Growth Patterns of *Montastrea annularis* Inhabiting the Patch Reefs of the Caye Caulker Marine Reserve, Belize

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ABSTRACT

Coral reefs are space limited communities that undergo a generally predictable succession after disturbance events. The Caribbean Coral Reef Studies (CCRS) program has been monitoring corals of the Caye Caulker Marine Reserve (CCMR) post disturbance from hurricane Keith in 2000 to investigate this recovery. Evidence indicates that the reef ecosystem in the reserve has failed to develop into a later succession model. This study tracks the growth of individual colonies of the hermatypic coral Montastrea annularis, a ubiquitous species that typically gains dominance in later succession communities, in order to investigate the perceived lack of progression. Plot photos of M. annularis *colonies were taken in situ from 2006 to 2009, concurrent with CCRS monitoring efforts, and the growth of colonies was calculated for all years as well as for each individual year. Findings indicate that there is considerable dynamic growth occurring which averages out to minimal overall change. Small colonies were found to exhibit a greater variability in growth rate than did medium or large sized colonies. Results concur with previous studies indicating that succession has halted at an early stage, though no specific cause is apparent.*

Introduction

In 2002, the Caribbean Coral Reef Studies program (CCRS) of the University of Wisconsin–Superior began monitoring the health of the Belizean barrier reef within the boundaries of the Caye Caulker Marine Reserve (CCMR) near the island of Caye Caulker, Belize. Dr. Edward Burkett initiated this study in order to monitor reef health and develop a reef recovery model after the reef was severely damaged by hurricane Keith in October 2000. It was expected that this study would reveal a typical post disturbance recovery in which succession would progress from a low diversity algae dominated system to a high diversity coral dominated system. By 2008, results of the CCRS study clearly showed that post hurricane succession in the CCMR resulted in the formation of algal dominated reefs that changed minimally over time with regards to coverage, species composition and diversity. Within two years following hurricane Keith the hard coral populations of the patch reefs of the CCMR became static with regards to growth and diversity; contradicting the predictions of most reef recovery models.

This paper is an investigation of the growth dynamics of individual colonies of the scleractinian coral *Montastrea annularis* over several years in order to determine rates and patterns of growth during post hurricane succession on the patch reefs of the CCMR following hurricane Keith, and is an attempt to elucidate the unexpected results of the CCRS research.

Species and Method Selection

The scleractinian coral *Montastrea annularis* was chosen as the target species for this study because it is the most abundant hard coral in the Atlantic Ocean and has been the dominant coral on most Caribbean patch reefs for millions of years (Budd 2001, Wiel 1994). Hermatypic corals, such as *M. Annularis,* contribute significantly to reef development by fixing calcium carbonate into an skeleton which becomes the substrate for future reef growth. *M. annularis* has a massive, boulder type growth form. Large colonies of *M. annularis* often split with maturity into a starburst pattern of smaller colonies which form coral heads that provide habitat and shelter for many species of fish and invertebrates and provide a food source for several coralivorous species (Hoffmeister 1968). Growth and mortality of individual *M. annularis* colonies is influenced by a multitude of environmental factors such as water depth, temperature, turbidity, nutrient levels, competition from other corals and algae, mechanical disturbance, and predation. The influence of these environmental factors can vary significantly over short distances in patch reef environments and may cause localized trends that are not recognized by broad scale methods of monitoring growth.

Scleractinian coral growth rates are often monitored in order to detect changes in reef health and to better understand how corals respond to environmental changes. There are many methods by which scientists monitor the growth of coral, both *in situ* and in controlled laboratory environments. Laboratory methods include weighing coral polyps before and after experimental treatments, weighing bare skeletons, and coating bare skeletons with wax and weighing the wax deposited (Crabbe 2009, Edmunds 2005, Homes 2008, Weil 1994). Laboratory methods are far more precise in quantifying growth, but they are limited by colony size, time, and equipment availability. *In situ* methods of measuring coral growth include measuring the two major axes of a coral head (length and width) to calculate area, monitoring outward growth via graduated nails or pins driven into the skeleton, dyeing coral skeletons to create reference date and then coring later on, and the emerging method of computer analysis using high resolution photography/video. One of the benefits of *in situ* methods is that colonies of all sizes can be accessed under natural environmental conditions, but data tend to be less accurate. *In situ* methods may damage coral during sampling, and considerable dive time is required in often remote locations (Homes 2008).

