

KECK GEOLOGY CONSORTIUM

21ST KECK RESEARCH SYMPOSIUM IN GEOLOGY SHORT CONTRIBUTIONS

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Keck Geology Consortium
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Students: Evan Anderson, Anna Lavarreda, Ken O'Donnell, Walter Persons, Jessica Williams

Development and Analysis of Millennial-Scale Tree Ring Records from Glacier Bay National Park and Preserve, Alaska (Glacier Bay)

Greg Wiles (The College of Wooster)
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The Biogeochemistry and Environmental History of Bioluminescent Bays, Vieques, Puerto Rico

Tim Ku (Wesleyan University) Suzanne O'Connell (Wesleyan University), Anna Martini (Amherst College)
Students: Erin Algeo, Jennifer Bourdeau, Justin Clark, Margaret Selzer, Ulyanna Sorokopoud, Sarah Tracy

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Short Contributions – Puerto Rico**

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ULYANA SOROKOPOUD: Wesleyan University

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THE MODERN AND GEOLOGIC RECORD OF PRIMARY PRODUCTION NUTRIENT LIMITATION IN THE BIOLUMINESCENT BAYS OF VIEQUES, PUERTO RICO

ERIN ALGEO: Trinity University
Research Advisor: Benjamin Surpless

INTRODUCTION

The primary objective of this project was to investigate past and present carbon, nitrogen, and phosphorus nutrient concentrations and $\delta^{13}\text{C}$ values of modern biota and sedimentary organic matter from two lagoonal habitats on the island of Vieques, Puerto Rico. These habitats, the bays of Puerto

Ferro and Puerto Mosquito, support bioluminescent dinoflagellates. Nutrient status within a bay's ecosystem can directly affect the dinoflagellate population (Phlips et. al, 2006). Changes in the bays' modern nutrient status affect primary producers, such as phytoplankton and the seagrass *Thalassia testudinum*, first, while past changes in overall environment and nutrient status are recorded in sediments deposited within the bays. By studying the past and present nutrient availability and the potential sources of those nutrients, we learn how and why future changes to the environment might affect dinoflagellate populations.

ENVIRONMENTAL SETTING

The sharing and distribution of nutrients between biota, including mangrove, seagrass, and dinoflagellates, are affected by the physical attributes of the bay. Those physical attributes, such as shape, size, and bathymetry, control hydrodynamics and might affect the dinoflagellate populations. The present day maximum concentrations of dinoflagellate are

significantly higher in Puerto Mosquito (PM) relative to Puerto Ferro (PF), with concentrations of up to 27,300 organisms per liter in PM, and only up to 425 organisms per liter in PF (Gasparish, 2007). Though the present dinoflagellate concentrations are higher in Puerto Mosquito (PM), the bay is smaller than Puerto Ferro (PF) (PM = 784,000 m²; PF = 929,000 m²) (Fig. 1). In addition, the ocean channel

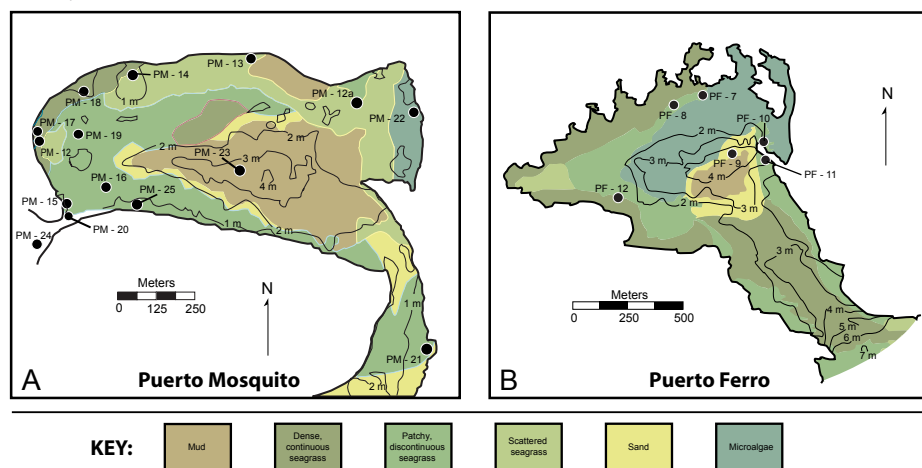


Figure 1. Sediment core locations, seagrass density distribution, and bathymetry of Puerto Mosquito (A) and Puerto Ferro (B). Modified from NOAA (1999).

