric and pennate diatoms, such as *Fallacia* Stickle and Mann, *Stephanodiscus, Synedra* Ehrenberg, and *Frustulia* Rabenhorst. Bahía Tapón samples included *Frustulia*, *Gyrosigma*, and *Stephanodiscus*. Puerto Ferro also included a dominance of *Campylodiscus, Amphipleura*, *Gyrosigma, Fallacia,* and *Pleurosigma*.

DISCUSSION

The presence of both centric and pennate diatoms in the samples from the three bays of Vieques, Puerto Rico, can be misleading. As cell sizes of marine diatoms can range over 4 orders of magnitude and diatoms can either be sessile or vagile, it must be assumed that both eolian as well as fluvial forces could have had an impact on the deposition of the diatoms. The small size of the diatoms can be problematic as their light weight may allow for air transport. Also, as planktonic diatoms are constructed to remain in suspension, they can



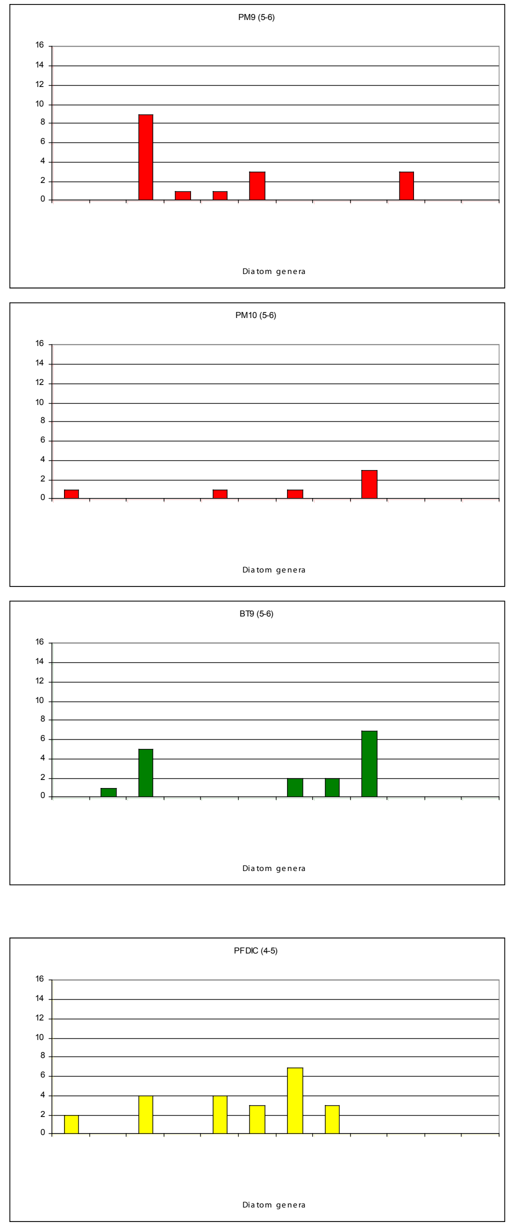


Figure 2. Diatom generic abundance from cores PM1 (5-9), PM 6 (4-5), PM8 (3-6), PM9 (5-6), PM10 (5-6), PFDIC (4-5), BT9 (5-6).

easily be transported laterally by both bottom currents and surface currents (Burckle, 1971). Burckle (1971) suggests that “anomalously high concentrations of planktonic forms can exist where none existed in the local, living assemblage.”

Broken diatoms may also indicate that displacement has taken place. The study of the Vieques bays was based on methods devised by Batarbee et al. (1984), in which the total diatom abundance per gram of sediment and diatom diversity were used. The diatoms in an aliquot of the original sample were counted and numbers per gram were determined. Due to the nature of the study, I was unable to replicate completely the methods of Batarbee et al. (1984).

Gyrosigma suggests seasonal turnover or turbulence, in which the diatoms could be moved from the benthic to the photic zone (Meyer, 2002). *Gyrosigma* further indicates warm temperatures and a relatively high organic content in the water. The high concentration of *Gyrosigma* and other diatom species within all three of the bays suggest similar environmental conditions in the Vieques area over the time represented by the cores in this study. Particular differences are representative of seasonal fluctuations in temperature, salinity, and nutrient concentration.