In this study, computer analysis of high resolution benthic photography was the method of choice, selected for its ability to track individual colonies accurately and show minute changes in colony size with minimal dive time. This method also has the benefit of creating a permanent raw data set that allows for future analysis and re-visitation.

Site Description

Caye Caulker Marine Reserve (CCMR) is a 10,000 hectare marine reserve that was established in 1998 by the Belizean government. The reserve, located off the east coast of Caye Caulker, Belize (17° 45’45”N, 88° 00’ 40”W) is oriented north to south and straddles the Belizean Barrier Reef. The CCMR contains sea grass beds and patch reef as well as fore and back reef ecosystems. The CCMR is used for diving, snorkeling, and limited fishing and is co-managed by the Forest and Marine Reserves Association of Caye Caulker (FAMRACC) and the Government of Belize (Naturalight 2010). This study was conducted in the lagoon area of the CCMR which consists of mixed sand, sea grass beds, patch reefs, and back reef habitats (Images 1 & 2).

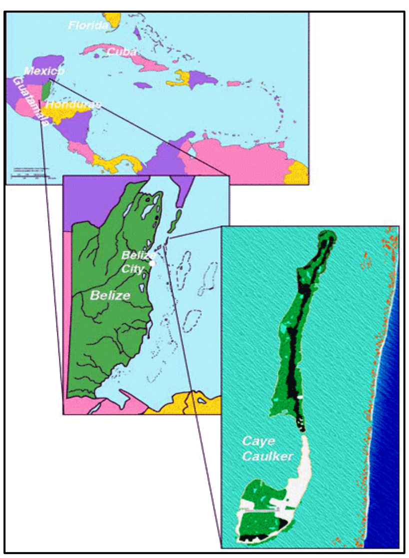

Image 1. Map showing location of study area.

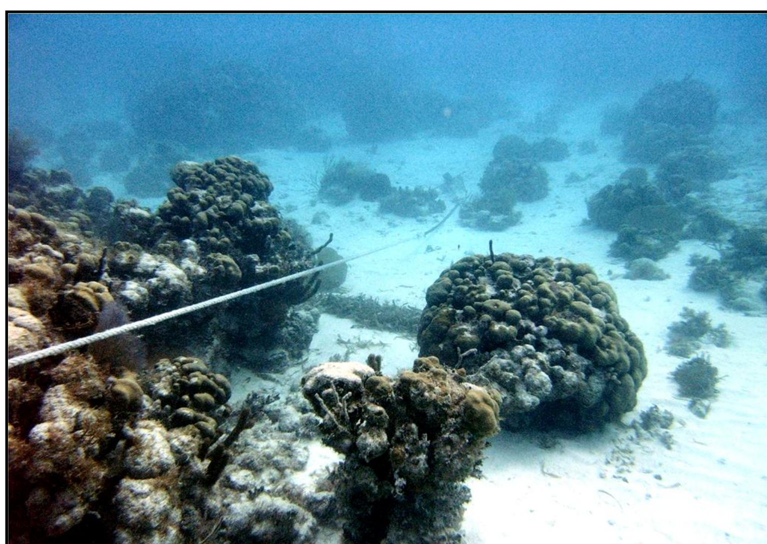
Image 2. Patch reef environment of Caye Caulker Marine Reserve.

In 2002, CCRS established ten permanent reef monitoring sites on the back reef and patch reefs within the CCMR. Each monitoring site consisted of a 50 meter transect which was oriented east to west and perpendicular to the barrier reef crest. Numbered aluminum tags were affixed to coral heads at two meter intervals using marine epoxy (Z-Spar Coatings) and 16" stainless steel posts were epoxied into holes bored into coral heads at each terminus to mark a total of 26 sampling points per transect. Using SCUBA equipment and underwater cameras, high resolution photographs were taken of the benthic community at each of the sampling points once each year in January from 2006 to 2009. Photographs were taken using a 0.5 m^2 aluminum quadrant attached to an aluminum camera mount and a 10 megapixel Canon camera in a Canon WP-DC8 housing. This apparatus allowed divers to photograph the benthic community at each sampling site from directly above (Images 3 & 4). This method and grid was used with minimal adjustment through 2009.

