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Bloom dynamics and chemical defenses of benthic cyanobacteria in the Indian River Lagoon, Florida

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ABSTRACT

Cyanobacterial blooms are predicted to become more prominent in the future as a result of increasing seawater temperatures and the continued addition of nutrients to coastal waters. Many benthic marine cyanobacteria have potent chemical defenses that protect them from top down pressures and contribute to the persistence of blooms. Blooms of benthic cyanobacteria have been observed along the coast of Florida and within the Indian River Lagoon (IRL), a biodiverse estuary system that spans 250 km along Florida's east coast. In this study, the cyanobacterial bloom progression at three sites within the central IRL was monitored over the course of two summers. The blooms consisted of four unique cyanobacterial species, including the recently described *Okeania erythroflocculosa.* The cyanobacteria produced a range of known bioactive compounds including malyngolide, lyngbyoic acid, microcolins A–B, and desacetylmicrocolin B. Ecologically-relevant assays showed that malyngolide inhibited the growth of marine fungi (*Dendryphiella salina* and *Lindra thalassiae*); microcolins A–B and desacetylmicrocolin B inhibited feeding by a generalist herbivore, the sea urchin *Lytechinus variegatus*; and lyngbyoic acid inhibited fungal growth and herbivore feeding. These chemical defenses likely contribute to the persistence of cyanobacterial blooms in the IRL during the summer growing period.

1. Introduction

Localized, episodic surges in the growth (blooms) of benthic marine cyanobacteria have been reported in tropical and subtropical zones worldwide (Paul et al., 2005; Ahern et al., 2007; Martin-Garcia et al., 2014; Yamashiro et al., 2014). These blooms can have negative impacts on benthic organisms and cause significant detrimental effects on ecosystem health (Watkinson et al., 2005). Cyanobacterial blooms are often associated with high nutrients and are predicted to become more pervasive as seawater temperatures increase due to climate change (Paul et al., 2005; Paerl et al., 2008; O'Neil et al., 2012; Paerl and Paul, 2012). Given optimal growth conditions (high nutrients, warm temperatures), cyanobacterial blooms will persist unless controlled by biotic factors such as grazing or infection (bacterial, fungal and/or viral) (Paerl and Otten, 2013). Saprotrophic and pathogenic fungi are prevalent among marine macrophytes and can act as driving factors in the collapse of cyanobacterial blooms (Hyde et al., 1998; Gerphagnon et al., 2013). Many cyanobacterial strains, however, persist in the environment by producing highly bioactive secondary metabolites that protect them from normal top-down controls (Capper et al., 2006; Soares et al., 2015).

Marine benthic cyanobacteria include a variety of filamentous species that are often chemically rich and grow attached to seagrasses, corals, macroalgae, and sediment. They are found in subtropical and tropical coastal waters worldwide and can form dense blooms especially during warm summer months (Paul et al., 2005; Watkinson et al., 2005). The morphological similarities among these cyanobacteria make taxonomic identification particularly difficult, and as a result many cryptic species have been overlooked and grouped together with other taxa based on phenotypic similarities (Engene et al., 2013a). Much of the previous research on benthic cyanobacterial blooms has focused on species that were reported to belong to the genus *Lyngbya.* Certain species in this genus inhibit settlement and increase larval mortality in scleractinian corals and octocorals (Kuffner et al., 2006), reduce growth and photosynthetic efficiency in adult corals (Titlyanov et al., 2007), and are correlated with increased tumor growth when ingested by green sea turtles (Arthur et al., 2008). Blooms of *Lyngbya* spp. have also been associated with changes in benthic

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invertebrate assemblages and depth distributions within the underlying sediment (Garcia and Johnstone, 2006; Estrella et al., 2011). Recent molecular investigation into *Lyngbya* spp. resulted in the reclassification of some members into the newly described genera *Moorea* and *Okeania* (Engene et al., 2012, 2013b), and the taxonomy of this group needs further revision based on molecular data (Engene et al., 2013a,b).

Seasonally reoccurring benthic cyanobacterial blooms have become common in southeastern Florida, especially along the south Florida reef tract (Paul et al., 2005). Reports of benthic cyanobacteria within the Indian River Lagoon (IRL) suggest that similarly persistent blooms may have taken hold here as well (Capper and Paul, 2008; Capper et al., 2016; Tiling and Proffitt, 2017). The IRL is a highly diverse estuary that extends along 40% of the east coast of Florida (Dawes et al., 1995). For this study, surveys were conducted over two growing seasons at three sites within the IRL to assess the density and composition of benthic cyanobacterial blooms within the lagoon. The production of feeding deterrent and antifungal compounds by all cyanobacteria discovered during the survey were investigated to get a better understanding of the factors that contribute to the ability of these cyanobacteria to persist and bloom in the Indian River Lagoon.

