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Seasonal changes in bioluminescence and dinoflagellate composition in a tropical bioluminescent bay, Bahía Fosforescente, La Parguera, Puerto Rico

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ABSTRACT

Decreases in bioluminescence in Bahía Fosforescente have been associated with alternations between bioluminescent (*Pyrodinium bahamense*) and non-bioluminescent (*Ceratium furca*) dinoflagellates, two potentially harmful algal bloom species (HABs). Until now, these changes in bioluminescence have never been quantified, and their relationship with seasonality remains unclear. This study quantified the bioluminescence potential (BP) in the bay with a high spatiotemporal resolution to evaluate the status of this phenomenon and to determine the link between seasonality on the BP and dinoflagellate composition. Biweekly measurements, from August 2012 to July 2013, were conducted at six stations with an Underwater Bioluminescent Assessment Tool. The highest BP were observed during the wet season and were correlated (Spearman rank correlation: $r = 0.89$, $n = 64$, $p < 0.001$) with high cell densities of *P. bahamense*. *Ceratium furca* cell densities surpassed those of *P. bahamense* during the dry season, with concomitant reductions in the BP. The presence of other potentially bioluminescent dinoflagellates, such as *Protoperidinium* spp., during the latter season, with abundances higher than those of *P. bahamense*, suggests their contribution to the BP. It is suggested that environmental changes exerted by different meteorological conditions cause variations in the BP by modulating the dinoflagellate composition. Overall, a higher BP were observed in the northern area of the bay, suggesting that wind-driven currents promoted the accumulation of organisms in this region. This study underscores how weather, changes in the abundance of these two potentially HAB species, and the BP at Bahía Fosforescente are critically linked.

1. Introduction

Dinoflagellates represent one of the most ubiquitous groups among the phytoplankton community in the marine ecosystem, occupying several ecological roles as primary producers, grazers, mutualists, parasites, and establishers of harmful algal blooms (HABs) (Gómez, 2012). Furthermore, dinoflagellates represent the only members of the phytoplankton community with the capability to emit light (Cusick and Widder, 2014), contributing significantly to the bioluminescence that occurs on the surface of oceans and coastal waters (Kelly and Tett, 1978; Tett, 1971).

Much effort has been spent to understand the bioluminescence phenomenon caused by these organisms, including the cellular mechanisms of light emission (reviewed by Valiadi and Iglesias-Rodriguez, 2013), diurnal/circadian rhythms (Akimoto et al., 2004; Knaust et al., 1998; Marcinko et al., 2013a), influence of environmental factors on light production (Latz and Jeong, 1996; Li et al., 1996; Sullivan and Swift, 1995; Sweeney, 1981), patterns and distribution (Lapota et al., 1989; reviewed by Marcinko et al., 2013b), ecological function of light production (Cusick and Widder, 2014; reviewed by Haddock et al., 2010 and Widder, 2010), and in situ molecular detection (Valiadi et al., 2014). Even though these studies have provided valuable information on the ecophysiology of bioluminescent dinoflagellates, much remains to be learned about the population structure of these organisms in relation to environmental conditions (Valiadi and Iglesias-Rodriguez, 2013).

Bahía Fosforescente, a bioluminescent bay located in the southwest coast of Puerto Rico, represents an ideal natural laboratory to study the environmental regulation of phytoplankton composition, occasionally resulting in the formation of blooms of the bioluminescent dinoflagellate *Pyrodinium bahamense* var. *bahamense* Plate (Margalef, 1957). For decades, the bioluminescence displayed by *P. bahamense* has made this bay an economically important tourist attraction. In contrast to other locales (i.e., Indian River Lagoon, Florida) (Landsberg et al., 2006), this species has not been associated with HAB's deleterious effects on marine species.

Dybas (2011) reported the drastic reduction or disappearance of bioluminescence in Bahía Fosforescente due to dredging at the entrance, supporting the notion of significant changes in the conditions favorable

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for the accumulation of abundant dinoflagellate populations. However, it is not possible to conclude that bioluminescence levels have dwindled because no systematic observation of this property has been conducted over the past 50 years. Recently, Soler-Figueroa and Otero (2015) showed that the abundance of *P. bahamense* is highly influenced by precipitation patterns due to changes in nutrient availability at daily to seasonal scales. This pattern is consistent with the increased dominance (Seixas, 1988; Walker, 1997; Soler-Figueroa, 2006) of mixotrophic, non-bioluminescent, dinoflagellates such as *Ceratium furca* var. *hircus* (recently named *Tripos furca* var. *hircus* (Schröd) F. Gómez; Gómez, 2012) (Sweeney, 1981; Valiadi et al., 2014). Overall, these results suggest that bioluminescence is variable and modulated by weather conditions. However, detailed measurements of bioluminescence and *P. bahamense* cell densities have yet to be conducted that would allow the evaluation of bioluminescence over time.

