STABLE ISOTOPE ANALYSIS OF SEDIMENTARY ORGANIC MATTER FROM BIOLUMINESCENT BAYS IN VIEQUES, PUERTO RICO, SUGGEST A LINK BETWEEN MANGROVE DECAY AND BIOLUMINESCENCE

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INTRODUCTION

The three bays considered as part of this research project, Puerto Mosquito (PM), Bahia Tapon (BT), and Puerto Ferro (PF), are all located on the south side of the island of Vieques, Puerto Rico. All three bays are surrounded by mangrove forests, all three have openings to the Carribbean Sea, and all are within walking distance of each other. Only Puerto Mosquito, however, contains high concentrations of the dinoflagellate pyrodinium bahamense that causes brilliant luminescence. This study was conducted in an effort to explain why these three bays, so similar in ecology, geomorphology, and geography display different degrees of bioluminescence.

The vegetation present in these bays includes two main components: marine vegetation and terrestrial mangroves (Keck 2006). Both shed off plant material that accumulates in the bays and decomposes. Mangroves are well known to be extremely productive ecosystems (Bouillon et al., 2003). The nutrient budget of each bay is affected in large part by the geochemical effect of mangrove decomposition. If the mangrove component of bay ecosystem varies, then the nutrient budget varies, possibly explaining the variance in bioluminescence.

Dr. Barbara Bernache-Baker, a board member of the Vieques Conservation and Historical Trust, explains that it is the abundance of vitamin B12, a product of microbial processes (Starr et al., 1957; Gillespe et al.,1971) and an essential nutrient upon which the dinoflagellates depend (Matsuoka et al., 2000), which makes bioluminescent bays possible (Bernache-Baker, 1995).

PF is most open to marine incursion, with a large bay mouth that is 250m wide. PM is the most closed off, with a bay mouth only 130 m wide, and very terrestrially embanked geomorphology (Keck 2007).

This study will investigate the importance of mangrove organic matter in causing dinoflagellate growth and thus luminesence. Stable isotope analysis on sediment from each bay will determine if the proportion of seagrass to mangrove organic material varies from bay to bay. Phytoplankton is another possible source of organic material in marine ecosystems, however it is not exclusively considered in this study.

METHODS

Sediment cores were collected from various sites within each bay (see map-TIM/Project director contribution). Sites were chosen to represent any environmental differences within each bay (near shore, off shore, near island, etc.). Observations about grain size as well as shell and plant abundance were recorded for each core by the entire research group. Mangrove samples including leaves and exposed roots were collected from each of the three bays near certain representative coring sites.

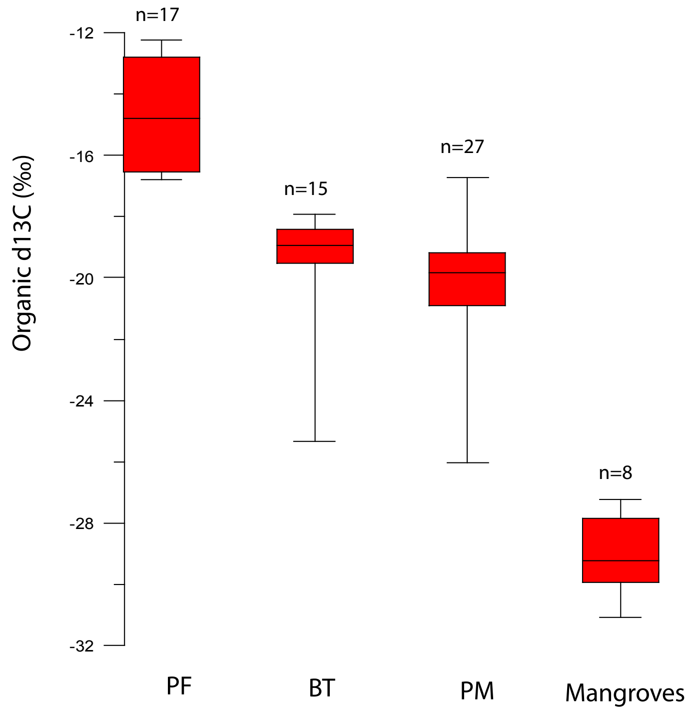
Core samples were analyzed for Total Inorganic Carbon (TIC), Total Organic Carbon (TOC) and nitrogen at Wesleyan University.