of PM is narrower than PF (100 m vs. 300 m), which potentially causes slightly higher average salinity and pH values in PM relative to PF (PM: pH = 8.15, salinity = 37.61‰; PF: pH = 8.00, salinity = 36.22).

Both bays are surrounded by mangrove forests, which protect the bays from pollution and excess sediment accretion and are sources for organic carbon and nutrients (Gonneea et al., 2004). The marginal areas of the bays have higher turbidity relative to the center of the bays or the ocean channel (e.g., Nelson, 2006), suggesting a higher suspended sediment load near shore, which might impact seagrass

density. Generally, the density of seagrass plants is greatest near the shore, with plant density decreasing with increasing distance from shore and with increasing depth (Fig. 1). All seagrass samples were taken at depths of less than two meters, because the seagrass did not grow below that depth (Fig. 1), the result of light limitation and/or substrate disturbance through bioturbation (Nelson, 2006).

METHODS

Sediment cores and seagrass and mangrove samples were procured from locations across Puerto Mosquito and Puerto Ferro in order to examine spatial variability of nutrient content (Fig. 1). The sedimentological characteristics of each core were thoroughly described in the field, and seagrass and mangrove samples were prepared using the method outlined in Fourqurean and Zieman (1992). The core sediment and biota were then analyzed for organic C, N, and P concentrations by coulometry, flash combustion, and spectrophotometry at Wesleyan University and Trinity University. After the removal of carbonate carbon, sediment organic matter from selected depths was analyzed for C isotopes at Indiana University.

RESULTS

Nutrient and isotope data from both bioluminescent bays reveal trends in the present and past nutrient availability in the ecosystems. By studying C:N:P ratios *Thalassia testudinum*, I assessed potential nutrient limitations of primary producers in the Vieques bays. The possible limiting nutrients are N and P, because C is widely available in bay ecosystems (e.g., Fourqurean and Zieman, 1992). The changes in sediment nutrient ratios and carbon isotopic composition reveal the sources of organic carbon through time.

A C:N:P ratio (by weight) of between 445:32:1 and 601:20:1 for *Thalassia testudinum* represents the ratio of a healthy organism growing without nutrient limitation (Patriquin, 1972). The ratio of all seagrass sampled in this study fall within that range. However, trends in relative N and P limitation suggest

spatial variation in seagrass density could be affected by nutrient availability, as suggested by Fourqurean and Zieman (2002).

The lowest C:N ratios are present in the back bays of PM (C:N ratios = 11.74 – 14.15) and PF (C:N ratio = 18.61) (Table 1), indicating high nitrogen availability. The availability of nitrogen decreased with increasing distance from shore, based on an increase in C:N values. Although the data set from PF is smaller, average C:N values were slightly higher in PF relative to PM, suggesting that the bay has decreased nitrogen availability (Table 1).

The maximum C:P ratios, therefore lowest phos-

Sample	C:N	C:P	N:P
PM 13	19.12	334.9	17.52
PM 14	17.82	453.8	25.47
PM 15	17.31	535.5	30.94
PM 16	26.99	402	15.21
PM 17	12.01	407.8	33.96
PM 18	14.15	481.6	34.04
PM 19	11.74	347.1	29.85
PM 21	18.98	487.9	26.04
PM ave.	17.27	431.33	26.63
PF 8	16.97	501.2	29.54
PF 12	20.25	373.7	18.52
PF ave.	18.61	437.45	24.03

Table 1. Nutrient ratios for *Thalassia testudinum* samples from Puerto Mosquito and Puerto Ferro, Vieques, Puerto Rico.

phorus availability, were observed in the back part of PM (PM - 15 and 18; C:P = 535.5 - 481.6) (Fig. 1; Table 1). The increased ratios were concentrated in more protected areas of the bay and areas of denser seagrass distribution. Another location with low phosphorus availability was the ocean channel of PM (C:P = 481.9). These ratios loosely suggest phosphorus availability increases with distance from shore.

