Available online at www.sciencedirect.com
SCIENCE DIRECT®
Marine Pollution Bulletin 50 (2005) 566–575
MARINE POLLUTION BULLETIN
www.elsevier.com/locate/marpolbul

Interaction between inorganic nutrients and organic matter in controlling coral reef communities in Glovers Reef Belize

T.R. McClanahan [a,*], R.S. Steneck [b], D. Pietri [c], B. Cokos [a], S. Jones [d]

[a] *Wildlife Conservation Society, Marine Programs, 2300 Southern Boulevard, Bronx, New York 10460-1099, USA*
[b] *School of Marine Sciences, University of Maine, Darling Marine Center, Walpole, Maine, 04573, USA*
[c] *Center for Environmental Research and Conservation, Columbia University, 1200 Amsterdam Avenue, New York, NY 10027, USA*
[d] *Osborne Laboratories of Marine Sciences, New York Aquarium, Wildlife Conservation Society, Surf Avenue at West 8th Street, Brooklyn, New York 11224, USA*

Abstract

We studied the responses of algae, corals, and small fish to elevated inorganic fertilizer, organic matter, and their combination over a 49-day summer period in cages that simulated the coral reef in the remote Glovers reef atoll, Belize. The addition of organic matter reduced while fertilization had no effect on the numbers of herbivorous damsel and parrotfishes. All measures of algal biomass were influenced by fertilization. The combined inorganic and organic enrichment produced the highest algal biomass, which is most likely due to the combined effect of higher nutrients and lower herbivory. The cover of turf and total algae were influenced by all treatments and their interactions and most strongly and positively influenced by fertilization followed by organic matter and the combination of organic matter and inorganic fertilizer. The inorganic and combined treatments were both dominated by two turf algae, *Enteromorpha prolifera* and *Digenia simplex*, while the nonfertilized treatments were dominated by brown frondose algae *Lobophora variegata*, *Padina sanctae*, and *Dictyota cervicornis*. The organic matter treatment had greater cover of *P. sanctae* and *D. cervicornis* than the untreated control, which was dominated by *Lobophora variegata*, also the dominant algae on the nearby patch reefs. Crustose corallines grew slowly (~2.5 mm/49 days) and were not influenced by the treatments when grown on vertical surfaces but decreased on horizontal coral plates in the combined organic matter and fertilization treatment. No mortality occurred for the two coral species that were added to the cages. *Porites furcata* darkened in the fertilized cages while there was a mix of paling and darkening for a small amount of the coral tissue of *Diploria labyrinthiformes*. Inorganic fertilization stimulates small filamentous turf algae and *Symbiodinium* living in coral but inhibits brown frondose algae. Organic matter inhibits small herbivorous fish, *L. variegata*, and encrusting coralline algae when growing on horizontal surfaces.

Keywords: Algal growth; Brown algae; Coralline algae; Fertilization; Organic matter; Nitrogen; Phosphorus; Pollution

1. Introduction

The ecology of coral reefs has changed as a result of recent disturbances (McClanahan, 2002; Szmant, 2002; Hughes et al., 2003; Gardner et al., 2003). This change has, in some instances, been explained by changes in water quality associated with increased agriculture and urbanization near coastal ecosystems (Smith et al., 1981; Littler et al., 1991; Bell and Elmetri, 1995; Lapointe, 1999). High levels of inorganic nitrogen and phosphorus concentrations are often considered to be the main contribution to this change, although pollution has many constituents. Organic matter is a second major component of pollution associated with dead and decaying plants and human and animal waste. The role of

* Corresponding author. Address: Kibaki Flats #12, Coral Reef Conservation Project, Kenyatta Beach Bamuri, P.O. Box 99470, Mombasa, Kenya. Tel.: +254 11 485570; fax: +254 11 472215.
E-mail address: tmcclanahan@wcs.org (T.R. McClanahan).