For this study, quadrant photographs collected by CCRS between 2006-2009 were compared for each sampling point. Individual colonies of *M. annularis* were visually identified and assigned an alpha numeric code, so that individual colonies could be tracked from year to year. The planar areas of *M. annularis* colonies were determined for each year they were present using Coral Point Count with Excel extensions (CPCe) area analysis software (Kohler 2006). Any colonies lying partially or entirely outside of the 0.5 m^2 photographic quadrant or obscured in any way were eliminated from the analysis. In addition to planar area, anomalies such as fish bites, spots, colony fragmentation, colony mortality, or partial colony mortality were recorded along with transect location and sample site location.

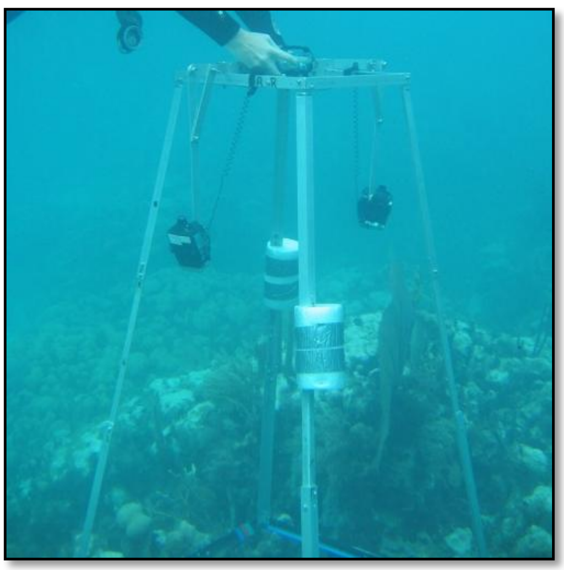

Image 3. Plot photography apparatus used for sampling.

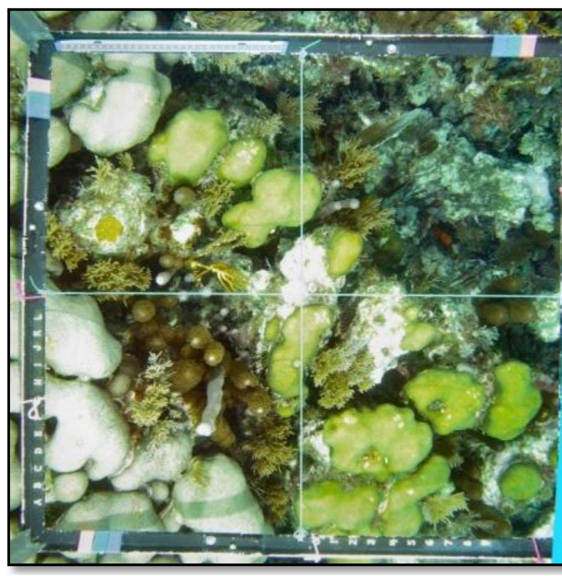

Image 4. Example of a typical plot photo (from 2008 data set).

<u>Growth Rate Formula Selection</u>

Use of planar growth rate as a way of measuring coral growth has associated logistic problems. If absolute growth rates are calculated as Δarea/Δtime, the rates would be heavily skewed towards large colonies. On the other hand, relative growth rates such as Instantaneous Relative Growth Rate (InstRGR) = [(1/Area) * (ΔArea/ΔTime)] and Mean Relative Growth Rate (MRGR) = [(ln area2- ln area1)/(time2-time1)], adapted from plant growth studies, tend to avoid large colony bias (South 1995). Comparisons of MRGR and InstRGR with regards to colony size bias indicates InstRGR was less skewed in relation to colony size, and therefore InstRGR was used for all analysis and comparisons in this study (Figure 1).