The N:P ratios of PM indicate relative phosphorus limitation near shore (PM - 15, PM - 17, PM - 18) and relative nitrogen limitation farther from shore (PM - 16) (Fig. 1; Table 1), supporting C:N and C:P data. This spatial relationship could not be evaluat-

ed in PF, where both samples are near shore (Fig. 1). Although the N:P ratios from PM suggest relative P limitation near shore and relative N limitation farther from shore, greater sampling density is required for validation.

Three cores from Puerto Mosquito were selected for isotopic analysis based on the hydrologic conditions of their location. PM - 14 is located in the back bay, PM - 23 in the central bay, and PM - 21 in the ocean channel. Changes in the total organic C and N (assumed to be organic N), $\delta^{13}\text{C}$, as well as C:N ratios with core depth can be correlated with sedimentary facies changes. The top sediment layer in PM cores is an organic rich, mixed carbonate-siliciclastic mud, though thickness varies with core location (Fig. 2). Below the top organic rich layer is a sedimentary layer dominated by molluscan shells and gravelly shell hash (Fig. 2), possibly related to a transgressive lag or a storm deposit in deeper water (e.g., Nelson, 2006). Below the gravelly shell hash is a gray or green-blue terrigenous mud. In PM-23, the shortest core, a gray terrigenous mud with low CaCO_3 content (0.75 wt.%) was present at the base (Fig. 2).

The organic-rich mud in PM - 21 and PM - 23 had relatively high N and organic C contents compared to the gravelly shell hash below (Fig. 2). PM - 14 was an exception; the organic-rich exhibited lower total N (0.06%) and organic C (1.6%) compared to the gravelly shell hash. This disparity might be related to a dilution effect caused by higher rates of terrigenous sediment deposition at PM - 21 and PM - 23, resulting in lower organic C concentrations (pers. comm. Tim Ku). The gravelly shell hash layer thickness is similar in all cores as are the total N (0.1%) and organic C (1-2%) contents in this layer (Fig. 2).

$\delta^{13}\text{C}$ values for the cores also are affected by changes in sedimentation. $\delta^{13}\text{C}$ values for PM - 14 are approximately (-19) within the organic-rich mud (Fig. 2). Below this, the organic-rich mud grades into the gravelly shell hash, $\delta^{13}\text{C}$ values decrease below (-20). $\delta^{13}\text{C}$ values for PM - 14 steadily increase with depth as the shell hash grades into terrigenous mud at approximately 50 cm. PM - 23 $\delta^{13}\text{C}$ values are similar

