Journal of Ecosystem & Ecography
ISSN: 2157-7625

Mini Review Open Access

Biology and Diet of Invasive *Caulerpa brachypus F. parvifolia* Blooms on Coral Reefs in the Southeast Region of the United States

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Abstract

Over the past 20 years, invasive chlorophyte blooms have devastated coral reefs off the southeast coast of Florida in an unprecedented sequence, with the non-native *Caulerpa brachypus F. parvifolia* being the most recent. We monitored benthic cover, water column dissolved inorganic nutrients, tissue C: N: P ratios, and stable nitrogen isotopes (δ15N) of C. brachypus and native chlorophytes (*Caulerpa racemosa, Caulerpa verticillata, Caulerpa mexicana,* and *Codium isthmocladum*) quarterly at two reef sites, the Princess Anne (PA) and North Colonel's Ledge (NCL) in 2003-2004. These observations helped us gain a better understanding of the ecology and nutrition of the *C. brachypus* invasion. Stormwater discharges from the Lake Worth inlet had an impact on the PA site, while NCL was located further away from these discharges.

Keywords: *Caulerpa brachypus F. parvifolia*; Coral reefs; Chlorophyte; Brachypus; Benthic cover

Introduction

The cover of *C. brachypus* decreased in July 2003 after cold temperatures (13°C) coupled with strong upwelling and high nitrate concentrations (21 μM) at NCL, indicating that upwelling can stress the growth of this tropical alga. Mean concentrations of ammonium (0.60 μM), nitrate (2.7 μM), and DIN (3.2 μM) were elevated in comparison to coral reef settings [1,2].

Methodology

Around the world, changes in coastal ecosystems have been attributed primarily to the invasion of both native and non-native macroalgae. Over the past 20 years, native and non-native chlorophytes have invaded coral reefs in southeast Florida in an unprecedented series of macroalgal blooms. In the summer of 1989-1990, spectacular blooms of detached Codium isthmocladum first appeared on deep reefs (24-43 m) off the coasts of northern Broward and southern Palm Beach counties. In the late 1990s, attached populations of C. isthmocladum, along with Caulerpa verticillata and Caulerpa racemosa, bloomed on reefs off the northern coast of Palm Beach County, following these initial blooms. The invasion of these reefs by *Caulerpa brachypus F. parvifolia* (Harvey) Cribb was found-3, 4].

The first record of this species and form in Florida's coastal waters was the finding of *C. brachypus F. parvifolia*. It has only been previously reported that *C. brachypus F. parvifolia* occurs in the western Pacific . Conversely, Littler and Littler (2000) report that the only known reports of *C. brachypus* in the western Atlantic/Caribbean region come from the Greater and Lesser Antilles. Historically, no reports of either form from Florida waters have ever been made [5].

Over the past 20 years, southeast Florida's coral reefs have experienced unprecedented macroalgal blooms, which have been linked to rising land-based nutrient inputs. The hypothesis that the summer Codium blooms of 1994-1995 were linked to increasing land-based nutrient pollution was supported by near-bottom seawater nutrient concentrations, δ15N, C: N: P ratios, alkaline phosphatase activity, and nutrient-enrichment bioassays proposed that the widespread Codium blooms were more likely to be caused by nutrient enrichment from upwelling, reduced herbivory from overfishing of grazers, and the 1983 sea urchin die-off Diadema antillarum. However, Florida fishermen do not specifically target herbivorous fish like surgeonfish and parrotfish, which make up a significant trophic group in fish assemblages on reefs in northern Palm Beach County (reef.org/db/reports/geo/TWA/3301) [6-8].

As with the Caribbean as a whole, D. antillarum was never abundant on these deep reefs and their die-off could not account for these deep-reef bloom phenomena (Lapointe, 1997). The nitrogen enrichment of these blooms was caused by land-based nutrient discharges, including sewage, rather than by a temporary summertime nitrate upwelling, as shown by recent mapping of δ15N in macroalgae at 21 stations over a network of shallow, mid-depth, and deep reefs in Palm Beach and Broward counties.