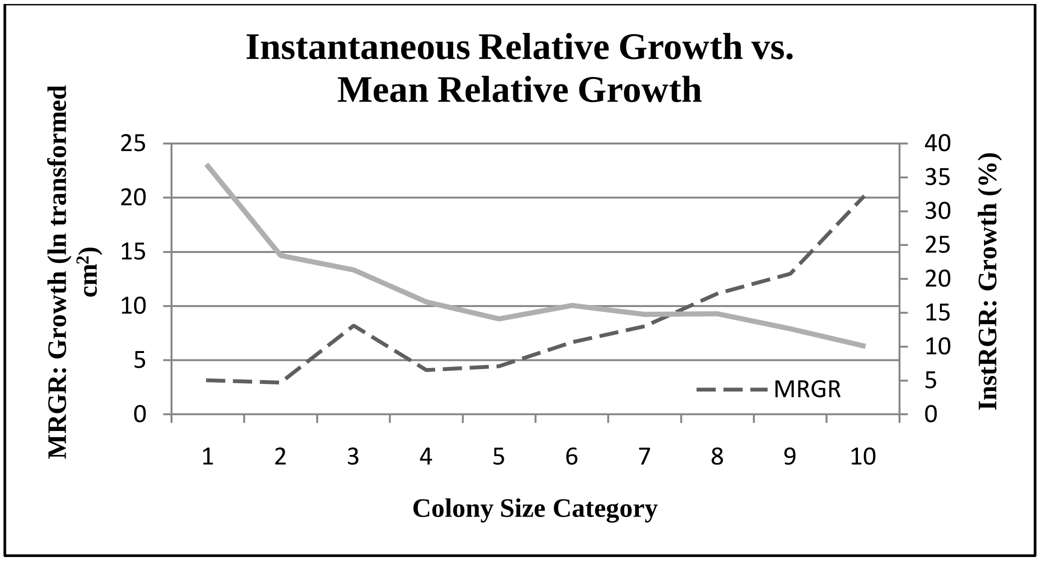

Figure 1. Comparison of mean relative growth rate (MRGR=[(ln area2- ln area1)/(time2-time1)]) (dashed line) and instant relative growth rate (InstRGR=[(1/Area) * (ΔArea/ΔTime)]) (solid line) to colony size categorized by equal percentage of total (i.e. size category 1= smallest 10% of colonies).

Data Analysis

Planar areas collected using CPCe were exported to Microsoft Excel. Colonies that had split since 2005 were summed as one colony and areas of non-coral located within the bounds of a living colony were subtracted from the colony area. Instantaneous Relative Growth Rates (InstRGR) were calculated (see formula selection) using Microsoft Excel and colonies with an InstRGR value exceeding 1 (greater than 100% yearly growth) were considered outliers and excluded from analysis. Stepwise multi-linear regression was performed to determine if year, transect location, colony size, colony fragmentation, fish predation, and/or algal growth were accurate predictors of *M. annularis* growth. Colonies of *M. annularis* were then divided into three size classes of equal numbers (each comprising 20% of total sample) buffered by an equal number of colonies that were not analyzed. Small colonies ranged in size from 0.5 to 13.04cm^2, medium size colonies from 27.4 to 45.0cm^2, and large colonies 84.6 to 985.7cm^2. Frequency analysis and Analysis of Variance (ANOVA) were then used to determine if differences existed in InstRGR between size classes.

Results

Multivariate stepwise regression of year, transect, colony size, colony fragmentation, fish predation, and algal growth on InstRGR failed to show a significant relationship between these factors and actual change in colony size. Table 1 shows that only five variables were predictive and the sum adjusted R square for those variables was <0.16, indicating that none of the independent variables were accurate predictors of colony growth.

Frequency analysis for all years showed that InstRGR of the smallest size class were considerably more variable and slightly negative (mean= -0.016, Std. dev= 0.343) compared to the mid and large size classes, which were slightly positive (mean = 0.02 & 0.05 and Std. Dev = 0.189 & 0.145, respectively) (Figures 2-5). The overall mean for colonies of all sizes and all years was slightly negative (mean = -0.03, Std. Dev= 0.257), indicating an overall decline in *M. annularis* in the CCMR. This pattern was consistent for all size categories across all three years.

One way ANOVA displayed similar results to frequency analysis, showing a significant difference in InstRGR between the smallest and median and large size classes (p<0.001, a=0.05) (Table 2). In addition, there was no significant difference between InstRGR of the larger two size classes. These results were again repeated when separated by year (Table 2) (p <.001, a=.05). The pattern deteriorated somewhat when the data was divided by transect (Table 3), with transects 8 & 9 showing no significant difference between small colonies and medium or large colonies and transect 1 showing no significant difference between small and medium colony InstRGR. This may have been influenced by reduced sample size (n> 20 for many cases).