Samples for organic carbon isotopic analysis were taken from selected cores and depth intervals. They were treated with HCl to remove inorganic carbon (CaCO3), and were then sent to the University of Arizona, along with samples of mangrove biomass for carbon isotope analysis.

RESULTS

Carbon isotope ratios of sediment organic matter from each bay vary (Fig. 1). PF has the highest organic carbon isotope ratio while PM has the lowest, apart from mangrove samples. The sample set processed for carbon isotopes included two outlying data points that represent core sites that were either in a marsh surrounding the bay (BT4) or were taken in the mangrove root system (PM3).   Excluding these two outliers, the averages for PF, BT, and PM were, respectively: -14.6 ± 1.7, -19.3 ±1.7, -20.2 ± 2.0 ‰.   Compared to organic material from sediment, mangrove biomass from all bays has a lower average carbon isotope ratio of -29.3 ± 1.2‰.   Carbon isotope ratios of seagrass are generally higher, from -3 to -15‰ (Bouillon et al., 2002; Coffin et al., 1989; Fry et al., 1984), as are carbon isotope ratios of marine plankton, from -17 to -22‰ (Ku 2007).

Figure 1. Box and whisker plot of organic carbon isotope ratio data for PF, BT, and PM sediment as well as mangrove clippings taken from all three bays.



The ratio between total organic carbon and total nitrogen in sediment samples also reflect variation in source organic material, in addition to the carbon isotope ratios (Gonneea et al 2003, Bouillon et al. 2004). Bouillon et al. determined that the range expected for the carbon to nitrogen ratio for mangrove litter is 25-30, and 6-12 for tidally imported material (Fig. 2). The accepted range for the organic carbon to nitrogen ratio in marine plankton is 5-10 (Ku 2007).