Caulerpa species are generally rare on oligotrophic coral reefs and are recognized as "indicator species" of nutrient enrichment from manmade or natural sources. The idea that rising levels of domestic sewage pollution were the cause of Caulerpa prolifera's expansion off the French Riviera was first put forth by Ollivier in 1929. High nutrient availability is critical to the success of invasive *Caulerpa taxifolia* in the Mediterranean, according to several studies. According to Delgado et al. (1996), bioassays conducted on *C. taxifolia* off the coast of Spain revealed that there is no year-round severe nutrient-limitation, and areas of explosive growth have been concentrated near urban stormwater and sewage discharges [9].

A ten-fold overestimation has been placed on taxifolia. Still, the invasion has produced large monospecific stands of *C. taxifolia*, which may have an effect on native seagrasses like *Cymodocea nodosa* and *Posidonia oceanica* (de Ville and Verlaque, 1995). Localized Caulerpa spp. blooms have also been observed in the wider Caribbean region

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Received: 03-Nov-2023, Manuscript No: jee-23-120735; **Editor assigned:** 06-Nov-2023, Pre-QC No: jee-23-120735 (PQ); **Reviewed:** 20-Nov-2023, QC No: jee-23-120735; **Revised:** 22-Nov-2023, Manuscript No: jee-23-120735 (R); **Published:** 29-Nov-2023, DOI: 10.4172/2157-7625.1000466

Citation: Martin H (2023) Biology and Diet of Invasive *Caulerpa brachypus F. parvifolia* Blooms on Coral Reefs in the Southeast Region of the United States. J Ecosys Ecograph, 13: 466.

in the vicinity of nutrient-enriched habitats. For instance, the tiny C. verticillata, which is typically found in mangrove habitats, forms thick mats on the vertical walls of canal systems in the Florida Keys that have been impacted by sewage.

The invasions of C. taxifolia in the Mediterranean and *C. brachypus F. parvifolia* (henceforth referred to as *C. brachypus*) in southeast Florida have a number of intriguing similarities. Both regions are subtropical, have extensive human activity on their watersheds, and have overlapping ranges of temperate and tropical species. Furthermore, both invader species are tropical, meaning that under ideal conditions of temperature, irradiance, and nutrient availability, they can grow explosively. Elton, in his groundbreaking study on biological invasions, stressed the significance of human-mediated vectors, particularly physical transport. Since then, it has become widely acknowledged that humans are the main agent causing the worldwide epidemic of biotic invasions in aquatic environments. Less is understood, though, about how human modification of chemical factors, like rising [10].

Results

On the other hand, less is known about how biological invasions and declines in biological diversity may be facilitated by human modification of chemical factors, such as rising anthropogenic land-based nutrient pollution. We carried out a 20-month field study with quarterly (winter, spring, summer, and fall) sampling at two reef sites with different exposures to land-based nutrient discharges from the Lake Worth Inlet, Palm Beach County, FL, in order to better understand the ecology, nutrition, and bloom dynamics of the non-native *C. brachypus* relative to native chlorophytes. The study was a component of the larger Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) project, which also included the following: (1) collecting and analyzing macroalgal tissue samples from time to time every three months; (2) using digital underwater video imagery of benthic transects at the Princess Anne (PA) and North Colonel's Ledge to determine spatial and temporal variation in native versus non-native chlorophyte abundance, including *C. brachypus*, *C. racemosa*, *Caulerpa prolifera*, *C. verticillata*, *Caulerpa mexicana*, and *C. isthmocladum*.

Discussion

To evaluate the type and extent of N vs. P limitation and the relative contributions of different natural and anthropogenic nitrogen sources, quarterly macroalgal tissue samples from the two reef sites are collected and analyzed for C: N: P and stable nitrogen isotope (δ15N) values. Additionally, near-bottom seawater samples from PA and NCL are collected every three months to determine the concentrations of soluble reactive phosphorus (SRP) and dissolved inorganic nitrogen (DIN = ammonium + nitrate + nitrite) in the water column. These measurements are used to characterize the spatial and temporal variation in nutrient availability.

Conclusion

This study offers the first documentation of the non-native chlorophyte *C. brachypus F. parvifolia* invading the coral reefs of southeast Florida. This Pacific native was first noted off the coast of northern Palm Beach County in May 2001, but it wasn't until the start of this study in the winter and early spring of 2003 that it produced large blooms.

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