Table 1. Stepwise multi-linear regression R values (InstRGR vs. Year, Transect, Colony size, Colony fragmentation, Fish predation, and Algal growth).

Model	R	R Square	Adjusted R Square	Std. Error	Predictors
1	0.311	0.097	0.095	0.2440174	MORTALITY
2	0.350	0.122	0.120	0.2406977	MORTALITY, Transect I
3	0.375	0.140	0.137	0.2383730	MORTALITY, Transect I, AREA
4	0.393	0.154	0.149	0.2366186	MORTALITY, Transect I, AREA, Transect E
5	0.404	0.163	0.158	0.2354635	MORTALITY, Transect I, AREA, Transect E, SPLIT

Table 2. Instantaneous relative growth rate (InstRGR) of *M. annularis* colonies for individual years divided by size category (negative values shaded). Alpha= 0.05

Colony size class	**Year**			
	All years	2007	2008	2009
Small	-0.161181	-0.178209	-0.14269	-0.162644
Medium	0.024048	0.027746	0.041339	0.003059
Large	0.045452	0.030681	0.060535	0.04514

Table 3. Instantaneous relative growth rate (InstRGR) of *M. annularis* colonies for individual transects divided by size category (negative values shaded). Alpha= 0.05

Colony size class	**Transect**								
	A	B	C	E	F	G	H	I	J
Small	-0.185948	-0.386837	-0.109814	-0.206165	-0.193285	-0.168614	-0.091225	0.022778	-0.184967
Medium	-0.042326	-0.007723	0.01867	0.100072	0.080807	0.026753	-0.062024	0.048485	-0.089335
Large	0.065933	0.029791	0.016242	0.085613	0.086473	0.001898	-0.024985	0.119034	0.009166

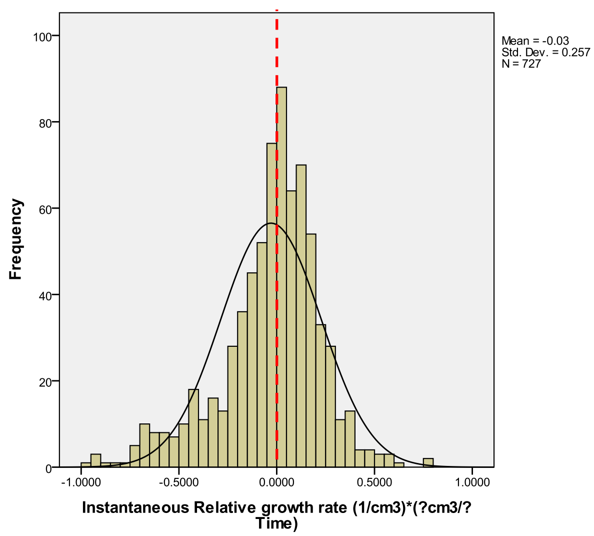

Figure 2.
(All Colonies, 2007-2009). Dashed line indicates zero growth value; apex of curve indicates mean growth.

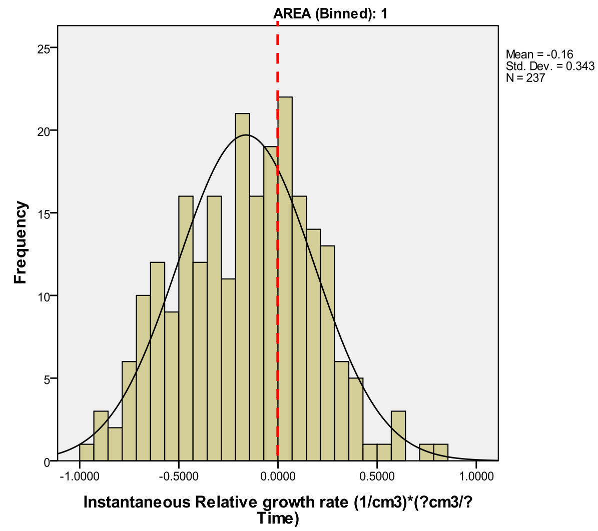

Figure 3.
(Small Size Class, 2007-2009). Dashed line indicates zero growth value; apex of curve indicates mean growth.