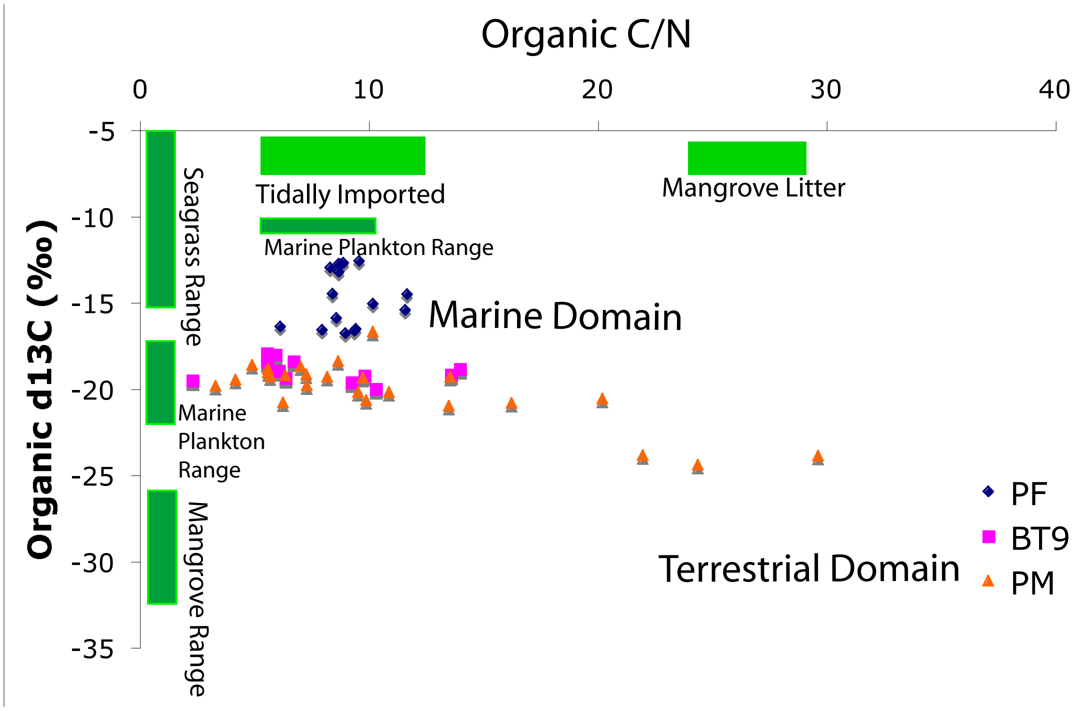


Figure 2. Plot of Organic C/N ratio to organic carbon isotope ratios for each core. The ranges expected for mangrove litter and tidally imported material are highlighted. Ranges expected for seagrass (-3 to -15 ‰), mangrove (-31 to -26 ‰), and marine plankton (-17 to -22 ‰) carbon isotope ratios are also highlighted (Coffin et al., 1989; Fry et al., 1984, Ku 2007).

TIC found in sediment also varies between bays, with more TIC in PF relative to BT and PM. The result is a positive correlation between TIC and the carbon isotope ratio (Fig. 3).

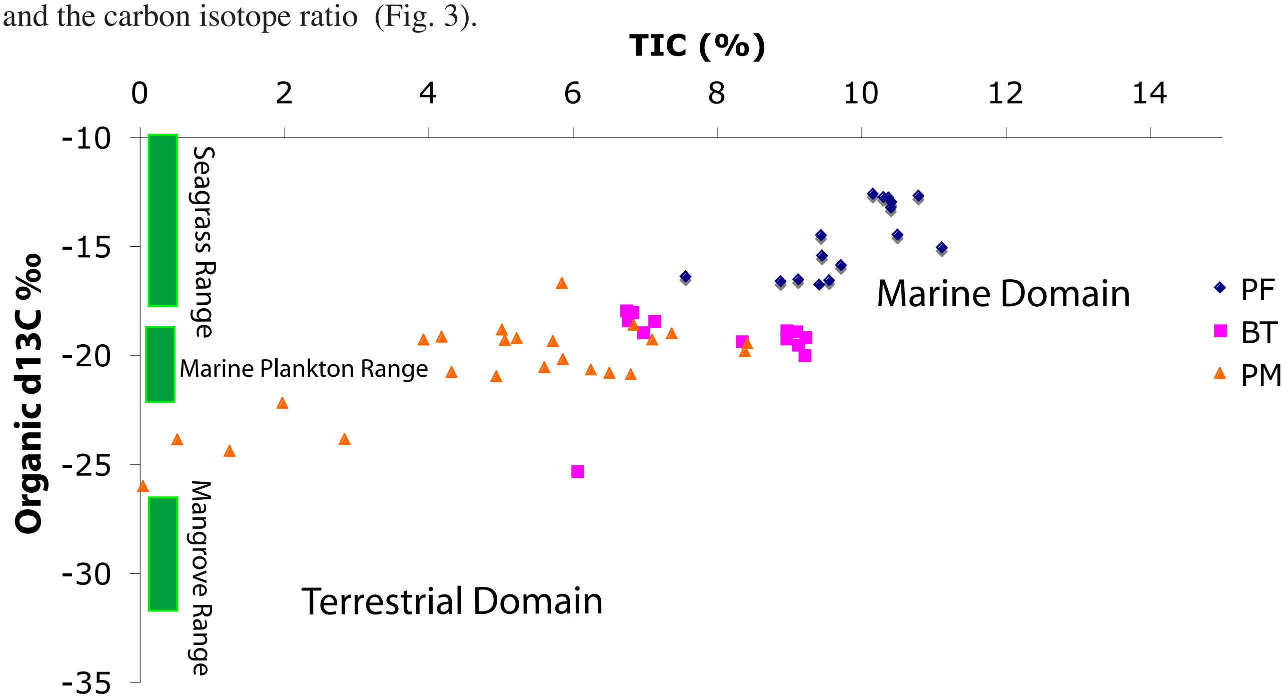


Figure 3. Total inorganic carbon (TIC%) vs. organic carbon isotope ratio for sediment. Marine and terrestrial domains based on combined d13C and TIC values constitute the more positive and more negative quadrants respectively.