To evaluate the bioluminescence trends of the bay, the bioluminescence potential (BP) at Bahía Fosforescente were quantified, after more than fifty years of no systematic observation (Clarke and Breslau, 1960). This study examined whether seasonality and different precipitation regimes influence the dinoflagellate composition and how these changes are reflected in the BP. In addition, the temporal (short-term and seasonal) and spatial patterns in the BP and their possible relationships with dinoflagellate composition were evaluated. Lastly, historical data of *P. bahamense* abundances were used to assess possible changes over time in their populations.

Results from this study broaden the knowledge of how different environmental conditions related to seasonality, influence the population structure of *P. bahamense* and *C. furca*, two potential HABs species (GEOHAB, 2001; Horner et al., 1997; Landsberg et al., 2006; Machida et al., 1999). These data also provide valuable information on the present state of Bahía Fosforescente, an important tourist industry and fisheries resource, which is vital for the establishment of effective management practices.

2. Methods

2.1. Study site

Bahía Fosforescente (Fig. 1) is located 3.2 km east of La Parguera, Lajas on the southwest (SW) coast of Puerto Rico (17° 58′ 30″ N; 67° 01′ 10″ W). The estimated area of the bay is 0.19 km^2 with an average depth of 3.5 m. The bay has an irregular shape with a narrow outlet to the coastal ocean (100–150 m) and shallow water (ca. 3.0 m). There are no rivers discharging into the bay, but infrequent watershed surface water flows in via three north inlets, especially during heavy rainfall events. Dispersal of surface water flow is also possible through the fringing mangrove (*Rhizophora mangle*) forest that separates the bay waters from the coastal salt flats. The bay is characterized by high evaporation rates due to the prevailing arid conditions of SW Puerto Rico (Margalef, 1961).

2.2. Field work

Sampling was conducted during two sampling campaigns, from August 29 to December 11, 2012, and from March 5 to July 19, 2013. The wet (Aug–Nov 2012) and dry (Jan – the first two weeks of April 2013)

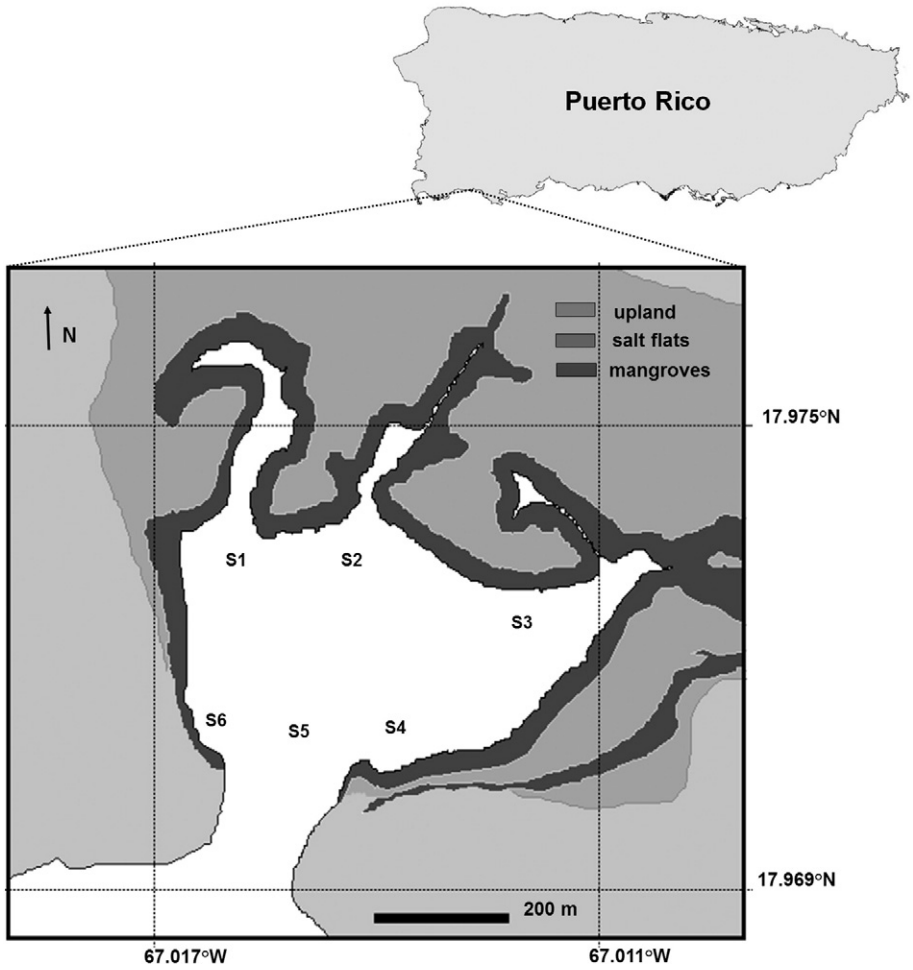

Fig. 1. Sampling stations at Bahía Fosforescente, La Parguera, Puerto Rico. (Source: Soler-Figueroa and Otero, 2015).