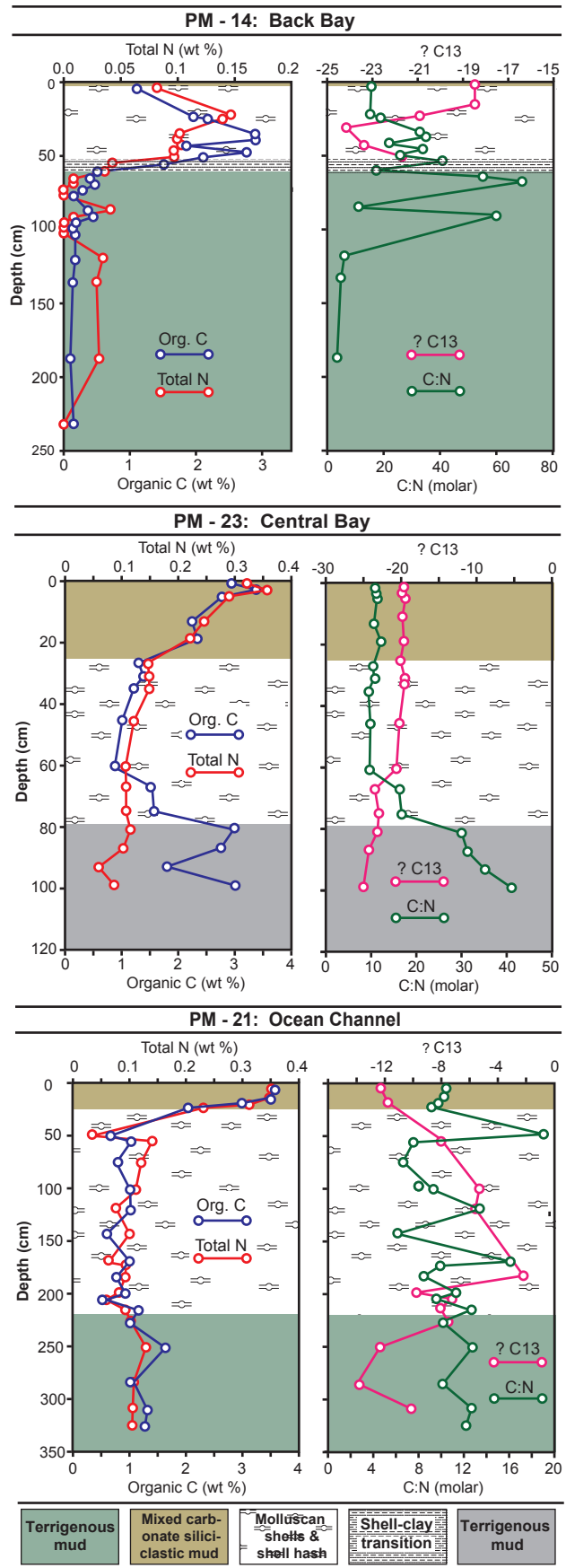


Figure 2. Down core analyses. Core depth (cm) vs. N, organic C, C:N, and $\delta^{13}\text{C}$, with sedimentary facies shown for reference

to PM - 14 near the top of the core (approximately (-20)), and remain constant to 60 cm (Fig. 2). At 60 cm, the base of the shell hash, the values decrease to (-25) and remain constant below that depth (Fig. 2). $\delta^{13}\text{C}$ values (-12) in the organic-rich top layer of PM - 21 are higher than PM - 14 or PM - 23 (Fig. 2) and the values continue to increase in the shell hash. At 180 cm, $\delta^{13}\text{C}$ reaches approximately (-3); however, $\delta^{13}\text{C}$ values more than (-5) might indicate error due to carbonate carbon contamination (pers. comm. Tim Ku). The terrigenous mud at the base of PM-21 exhibits $\delta^{13}\text{C}$ values below (-10) (Fig. 2).

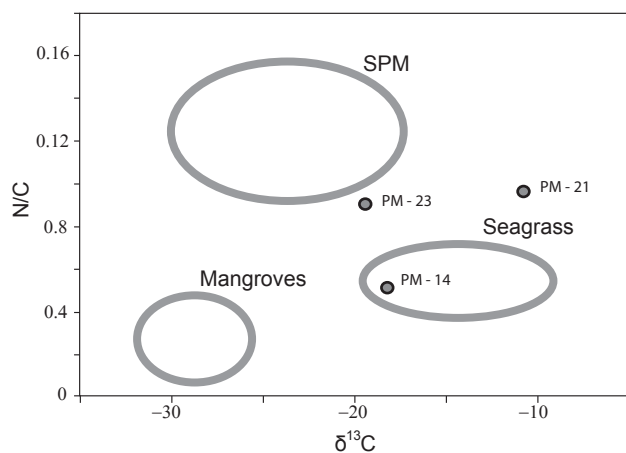


Figure 3. N/C vs. $\delta^{13}\text{C}$ with data from the tops of cores PM-14, PM-21, and PM-23. The ranges in values for potential sources of organic material are indicated by grey ovals (SPM, seagrass, and mangrove). These values are from a study performed in a similar lagoonal ecosystem by Gonneea and others (2004). Figure modified from Gonneea and others (2004).