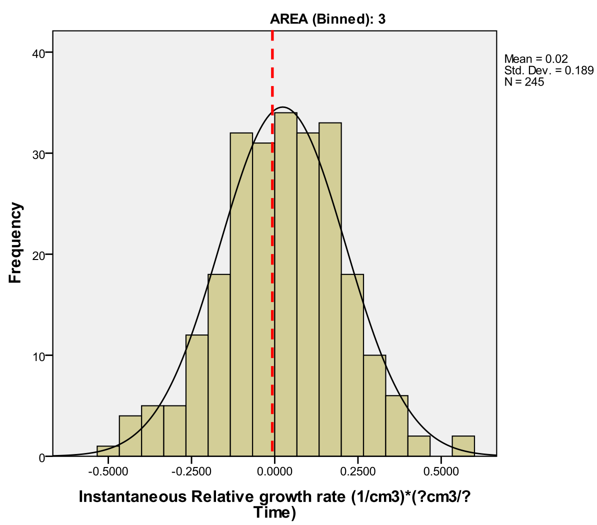

Figure 4.
Histogram of InstRGR (Medium Size Class, 2007-2009). Dashed line indicates zero growth value; apex of curve indicates mean growth.

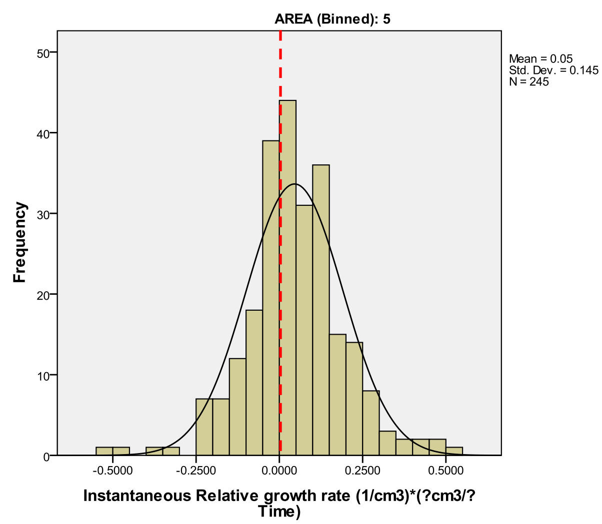

Figure 5.
Histogram of InstRGR (Large Size Class, 2007-2009). Dashed line indicates zero growth value; apex of curve indicates mean growth.

Discussion

The higher variability of InstRGR of small colonies is expected considering the increased susceptibility of smaller colonies to destruction by a single disturbance event. A single instance of parrotfish focus biting, bleaching, or mechanical disturbance may completely obliterate a colony of few polyps whereas a larger colony could weather the disturbance and continue growing. Additionally, a small colony and a large colony which increase by the same area in cm^2 will exhibit very different rates of change percentage-wise. Being that the formula for InstRGR is percentage-growth based, it tends to indicate higher variability in smaller colonies.

The findings of this study support results of previous CCRS studies in the CCMR which indicate a minimal change in the total scleractinian coral bottom cover between 2006 and 2009 (Burkett, unpublished data). When percent bottom coverage of *M. annularis* from previous CCRS data is compared to mean InstRGR for the same years, both show insignificant changes*;* hence the *M. annularis* population of the CCMR is not changing significantly with regards to bottom coverage (Figure 6). Lack of overall *M. annularis* growth does not necessarily indicate the reef is static. In fact, this study reveals that the *M. annularis* population in the CCMR is highly dynamic with approximately 50% of the colonies experiencing annual growth and 50% of the colonies showing varying degrees of annual mortality. Since *M. annularis* annual growth and mortally are nearly equal, the result is no net change in overall percent bottom coverage of the population over time. The lack of *M. annularis* growth previously reported by CCRS, though accurate, can now be explained by this highly dynamic, size dependent growth and mortality of individual colonies.