Other correlations exist between the abundance of identifiable plant fragments and carbon isotope ratios of sedimentary organic matter. In particular, samples with more halimeda plant fragments present also have more positive carbon isotope ratios, while samples with more mangrove fragments are more negative (Fig. 4).

evidence of a marine plankton source in addition to a mixing between mangrove and seagrass (Ku 2007).

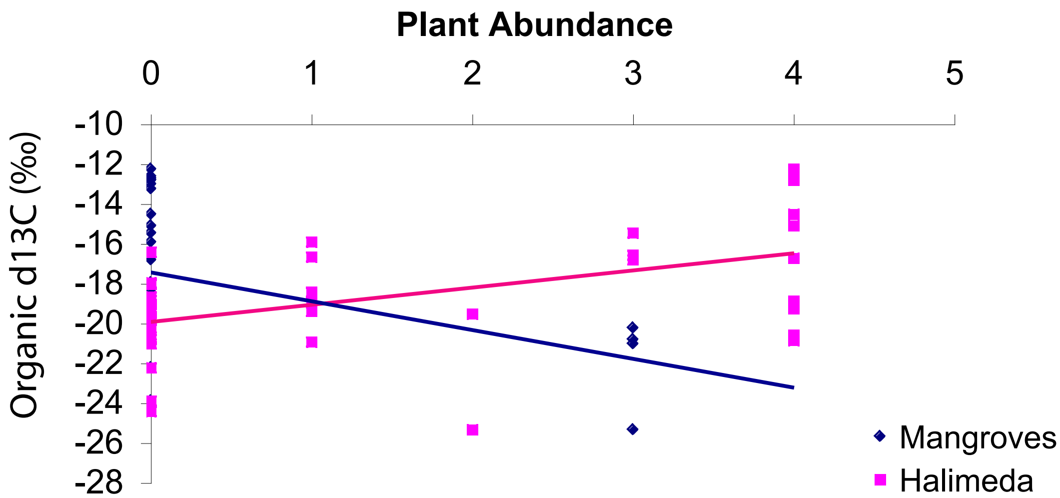


Figure 4. Plant abundance vs. organic carbon isotope ratios. Plant abundance was assigned based on a 0-5 scale, where 0=not present and 5=very abundant (Nelson, Keck 2007).

DISCUSSION

Mangrove Organic Matter and Bioluminescence

The difference in carbon isotope ratios between bays is interpreted to represent a difference in the source organic material that is deposited as sediment. In particular, higher values indicate that marine vegetation, most likely halimeda, a calcareous algae, or thalassia, a seagrass, is a major source of organic matter, while lower values indicate that terrestrial vegetation, most likely mangroves, is a major source of organic matter. Because carbon isotope ratios fall in and between expected ratios for seagrass and observed ratios for mangroves, some degree of mixing of marine and terrestrial vegetation also must have occurred. Marine plankton typically has carbon isotope ratios between –17 to –22‰, meaning that this range could be interpreted as

The ratio between organic carbon and nitrogen in the sediment changes between bays, pointing to differing organic sources from bay to bay similar to those indicated by the carbon nitrogen ratios. PF has the highest carbon isotope ratios as well as low carbon nitrogen ratios, indicating tidally imported organic material. PM has the lowest carbon isotope ratios as well as the highest carbon nitrogen ratios, indicating mangrove litter (Bouillon et al. 2003).

Aside from representing a predominant mangrove contribution, many of the carbon isotope ratios and organic carbon nitrogen ratios for PM fall within the expected range for marine plankton, or for dinoflagellates (Hereid, 2007). Given the history of sustained blooms of dinoflagellates in PM, it is likely that a large portion of the organic sediment in this bay is in fact composed of dinoflagellates themselves (Ku, 2007).

The amount of total inorganic carbon (TIC) also varies from bay to bay. A probable source of this carbon is calcite and/or aragonite produced by marine organisms. As in the case of carbon isotope ratios, higher values are indicative of a larger proportion of sediment coming from marine rather than terrestrial sources. As a result, there is a positive correlation between TIC and carbon isotope ratios for the sampled cores. Marine and terrestrial end members for TIC and carbon isotope ratios are proposed based on these relations (Fig.2).