DISCUSSION

The nutrient availability in the lagoonal systems of Vieques helps explain the relatively high concentrations of bioluminescent dinoflagellates. The present-day nutrient contents of *Thalassia testudinum* in this study exhibit average C:N and C:P ratios near the minimum observed in a larger study performed in Florida Bay (Fourqurean and Zieman, 2002) (Table 2), suggesting higher relative availability of both nitrogen and phosphorus. The waters of the bioluminescent bays of Vieques are more isolated from the open ocean than Florida Bay, so hydrodynamics might influence the observed difference. Also, terrestrial sources are the main suppliers of phosphorus

Ratio	Site	Min	Max	Mean
C:N	Florida Bay	11.1	47.1	24.6
	Pt. Mosquito	11.7	26.0	17.3
	Pt. Ferro	17.0	20.3	18.6
C:P	Florida Bay	373.4	1901.3	937.4
	Pt. Mosquito	334.9	535.5	431.3
	Pt. Ferro	373.7	501.2	437.5
N:P	Florida Bay	15.4	107.1	40.2
	Pt. Mosquito	15.21	34.4	26.6
	Pt. Ferro	18.6	29.5	24.0

Table 2. Comparison of C:N, C:P, and N:P nutrient ratios. Data from Fourqurean and Zieman (2002) and this study.

and nitrogen for marine ecosystems (e.g., Fourqurean and Zieman, 2002), so increased interaction with the land could be another factor that influences the differences in ratios, since all samples in this study were taken less than 200 meters from shore.

Within the bays, the spatial distribution of nitrogen content appears similar to the distribution in Florida Bay. Fourqurean and Zieman (2002) observed decreased nitrogen availability with increasing distance from shore, similar to observations made in this study, permitting the hypothesis that C:N ratios are scale invariant. While light availability is known to decrease both C:P and C:N ratios (Abal et al. 1994; Grice et al. 1996), the shallow depths of both bays and less turbid water near the deepest portions of the bays (Nelson, 2006) suggest that light availability is not a factor. In addition, the average C:N ratio in Puerto Ferro suggests that Puerto Mosquito has greater nitrogen availability, perhaps due to the smaller size of Puerto Mosquito and its lesser interaction with the open ocean.

Areas of decreased P availability are concentrated in protected areas of Puerto Mosquito and areas of denser seagrass distribution. Another location of low phosphorus availability was the ocean channel. Thus phosphorus availability appears to increase with distance from shore; opposite of what is expected, assuming that terrestrial sources provide most phosphorus. However, Fourqurean and Zieman (2002) suggest offshore sources of P are as important as terrestrial sources. Although difficult to evaluate in PM or PF, phosphorus limitation in Florida Bay

was correlated with smaller grain size, due to the increased surface area allowing increased P-sorption (Fourqurean and Zieman, 2002).

Gonneea and others (2004) studied the sources of organic matter by comparing C:N and $\delta^{13}\text{C}$ values from sediment analyses to values from three potential sources of organic C (suspended particulate matter, seagrass, and mangrove) (Fig. 3). Assuming the values of end members in the study performed by Gonneea and others (2004) are similar to the values for the bays of Vieques, sediment values from both PM-14 and PM-23 suggest that seagrass is most recent source of organic material, while in the past, mangrove was the dominant source (Figs. 2 and 3). Nutrient and isotopic values from PM-21 indicate a constant seagrass source through time.

The organic matter source shifts in both PM-14 and PM-23 (Figs. 1 and 2), indicate a possible sea level transgression. Sediment with mangrove as a source is must be located near shore while a seagrass source could be located farther from shore, in deeper water. The sediment history, sedimentation rate based on ^{210}Pb data (pers. comm. T. Ku), as well as the most likely organic matter source indicate a sea level transgression about 1800 – 2300 years ago. Based on sedimentation data (the organic-rich layer), the conditions that have supported the dinoflagellate population are a recent phenomena, beginning 300 – 1900 years ago (pers. comm. T. Ku). Therefore, while the present-day habitats of Puerto Mosquito and Puerto Ferro show great ability to support dinoflagellate populations, past changes in the bays' environment appear to be natural. So while protection of the habitat from future development is important, this does not ensure long-term success of the species in the bays of Vieques .

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