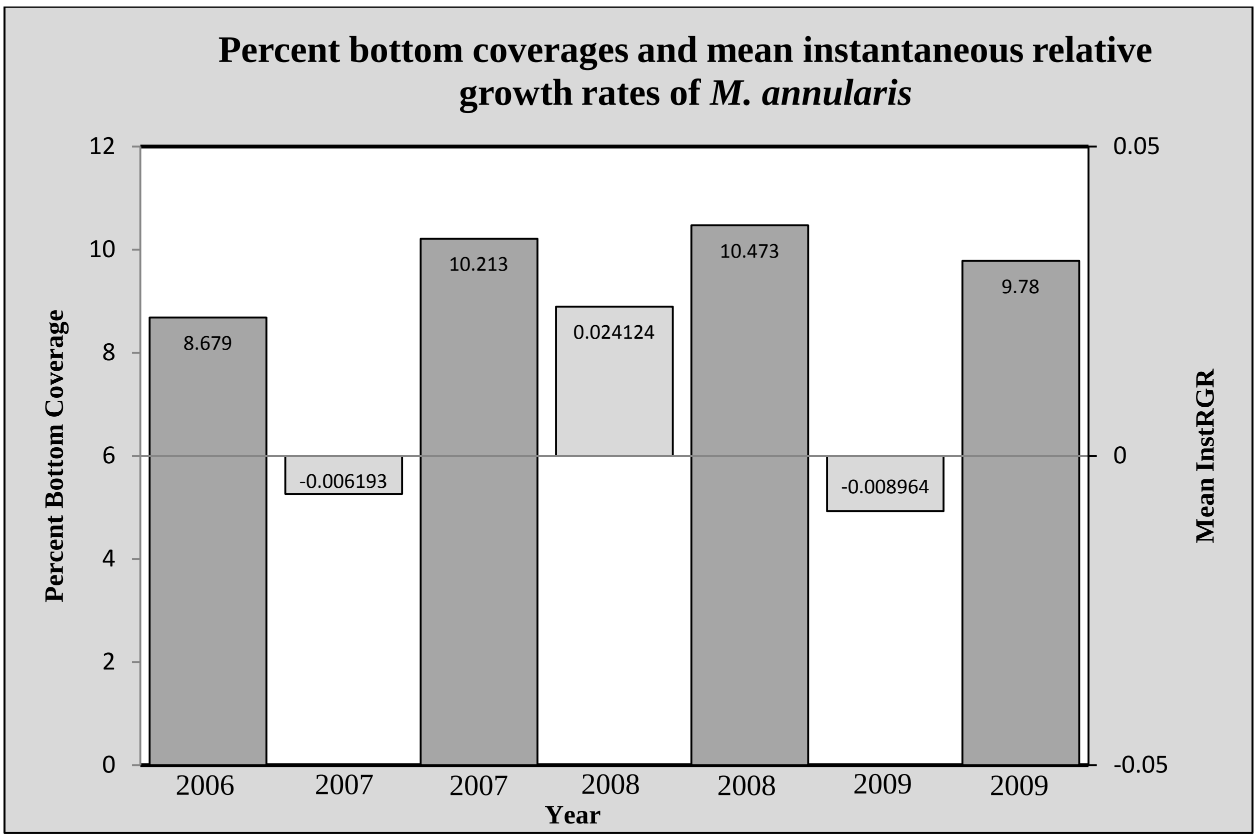

Figure 6. Percent bottom coverage of *M. annularis* 2006-2009(dark grey- from CCRS study data) compared to mean instantaneous relative growth rate of *M. annularis* colonies for the same years (light grey).

Previous studies, conducted by the University of Wisconsin–Superior's Caribbean Coral Reef Studies program, indicate that the percent bottom coverage of *M. annularis* growing on the patch reefs of the Caye Caulker Marine Reserve did not change significantly between 2006 and 2009. Results of this analysis clearly indicate that although the total coverage of *M. annularis* did not change over time, individual colonies within the population experienced significant growth and/or mortality. Approximately half of the colonies studied experienced annual growth while the remaining half suffered an equal level of mortality. Overall, the growth and mortality patterns of this population were found to be extremely dynamic; a sharp contrast to the original assumption that the population growth was static over time. Interestingly, small colonies were found to exhibit a greater variability in growth rate and survivorship than did medium or large sized colonies possibly due to their higher susceptibility to mortality associated with predation and disturbance.

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