Perhaps the most important observation is that differences in carbon isotope ratios and TIC between bays correlate with differences in bioluminescence. PM has the lowest carbon isotope ratios and TIC values, meaning that its organic matter input is dominated by mangroves, and its sediment also comes predominantly from terrestrial sources relative to other bays. PM does, however, still have significant calcium carbonate concentrations in most surface sediments, ranging from ~30-85 wt.%, as expected for a coastal estuarine environment (Keck 2007). PM is also the most bioluminescent bay. Assuming that the same organic matter that ends up being deposited as solid sediment is also the major source of dissolved organic matter in bay waters, these data suggest a causal relation between bay waters dominated by input from decaying mangroves, and bioluminescence. In turn, mangrove organic matter has been suggested to be a source of vitamin B12 and other nutrients critical to dinoflagellate growth.

Hydrodynamics Controls on the Source of Organic Matter in Bays?

Based on the interpretations above, it appears that a large proportion of dissolved organic matter from mangroves in bay water is needed to have a bioluminescent bay. This begs the question of why dissolved organic material from mangroves is more predominant in PM as opposed to PF. One possible reason is that hydrodynamic cycling varies between bays.

Increased hydrologic cycling could explain why PF and BT have higher carbon isotope ratios. A higher exchange rate with the sea means that terrestrial nutrients entering the water column of the bay are either washed away or are diluted. If these nutrients have a source in the decay of mangrove organic material, and if they are crucial to hosting abundant dinoflagellate populations, then abundant hydrologic cycling reduces the likelihood of bioluminescence.

Elevated TIC also suggests elevated exchange rate between the water in the bay and the sea. The bays that fall closer to the marine end member in their carbon isotope ratios (the bays with more positive ratios reflect a dominance of seagrass in the organic carbon contribution) and TIC values are bays that cannot host bioluminescence. When mangroves are flushed out, the terrestrial geochemical influence crucial to dinofl dinoflagellates is overlain by seagrass and inorganic carbon.

CONCLUSION

Using carbon isotope ratios, this study suggests that bioluminescence in Vieques, Puerto Rico, requires that the source of organic matter in bays is from terrestrial mangrove. This relative abundance of mangrove plant material is most likely variable between bays due to variable hydrodynamic cycling. Future studies would be wise to investigate the specific nutrients that mangroves contribute to the waters of these bays.

REFERENCES

Bernache-Baker, The Bioluminesscent Bays of Vieques 1995, http://biobay.com/cd/articlew/barb1.htm

Bouillon, S., Dahdough-Guebas, F., Rao, A.V.V.S, Koedam, N., Dehairs, F, 2003, Sources of organic carbon in mangrove sediments: variability and possible ecological implications: Hydrobioligia, no. 495, p. 33-39.

Fricke, Henry. Personal Communication. 2007.

Gillespie, Paul A., Morita, Richard Y., 1972, Vitamin B12 Production and Depletion in a Naturally Occurring Eutrophic Lake: Applied Microbiology, p. 341-348

Gonneea, Meagan Eagle, Paytan, Adina, Herrera-Silveira, Jorge A., 2004, Tracing organic matter sources and crbon burial in mangrove sediments over the past 160 years: Estuarine, Coastal and Shelf Science, p. 211-227.

Hereid, Kelly, 2007, Pyrodinium bahamense var. bahamense cysts as a dinoflagellate population and depositional environment proxy in Puerto Mosquito, Vieques, Puerto Rico.

Keck Project Announcement, 2006

Ku, Tim. Personal Communication. 2007.

Matsuoka, Kazumi, Fukuyo, Yasuwo. Technical Guide for Modern Dinoflagellate Cyst Study. October 2000.

Nelson, Andrew, 2007, The progression of sedimentological facies and their control of biogeochemical processing of the bays of Vieques, Puerto Rico.

Starr, Theodore J., Jones, Mary E., Martinez, Domingo. 1957 The Production of Vitamin B12-Active Substances by Marine Bacteria: Limnology and Oceanography, vol.2, no. 2, pp. 114-119.