2. Methods

2.1. Bloom dynamics

The percent cover of benthic cyanobacteria was monitored throughout the summer months (April–September) in 2011 and 2012 at three sites in the Indian River Lagoon near Fort Pierce, FL. Site 1 (N 27° 27.202, W 80° 18.597) was a stand-alone seagrass flat with an area of 157 m × 43 m. Site 2 (N 27° 28.366, W 80° 18.669) was a seagrass flat attached to Little Jim Island (Fort Pierce) with an area of 267 m × 66 m. Site 3 (N 27° 31.987, W 80° 20.907) was a seagrass flat along the coastline near Harbor Branch Oceanographic Institute with an area of 65 m × 21 m. In the summer of 2011, each site was monitored once a week during low tide starting on April 14 and continuing until the bloom died off in September. The sites were monitored once every two weeks during the summer of 2012 starting April 18 and ending in September when the bloom

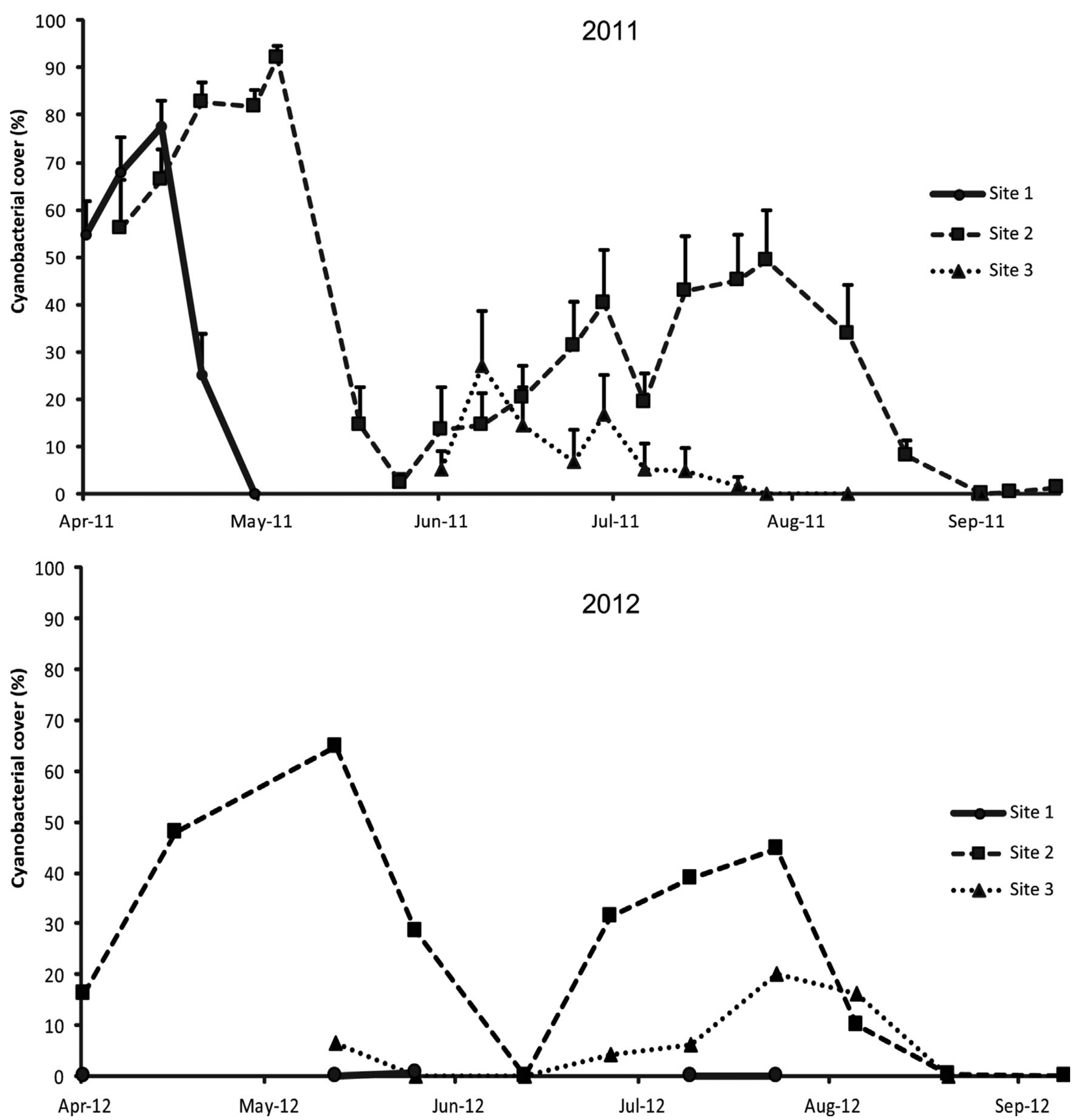

Fig. 1. Mean (±SE) percent cover of cyanobacteria at three sites within the Indian River Lagoon over the course of two summers.