0025-326X/$ - see front matter © 2005 Published by Elsevier Ltd.
doi:10.1016/j.marpolbul.2005.01.005

organic matter, which is frequently associated with inorganic nutrients, has not been separated from inorganic enrichment or well studied on corals, algae, and the associated fish communities. It is possible that other constituents of pollution cause some of the observed patterns of reef degradation often associated with nutrients. For example, inorganic nutrient enrichment experiments have failed to find a clear relationship between their concentrations and the enhanced abundance of brown frondose algae (Miller et al., 1999; Koop et al., 2001; Diaz-Pulido and McCook, 2003; McClanahan et al., 2002, 2003), a common dominant on degraded reefs (McClanahan, 2002; Gardner et al., 2003; Hughes et al., 2003). In order to understand the full consequences of pollution, the other constituents of pollution must be experimentally manipulated to determine their potential role in reef degradation. Here, we studied inorganic and organic enrichment in an experimental design that allowed us to evaluate the individual factors and their interaction. We examined the response of these two factors on three aspects of the coral reef, namely benthic algae, hard corals, and the small fish.

2. Methods

2.1. Study sites

This study was conducted in Glovers Reef, Belize in the site described by McClanahan et al. (2002). The important features of this site are that it is a large and remote coral reef atoll situated approximately 45 km off the coast of mainland Belize. The study was conducted in a portion of the atoll lagoon where a marine reserve has excluded fishing since 1995. The study was conducted in a water depth of 2-m on the windward side of one patch reef approximately 150 m offshore from the Middle Cay Research Station dock. Therefore, the site and background conditions were unlikely to be influenced greatly by mainland or urban waste and runoff. The waters in this area are calm with a small (<0.5 m) tidal range; low currents (<1 m/s) and no waves or other physical disturbances such as hurricanes were experienced during this summer study period (June to August 2002).

2.2. Experimental design and measurements

Using 16 closed cages we exposed corals, algal, and associated fish communities to two levels of organic matter and an inorganic slow-release fertilizer in a two-factor and two-level interactive design. One treatment was the environmental background conditions and additions of fertilizer and organic matter were applied to the other treatments. There were four replicates per treatment: (1) control or background conditions, (2) the addition of organic matter, (3) the addition of inorganic fertilizer and the (4) the addition of both organic and inorganic fertilizer. Cages were constructed with PVC frames with dimensions of 50-cm lengths and widths and 20-cm heights and covered by a 3-cm mesh plastic caging material. Cages were tied to cement masonry blocks, which kept them solidly on the reef bottom. Cages were cleaned of algae and other settling organisms with wire brushes every other day.

Closed-top treatments exclude large herbivorous fishes and larger predators but allow small fishes such as damselfishes (*Stegastes* spp.), wrasses, and small parrotfish (*Sparisoma aurofrenatum* and *Scarus iserti*) to enter and forage (McClanahan et al., 2002), and we counted their abundance in each cage three times over the study period. During counts each cage was observed for 3 min, taking care not to disturb the area by stirring sediments or abrupt movements. Within each cage, the number of damselfish, parrotfish, and wrasses observed during 1 min were counted.

Inorganic fertilizer was added to half of the cages as previously described (McClanahan et al., 2002, 2003) such that each fertilized cage received two doses of 500 g P_2O_5, 215 g ammonium and 57.5 g nitrates distributed beneath the cage at a monthly interval. The addition of 5-kg of untreated and fine sawdust collected from a sander at a local woodshop constituted the organic matter treatment. Wood dust was placed in fine mesh nylon bag (i.e. mosquito netting) and placed beneath half of the cages. In the combined inorganic and organic matter enrichment the fertilizer was added to the wood dust in the same mesh bag.

Water samples were collected 1-cm above the coral plates in acid-washed 100 ml and 500 ml bottles and analyzed for suspended solids, nitrate, and soluble phosphates on the same day with a Hach DR/2500 spectrophotometer using the cadmium reduction for nitrate and ascorbic acid methods for phosphorus. Samples were collected twice, one week after the initiation of the experiment and one week before the end of the experiment. Unrealistically high values of phosphates in the second sampling period in control cages indicated contamination of these samples and these data were, therefore, not presented.

Eight plates of dead *Acropora palmata* were placed in each cage along with living coral to simulate the reef benthos. Plates collected from the shallow reef flat on the windward side of the atoll rim were scraped with a wire brush and bumps removed with a stone blade of a hacksaw to ensure similar initial conditions and to make it easier to scrape algae from their surfaces. Despite the scraping, some crustose coralline algae remained. Seven of the plates were used for the weekly sampling of algal biomass and one was sampled at the end of the experiment for analysis of algal species composition. During the weekly sampling, the relative cover