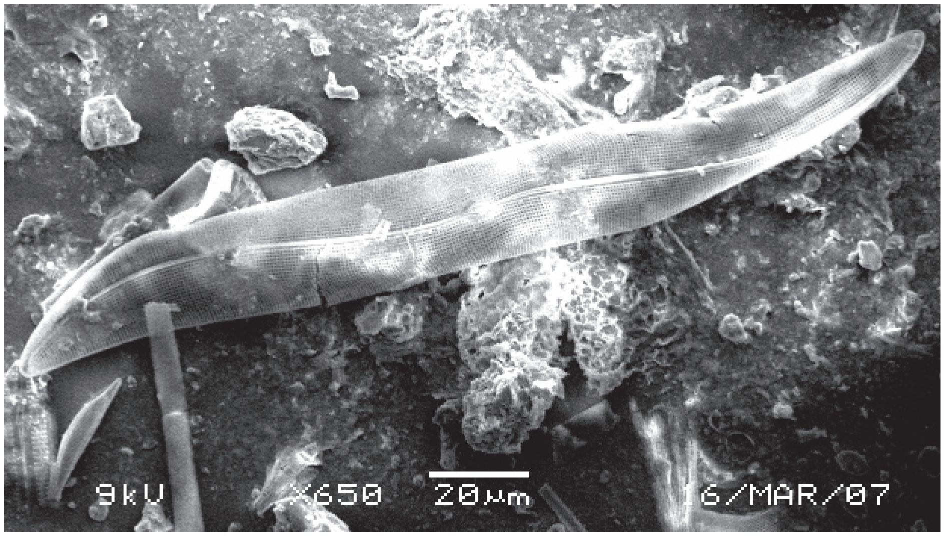


Figure 3. Member of genus *Gyrosigma* at the coring site Puerto Mosquito 5, 4-5 cm. SEM photograph.

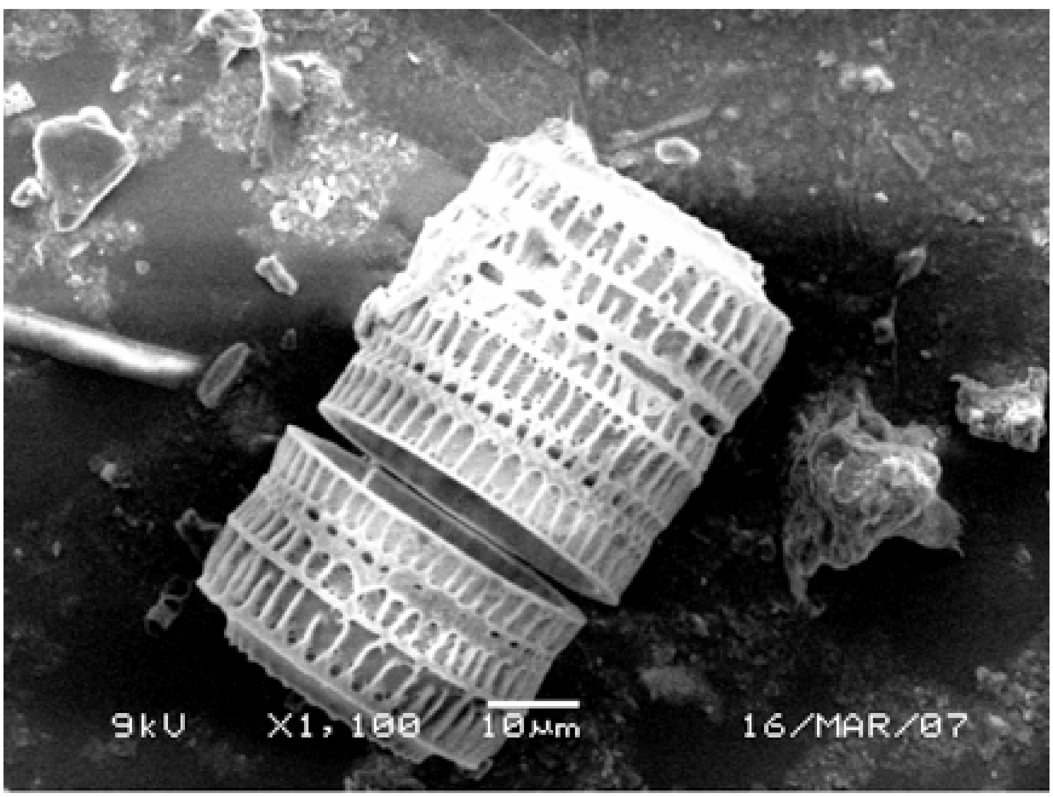


Figure 4. Member of genus *Stephanodiscus* Ehrenberg at the coring site Puerto Mosquito 5, 4-5 cm. SEM photograph.

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